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PREFACE

This Fish Bulletin, "The California Halibut, Paralichthys californicus, Resource and Fisheries," is the result of a 3-year process which began with an idea to hold a workshop to update management strategies. It soon became apparent that a diverse and relatively large group of academic, private, and government (state, federal, and local) scientists independently were either already conducting research or interested in developing, from historical databases, a better understanding of some aspects of the biology of, or fisheries for, California halibut. Because of the breadth of research and the level of interest, the California Department of Fish and Game developed the concept of holding a symposium to help fisheries managers better understand the status of current research, to identify areas where additional research is needed, and to publish this information in one peer-reviewed document. At this point, a committee of volunteers was formed and we began a timely team effort to plan and develop the symposium. To optimize the results of the symposium, a general call for papers was made inviting anyone involved with California halibut research to participate. Based upon the response, symposium sessions were established for: 1) Habitat, Distribution, and Early Life History; 2) Adult Life History; 3) Commercial Fisheries; 4) Recreational Fisheries; and 5) Management, Population Dynamics, and Fisheries Interactions. The symposium was held May 23–24, 1989 in San Pedro, California. It was sponsored by the California Department of Fish and Game, National Marine Fisheries Service, American Institute of Fishery Research Biologists, and the Cabrillo Marine Museum, whose staff also hosted the symposium. The symposium attracted approximately 150 people and included 25 papers authored or co-authored by scientists representing a diverse group of private and public organizations, which included: California State University, Northridge; Centro de Investigación Cientifica y Educación Superior de Ensenada (CISESE); Coastal Research Center, San Rafael; ERC-Environmental and Energy Services Company, Pacific Gas and Electric Diablo Canyon Laboratory; MBC Applied Environmental Sciences, Costa Mesa; MEC Analytical Sciences, Carlsbad; Minerals Management Service; Natural History Museum of Los Angeles County; Scripps Institution of Oceanography, La Jolla; University of California, Davis—School of Fisheries; University of California, Santa Barbara—Marine Science Institute; and the VANTUNA Research Group, Occidental College. The symposium was concluded with a panel discussion designed to gain perspectives from representatives of academia, the commercial and recreational fishing industries, and fisheries management on, "Where we should go with research and management as it relates to the California halibut."

After the symposium, we began the somewhat arduous task of extracting final draft papers from a group of contributors, many of whom had made a commitment above and beyond their regular workday requirements, and submitting these drafts for peer review. We thank the authors for their diligence and acknowledge the reviewers for their professional reviews and, most gratefully, timely responses.

Reviewers included: Dr. Larry G. Allen; Dr. M. James Allen; Deborah Aseltine; Dr. Kevin Bailey; Philip Beguhl; Dr. Louis Botsford; Dr. Lawrence Buckley; Dr. Frank Bulow; Dr. Ed DeMartini; Robert Demory; Dr. Rick Deriso;

Earl Ebert; Larry Espinosa; Gene Fleming; Terry Forman; Dena Gadomski; Dr. E. W. Gudger; Dr. Don Gunderson; Dr. M. Gregory Hammann; Dr. Ray Hilborn; Dr. Michael H. Horn; Dr. Larry Jacobson; Dr. Sharon Kramer; Arthur C. Knutson; Dr. Gordon H. Kubota; Mike Lapointe; Bud Laurent; Dr. William H. Lenarz; Dr. Milton Love; Dr. Alec McCall; Dr. Dan Margulies; Dr. Gordon A. McFarlane; Dr. Richard Methot; Kenneth Miller; Bruce Mundy; Dr. Mark Ohman; Dr. Norman Parks; Dr. James Power; Dr. Laura Richards; Donald Schultze; Dr. Barry Smith; Jerome Spratt; Dr. Robert Stickney; Jack Tagart; Gail Theilacker; Dr. Russell Vetter.

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Thanks again to all who participated.

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1. The Biological Environment of The California Halibut, Paralichthys californicus

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1.1. ABSTRACT

The California halibut, Paralichthys californicus, is an important benthic ambusher of shallow nearshore areas and embayments of California and Baja California. Although it settles to the bottom at a small size, it eventually grows to become one of the largest nearshore fishes in the area. As it grows it moves from nursery areas in bays, harbors, and semiprotected coastal areas to sandy bottoms along the open coast. In the course of its life, the California halibut lives with many other inshore species, including those which are frequently found in the same assemblage. Some of these may be competitors, predators, or prey whereas others may interact little with halibut. of the potential competitors, those with similar foraging behaviors to California halibut could be most important. Many potential competitors perform a similar role as the California halibut in geographically or bathymetrically adjacent assemblages. Dissimilar foragers may also feed on the same prey and could have local impacts on the food supply. Key species in the environment of the California halibut include prey organisms such as mysids and northern anchovy, Engraulis mordax; potential competitors such as speckled sanddab, Citharichthys stimaeus, and California lizardfish, Synodus lucioceps; and predators such as thornback, Platyrhinoidis triseriata, and California sea lion, Zalophus californianus. California halibut is probably replaced ecologically to the north by sand sole, Psettichthys melanostictus, and to the south by Cortez halibut, Paralichthys aestuarius.

1.2. INTRODUCTION

The California halibut, Paralichthys californicus, is one of the most important flatfishes to recreational and commercial fisheries in nearshore waters of central and southern California (Frey 1971; Squire and Smith 1977; NMFS 1985; MBC 1987a; CDFG 1989). It is one of the largest bony fishes of these waters (Eschmeyer et al. 1983). Although its importance has long been recognized (Jordan 1887; Clark 1930, 1931; Ginsburg 1952; Frey 1971; CDFG 1989), it has not been well studied. Most studies of California halibut have focused on aspects of the life history or fisheries of this species with little emphasis on its ecological position in the nearshore fish assemblage. However, because of its use of bays (i.e. estuaries and lagoons) as nursery grounds and the steady human encroachment into this habitat, there has been renewed interest in the biology of this species.

This paper will review and summarize information on the biological environment of the California halibut and will describe its prey, potential competitors, associates, predators, and parasites. Many judgments given here are based on data presented in my dissertation (i.e. M.J. Allen 1982) and are the result of a careful examination of the morphology, feeding habits, and distribution of the demersal fishes of the southern California shelf.

1.3. GENERAL DISTRIBUTION AND ECOLOGY

1.3.1. Distribution

The California halibut is found from the Quillayute River, Washington, to Magdalena Bay, Baja California Sur (Figure 1) (Miller and Lea 1972; Eschmeyer et al. 1983). However, it only occurs occasionally north of Point Arena, California (C.W. Haugen, California Department of Fish and Game, pers. comm.) and is most common from Morro Bay south (Fitch and Lavenberg 1971). It is often very abundant in Morro Bay and Mission Bay, California (Fitch 1965). An early reference to an isolated population in the Gulf of California by Norman (1934) was apparently regarded as an error by Ginsburg (1952). Similarly recent references (Castro Aguirre et al. 1970; Miller and Lea 1972) to the presence of the species in the Gulf are also apparently in error (S.H. Kramer and R.H. Rosenblatt, Scripps Institution of Oceanography, pers. comm.). Although the range of the California halibut extends across most of the Oregonian and San Diegan zoogeographic provinces of Briggs (1974), it is probably best classified as a Montereyan-San Diegan species because it is only common in the Montereyan subprovince (central California; Hubbs 1974) and the San Diegan province (southern California and Baja California).

The California halibut occurs at depths from the shoreline in bay nursery grounds (Kramer and Hunter 1987; Kramer 1990; MBC 1990) and the surf zone (Kramer and Hunter 1988) to 185 m (Haaker 1975). However, about 98% of its occurrences in otter trawl (7.6-m headrope) surveys in southern California are from depths less than 60 m (Figure 2; M.J. Allen 1982). Adults are most abundant at depths less than 20 m and occur most frequently at depths less than 30 m (Frey 1971; Feder et al. 1974; M.J. Allen 1982). Based upon its depth range of common occurrence, the California halibut is best classified as an Estuarine-Inner Shelf species (using the terminology of M.J. Allen and Smith 1988).

1.3.2. Life History

California halibut is a broadcast spawner with eggs being fertilized externally. In the lab halibut have been observed spawning near the water surface (tank bottom depth of 2–3 m), extruding reproductive products (J. Rounds, Natural History Museum of Los Angeles County, pers. comm.). In nature, spawning is thought to occur on sandy bottoms over depths of 6–20 m along the coast outside embayments (Haaker 1975). Based on the distribution of halibut larvae, spawning probably occurs from about San Francisco Bay, California, to Magdalena Bay (Ahlstrom and Moser 1975). The spawning season is generally thought to extend from February to August with most spawning occurring in

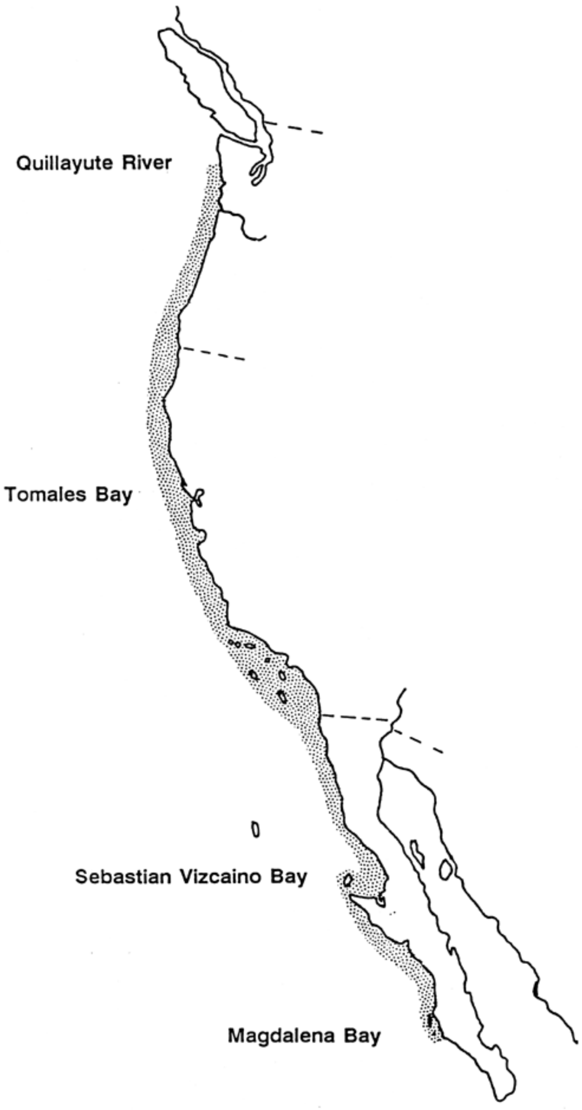
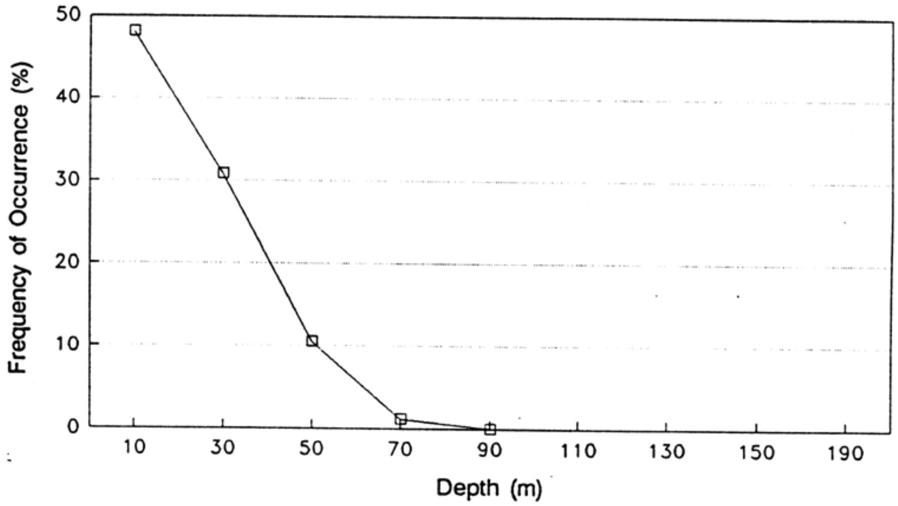


FIGURE 1. Geographic distribution of the California halibut, *Paralichthys californicus*.

FIGURE 1. Geographic distribution of the California halibut, Paralichthys californicus

a) Frequency of occurrence



b) Mean abundance

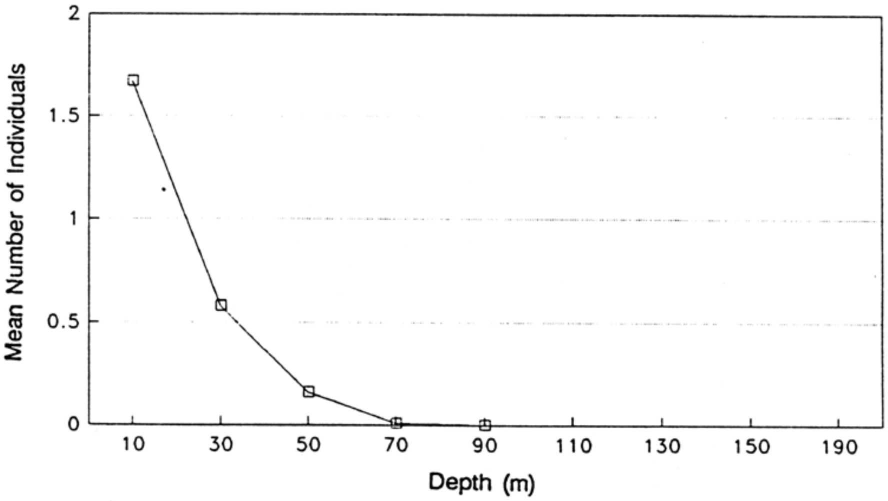


FIGURE 2. Depth distribution of California halibut, *Paralichthys californicus*, in southern California based on 342 otter trawl (7.6-m headrope) samples, 1972–73.

FIGURE 2. Depth distribution of California halibut, Paralichthys californicus, in southern California based on 342 otter trawl (7.6-m headrope) samples, 1972–73

May (Frey 1971; Feder et al. 1974). However, because settlement can occur as early as December (Kramer and Hunter 1988), some fall spawning may occur.

Halibut eggs are 0.7–0.8 mm in diameter (Ahlstrom et al. 1984) and are most abundant in the water column close to shore. Eggs were previously thought to be demersal (Haaker 1975), but are now known to be pelagic (L.G. Allen 1988). Halibut larvae hatch at about 2.0 mm and metamorphose (and settle) at 7.5–9.4 mm (Ahlstrom et al. 1984). They metamorphose at about 20–29 d (L.G. Allen 1988). The larvae are pelagic (Frey 1971), occur most commonly in the water column between the 12 and 45 m isobaths, and are common from March to September (Plummer et al. 1983). They are most abundant between Santa Barbara, California, and Punta Eugenia, Baja California Sur (latitude 27° 51'N.) (Ahlstrom and Moser 1975).

Transforming larvae generally settle to the bottom in bays but may also settle in shallow waters of the open coast (Kramer and Hunter 1987; L.G. Allen 1988; Kramer and Hunter 1988; L.G. Allen et al. 1990; M.J. Allen and Herbinson 1990; Kramer 1990). Small juveniles are most abundant in bays (Haaker 1975; Plummer et al. 1983; Kramer and Hunter 1987; L.G. Allen 1988; Kramer and Hunter 1988; Kramer 1990; MBC 1990). Small juveniles less than 10–15 cm standard length (SL) are generally rare on the outer coast (M.J. Allen 1982; Plummer et al. 1983; Kramer and Hunter 1987; L.G. Allen 1988; MBC 1990). The occurrence of small halibut along the coast has been noted in the past in fish stomach analysis studies (Ford 1965). However, successful recruitment was first noted in 1988 (Kramer and Hunter 1988; L.G. Allen et al. 1990; Kramer 1990). Successful recruitment also occurred in semiprotected portions of the coast in 1989 (M.J. Allen and Herbinson 1990).

After settling in the bays, the juveniles remain there for about 2 years until they emigrate to the coast. Males mature at 2–3 years and 20–23 cm SL; females mature at 4–5 years and 38–43 cm SL (Fitch 1965; Fitch and Lavenberg 1971; Haaker 1975). Males emigrate out of the bays when they mature (i.e. at 20 cm) but females migrate out as subadults at a length of about 25 cm. Subadults remain nearshore at depths of 6–20 m (Clark 1930; Haaker 1975). California halibut may reach 152 cm and 33 kg (Eschmeyer et al. 1983). Individuals may live as long as 30 years (Frey 1971).

Juveniles and adults occur on sandy sediments but sometimes concentrate near rocks, algae, or Pacific sand dollar, Dendraster excentricus, beds (Feder et al. 1974). As with other flatfishes, they frequently lie buried or partially buried in the sediment. Adults move inshore to spawn during the spring and summer and offshore during the winter (Ginsburg 1952; Haaker 1975). These movements may also be associated with schools of prey (e.g. schools of California grunion, Leuresthes tenuis, are abundant near the surf zone during the spring and summer; Feder et al. 1974). California halibut show little coastwise movement but occasional individuals move as far as 224 km at a rate of 0.42 km/d (Fitch and Lavenberg 1971).

1.3.3. Feeding Habits

1.3.3.1. Functional Morphology

The body plan of the juvenile and adult California halibut is that of an oval flatfish with a large, symmetrical mouth (i.e. with the same tooth size and development on eyed and blind sides) with relatively large, sharp canine teeth. The gill rakers are relatively long and serrated. It has relatively small eyes, olfactory rosettes (with 9–10 lamellae), and cephalic lateralis pores on the snout and mandibles (M.J. Allen 1982).

The firm body and large caudal fin are associated with good swimming abilities. In addition, large caudal fins in flatfishes are associated with the ability to make fast starts from the bottom (Webb 1981); fast starts are used in pursuing prey (M.J. Allen 1982) or escaping predators. Although the eyes are small, California halibut generally locates its prey by sight (Haaker 1975; M.J. Allen 1982). The relatively small eyes (for a visual feeder) may be related to their upward orientation, the relatively bright surface in shallow waters, and a possible need to reduce the amount of incoming light (M.J. Allen 1982).

California halibut feed during the day and night, but show a preference for daytime feeding (Haaker 1975). The species is an ambusher and typically lies partially buried in the sand. During foraging it lies in a stationary position, watching prey with its eyes until the prey comes to within three (halibut) head lengths away (Haaker 1975). It then darts forward and slightly upward to seize the prey. However, if the lunge is initially unsuccessful, the halibut may vigorously pursue prey all the way to the surface. Large individuals have been observed to jump clear of the surface of the water as they make passes at schools of fish (Fitch 1965).

1.3.3.2. Prey

After absorbing their yolk, halibut larvae probably feed on tiny planktonic organisms. However, the diet of larvae has not been examined.

L.G. Allen (1988) found that just-settled California halibut (0.7–2.0 cm) in Alamitos Bay and Long Beach Harbor fed primarily on harpacticoid copepods and gammaridean amphipods, with some polychaetes, mysids, and crab megalopae also being taken. Somewhat larger halibut (2.0–8.0 cm) ate mysids, gammaridean amphipods, and small fish.

Haaker (1975) also found that the diet of juvenile California halibut in bays changed as the fish grow, with fish and crustaceans occurring in the diet of juveniles and fish alone in adults. The smallest juveniles (1.2–5.5 cm SL) fed on small crustaceans including amphipods (Amphithoe sp., Corophium sp., and Caprella sp.); cumaceans, Oxyurostylis sp.; copepods, Calanus sp.; mysids; and gobies (arrow goby, Clevelandia ios; shadow goby, Quietula y-cauda; longjaw mudsucker, Gillichthys mirabilis) . Halibut in the 5.5–23.0 cm SL size range fed on bay shrimp, Crangon sp.; ghost shrimp, Callianassa sp.; topsmelt, Atherinops affinis; California killifish, Fundulus parvipinnis; and gobies. Subadults and adults greater than 23.0 cm SL ate primarily fish, including topsmelt; California killifish; northern anchovy, Engraulis mordax; and gobies. Other species in the diet of bay-living halibut included ostracods and acteonid snails.

In the shallow coastal zone (6–30 m) there is also a change in diet with size (Roberts et al. 1981; Plummer et al. 1983). Juveniles (12.4–24.5 cm SL) fed primarily on the mysids, Neomysis kadiakensis and Metamysidopsis elongata, and larval fish (Plummer et al. 1983). Subadults and adults of 24.5–30.0 cm SL fed on northern anchovy and mysids. Subadults and adults greater than 30.0 cm SL fed primarily on northern anchovy. The largest individuals (68.9 and 82.0 cm SL) had eaten white croaker, Genyonemus lineatus, and hornyhead turbot, Pleuronichthys verticalis. Other prey eaten at these depths include juvenile and adult croakers (Sciaenidae) and other mysids (Alienacanthomysis (= Acanthomysis) macropsis; Holmesimysis (= Acanthomysis) costata; H. (= A.)

sculpta; Mysidopsis californica; M. intii; Neomysis rayi) ; and northern anchovy larvae (Roberts et al. 1981).

Subadult and adult California halibut (23.0–49.5 cm SL) from a broader depth range (12–60 m) off southern California fed predominantly on northern anchovy (M.J. Allen 1982). Other prey included mysids (Exacanthomysis (= Acanthomysis) davisi; Holmesimysis costata; Mysidopsis intii; Neomysis kadiakensis) ; cumaceans, Diastylopsis tenuis; eusirid amphipods; blackspotted bay shrimp, Crangon nigromaculata; Pacific hake, Merluccius productus; spotted cusk-eel, Chilara taylori; rockfishes, Sebastes spp.; white croaker, and pink seaperch, Zalembius rosaceus.

Ford (1965) noted that juvenile and adult California halibut (12.4–77.8 cm) in the nearshore zone (4–47 m) ate barnacles, Balanus sp.; mysids, Metamysidopsis elongata and Neomysis kadiakensis; cumaceans, Diastylopsis tenuis; isopods; blackspotted bay shrimp; pelagic fishes; speckled sanddab, Citharichthys stigmaeus; and California tonguefish, Symphurus atricauda.

California halibut near kelp beds fed on northern anchovy, topsmelt, small flatfish, and shrimp (Quast 1968). Frey (1971) noted that more than half of the disgorgements from 14,000 California halibut taken by trawl off California were northern anchovy. Other prey included queenfish, Seriphus politus; white croaker; and octopus, Octopus sp. Other general accounts indicate that California halibut feed on squid; small California halibut; Pacific sardine, Sardinops sagax; California grunion; jacksmelt, Atherinopsis californiensis; queenfish; California corbina, Menticirrhus undulatus; walleye surfperch, Hyperprosopon argenteum; tube-snout, Aulorhynchus flavidus; and kelpfish, Clinidae sp. (Feder et al. 1974).

In Tomales Bay, California halibut of 65.4–83.8 cm SL had eaten Pacific saury, Cololabis saira; Pacific herring, Clupea pallasii; sanddabs, Citharichthys spp.; white seaperch, Phanerodon furcatus; and California market squid, Loligo opalescens (Bane and Bane 1971).

As noted by Haaker (1975), the California halibut is an ambusher. Ambushers expend relatively little energy searching for prey and rely on prey approaching sufficiently close to be captured (M.J. Allen 1976b). Ambushers may hence have a high percentage of empty stomachs and a low number of prey species per stomach. California halibut from a given location generally have a high percentage of empty stomachs. In Anaheim Bay about 28% of the halibut had empty stomachs during the day and 41% at night (Haaker 1975). In coastal areas 46–64% may have empty stomachs (M.J. Allen 1982; Plummer et al. 1983). Examination of the stomachs of 40 species of demersal fishes from southern California indicated that ambushers had the lowest number of prey species per stomach (M.J. Allen 1982). Halibut along the coast averaged about 3.6 prey items and 1.8 prey species per stomach (M.J. Allen 1982).

In summary, the diet of the California halibut changes from harpacticoid copepods, amphipods, and gobies in small bay-living juveniles to mysids in coastal subadults. Larger subadults and adults feed primarily on northern anchovy, and the largest individuals eat croakers and other larger fishes.

1.4. POSSIBLE COMPETITORS

A number of species could compete for food with California halibut. Competition is the use of a resource by an individual (or species) which reduces the availability of that resource to another individual (or species) (Ricklefs 1973). Thus, for competition to occur, a species would generally have to occur in the same area as the halibut. However, co-occurrence would not be necessary if the two species fed on mobile prey. For competition to have any impact on either species, food would have to be limiting. Fish of different species may feed on the same species of prey in a given area without affecting the behavior of the other species. However, if food is limiting, competition could result in the displacement (spatial, temporal, dietary, or behavioral) of one or both species. Competition in this sense has not been studied or observed between California halibut and any other species.

Although competition has not been studied with regard to California halibut, it is nevertheless possible to predict which species could be potential competitors of California halibut based upon the knowledge of functional morphology, diet, and foraging behavior of a species (M.J. Allen 1982). Possible competitors of California halibut include species that forage in a similar manner (i.e. ecological counterparts) and those which forage differently. The term ecological counterpart is generally applied to species of different phylogenetic origins which occur in different areas but which have converged phenotypically to perform similar ecological roles (Ricklefs 1973). However, here it will be applied to species occurring in different communities or in the same community which forage in a similar manner. A group of these species will be called a foraging guild (Root 1967; M.J. Allen 1982).

1.4.1. Ecological Counterparts

Species which forage in a similar way as the California halibut are benthic ambushers (Figure 3). These species have four basic types of morphology: (i) flatfishes with large symmetrical mouths; (ii) flatfishes with medium-sized symmetrical mouths; (iii) large-mouthed elongate roundfishes without swim-bladders; and (iv) depressed (flattened) sharks.

1.4.1.1. Large-mouthed Flatfishes

The species with the most similar morphologies to that of the California halibut are the flatfishes with large, symmetrical mouths. Five species have ranges which overlap with the California halibut. These include Cortez halibut, Paralichthys aestuarius; fourspot sole, Hippoglossina tetrophthalmus; bigmouth sole, Hippoglossina stomata; arrowtooth flounder, Atheresthes stomias; and Greenland halibut, Reinhardtius hippoglossoides. All of these species probably have similar foraging behaviors.

Based upon its similarity in morphology and bathymetry, the Cortez halibut (Figure 3) is probably the ecological replacement of California halibut in the nearshore zone (to 44 m) and bays of coastal Baja California south of Magdalena Bay and in the Gulf of California (Ginsburg 1952; Haaker 1975; Thompson and McKibbin 1976). The fourspot sole occurs over a similar range as the Cortez halibut (i.e. from Magdalena Bay to Tiburon Island, Gulf of California; Ginsburg 1952; Thompson and McKibbin 1976) but occurs at depths of 38–138 m (Ginsburg 1952).

Both the Greenland halibut and arrowtooth flounder (Figure 3) occur along deeper waters of the shelf, and probably have little direct contact with the

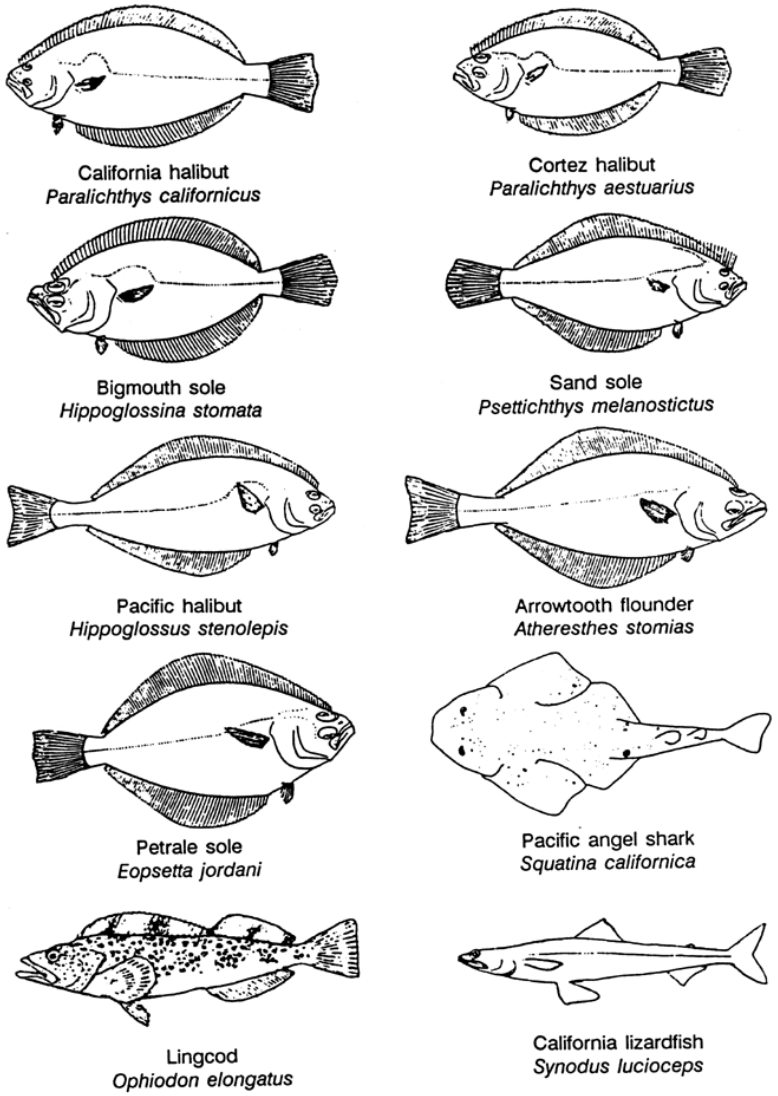


FIGURE 3. Important benthic ambushers along the West Coast of the United States and northern Mexico.

FIGURE 3. Important benthic ambushers along the West Coast of the United States and northern Mexico

California halibut. The arrowtooth flounder occurs from San Simeon, California, north to the western Bering Sea at 18–900 m (M.J. Allen and Smith 1988). The Greenland halibut extends from northern Baja California to the Sea of Japan in the Pacific at depths of 14–2000 m (M.J. Allen and Smith 1988). However, it is rare south of Alaska and occurrences of this species within the range of the California halibut are so anomalous as to be unimportant.

Based upon its similar morphology, size-specific diet, and geographic range, bigmouth sole is probably the ecological replacement of subadult California halibut in deeper waters of the southern California and Baja California shelf. The bigmouth sole occurs from Monterey Bay, California, to the Gulf of California (Eschmeyer et al. 1983) at depths of 10–150 m. The species is most abundant at 50 m (M.J. Allen 1982). The bigmouth sole is a smaller (40 cm SL maximum), leaner species than the California halibut and has larger eyes (M.J. Allen 1982). It transforms and settles at a slightly larger size (9–12 mm) (Ahlstrom et al. 1984), with the smallest individuals occurring from 30–140 m (M.J. Allen 1982). The diet of bigmouth sole consists primarily of mysids and gammaridean amphipods (M.J. Allen 1982). California halibut feed on similar prey as do bigmouth sole of the same size (M.J. Allen 1982; Plummer et al. 1983). However, the two species are spatially segregated when the same size, with the California halibut being more abundant at shallower depths (i.e. <20 m) and the bigmouth sole at greater depths (M.J. Allen 1982). Larger California halibut may live in the same area with bigmouth sole but probably would not compete because they feed on northern anchovy (a species that probably swims too fast for bigmouth sole to capture).

1.4.1.2. Medium-mouthed Flatfishes

A number of flatfishes occurring within the range of the California halibut have medium-sized symmetrical mouths. These include the Gulf sanddab, Citharichthys fragilis; Pacific sanddab, C. sordidus; speckled sanddab, C. stigmaeus; longfin sanddab, C. xanthostigma; fantail sole, Xystreurys liolepis; slender sole, Eopsetta (= Lyopsetta) exilis; petrale sole, Eopsetta jordani; flathead sole, Hippoglossoides elassodon; Pacific halibut, Hippoglossus stenolepis; and sand sole, Psettichthys melanostictus.

Because of the smaller mouth, these species generally include more benthic food in their diet than do the large-mouthed flatfishes, which feed almost entirely on nektonic prey. The fantail sole, in particular, has better developed teeth on the blind side of the head and feeds more extensively on benthic prey (e.g. crabs) than do the other species (M.J. Allen 1982). The other species include more nektonic prey than the fantail sole (M.J. Allen 1982), and some species have special adaptations which may make them more similar in behavior to the California halibut.

Because of its similarity in morphology, diet, apparent foraging behavior, and bathymetry, the sand sole appears to be an ecological replacement of the California halibut from northern California north. It ranges from the Bering Sea to Redondo Beach, California, at depths of 1–325 m. It is most abundant in the shallow coastal zone at depths less than 50 m (M.J. Allen and Smith 1988) and appears in bays from Elkhorn Slough, California, (Kukowski 1972) northward. This species grows to 63 cm (Eschmeyer et al. 1983). Although it has a medium rather than a large mouth, it has strong canine teeth which suggest that nektonic prey are important. It feeds during the day on Pacific herring, mysids, shrimp, and squid (Miller 1967). Smaller individuals feed on gammaridean amphipods (Simenstad et al. 1979).

The petrale sole is sometimes called a "halibut" by uninformed anglers because of its large size (to 70 cm) (Eschmeyer et al. 1983) and similar morphology. It ranges from the Alaska Peninsula to the Coronado Islands, Baja California, and from 0–550 m (M.J. Allen and Smith 1988). It is most common at 50–200 m (M.J. Allen and Smith 1988) and does not occur at depths less than 30 m in southern California (MBC 1987a). Juveniles occur from 20–80 m (Ketchen and Forrester 1966; Pearcy et al. 1977). Juveniles feed on mysids and small fishes whereas adults feed on euphausiids, shrimp, and pelagic fishes (Hart 1973; Pearcy et al. 1977). The petrale sole is the major halibut-like fish of the middle and outer shelf within the northern part of the range (south to central California) of the California halibut.

The Pacific halibut grows much larger than the California halibut, reaching 267 cm and 363 kg (Eschmeyer et al. 1983). It also has a much broader depth range (6–1097 m) (M.J. Allen and Smith 1988). Although individuals have been taken to Punta Camalu, Baja California (R.H. Rosenblatt, Scripps Institution of Oceanography, pers. comm.; M.J. Allen and Smith 1988), Pacific halibut are not abundant south of Tomales Bay. This species replaces the California halibut in the commercial fishery north of Tomales Bay (Bane and Bane 1971). Small juveniles are most abundant at depths less than 15 m but larger juveniles occur as deep as 370 m (Best 1981). Pacific halibut smaller than 30 cm SL feed on shrimp, flatfishes, and Pacific sand lance, Ammodytes hexapterus, and larger individuals feed on fishes, crabs, and cephalopods (Hart 1973; Hunter 1979). The importance of crabs in its diet indicates that its foraging is more benthic than that of the California halibut.

The remaining medium-mouthed species are small and could compete with California halibut only if they lived in shallow water with the halibut juveniles. The Gulf sanddab, Pacific sanddab, slender sole, and flathead sole are all deeper living species which are not likely to live in shallow water (M.J. Allen 1976a; M.J. Allen 1982; M.J. Allen and Smith 1988). In addition, the flathead sole is abundant only north of Cape Mendocino. Only the speckled sanddab and longfin sanddab are shallow-living species, with the former being the more abundant species within the range of the California halibut.

The speckled sanddab is the most abundant small benthic fish in the shallow, soft-bottom coastal zone of southern California (M.J. Allen 1982). This species is a small (usually less than 13 cm), active predator which feeds largely on mysids and gammarids, but also on more sedentary prey (e.g. crabs and worms; Ford 1965; M.J. Allen 1982). It does not enter far into lagoons and estuaries. However, because of its abundance along the nearshore coast and its aggressiveness (Ford 1965), it may affect the abundance of similar-sized California halibut in the shallow coastal zone.

1.4.1.3. Large-mouthed Elongate Roundfishes without Swimbladders

At least two species of large-mouthed, elongate roundfishes without swimbladders are also important benthic ambushers within the range of the California halibut. These are the California lizardfish, Synodus lucioceps, and lingcod, Ophiodon elongatus.

Because of an extensive overlap in diet, habitat, geographic and bathymetric distributions, and probable foraging behavior, the California lizardfish may be the most important potential competitor of medium-sized California halibut (M.J. Allen 1982). The California lizardfish ranges from San Francisco to Guaymas, Sonora, Mexico, at depths of 2–229 m (Eschmeyer et al. 1983). It is most common at depths of 20–60 m (M.J. Allen 1982), the depths at which subadult and adult California halibut are common. After the larvae undergo transformation they remain as pelagic juveniles until reaching about 4.5 cm in length (Fitch and Lavenberg 1971); they settle to the bottom at this size at depths of 15–45 m (M.J. Allen 1982). The California lizardfish reaches a length of about 64 cm (Eschmeyer et al. 1983). It has large canine teeth for grasping fish prey. The species probably forages during the day (M.J. Allen 1982). Lizardfish generally lie partially buried in the sediment, often near reefs, or rest on their pelvic fins at a slight angle to the substratum (Turner et al. 1969). As with other lizardfishes elsewhere, they probably lie in wait for nektonic prey and dart upward from the bottom when making a strike (M.J. Allen 1982). Their major prey is northern anchovy and the mysid, Neomysis kadiakensis (M.J. Allen 1982), but they are also known to eat white croaker and squid (Fitch and Lavenberg 1971).

Another important potential competitor of California halibut in central California is the lingcod. Lingcod range from the Alaska Peninsula to Ensenada, Baja California, and in depth from the intertidal zone to 427 m (M.J. Allen and Smith 1988). The species is rare along the mainland coast of southern California. Lingcod grow to 152 cm, the same maximum length as the California halibut (Eschmeyer et al. 1983). Juvenile lingcod are pelagic to about 7 cm before settling to the bottom at depths from the intertidal zone to 60 m (Limbaugh 1955; Miller and Geibel 1973). For the first 2 years juveniles live on mud and sand bottoms (Frey 1971; Eschmeyer et al. 1983). They often occur in bays (Eschmeyer et al. 1983; MBC 1987a) from central California north but not in southern California. Juvenile lingcod are often associated with algae and seagrasses and may occur near rocks (Phillips 1959; Rutenberg 1962; Miller and Geibel 1973; Eschmeyer et al. 1983). At a size of about 40–60 cm, lingcod move to rocky bottoms, and this habitat becomes the primary habitat of the adult (Garrison and Miller 1982). Juveniles on the soft bottom feed on young Pacific herring (Miller and Geibel 1973). Adults feed largely on fishes (rockfishes, greenlings, Pacific herring, Pacific sand lance), cephalopods (squid and octopus), and crustaceans (shrimp and crabs) (Hart 1973; Miller and Geibel 1973; MBC 1987a). Lingcod generally lie in wait for prey (Quast 1968) and then rapidly dart at the prey from behind or below (Rutenberg 1962).

1.4.1.4. Depressed Sharks

One species of shark with an extremely depressed body is also a benthic ambusher. This is the Pacific angel shark, Squatina californica. The Pacific angel shark ranges from southern Alaska to the Gulf of California but is rare north of California. It is found on sand and mud bottoms (often near rocks and kelp) at depths of 3–183 m but is most common at 3–46 m. The Pacific angel shark grows to 152 cm, the same size as the California halibut (Eschmeyer et al. 1983). Because the species is viviparous (Wourms 1977), juveniles enter the nearshore environment at a much larger size than do most bony fishes. It has a terminal mouth and the ability to cock its head at a slight upward angle. Angel sharks generally wait partially buried until prey approaches, at which time they lunge forward at the prey (Webster 1962). The broad pectoral and pelvic fins are used for pushing off the bottom in pursuit of prey. The Pacific angel shark is nocturnally active (Standora 1972) and feeds on active fishes such as blacksmith, Chromis punctipinnis; white seaperch; rockfishes; California corbina; queenfish; and California halibut (Limbaugh 1955; Carlisle 1969; Standora 1972; Sandell 1973).

1.4.1.5. Foraging Guild Member Relationships

M.J. Allen (1982) placed the California halibut in a foraging guild of bottom-living pelagivores. Species of this guild lack swimbladders and ambush pelagic prey from a stationary position on the bottom. Other important members of this guild in southern California include the bigmouth sole and the California lizardfish. In terms of relative abundance in 1972–73, the California lizardfish was the dominant species of this guild at depths of 10–40 m and the bigmouth sole from 50–170 m (Figure 4). The California halibut accounted for only about 20% of the abundance of these three guild members at 10 m and accounted for less at other depths. The bigmouth sole was more abundant than the California halibut at depths greater than 20 m.

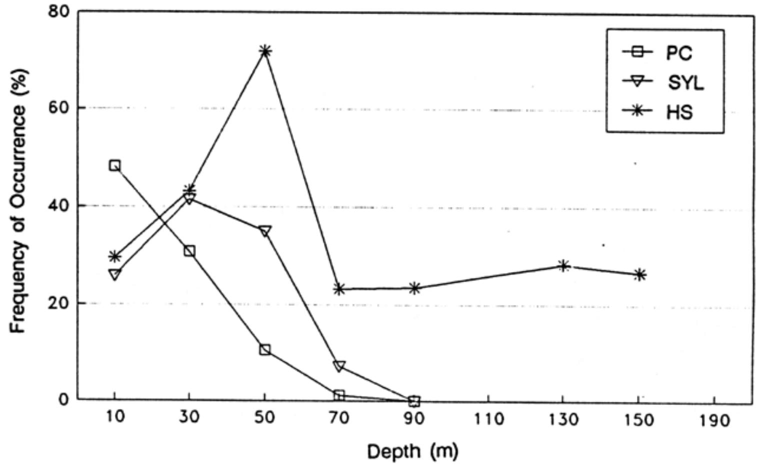
From the information mentioned above, the guild could be expanded to include a nocturnal member (Pacific angel shark) and a rocky bottom member (lingcod). Other species of large- or medium-mouthed flatfishes could be included as one progresses upcoast or downcoast within the range of the California halibut, but the probable northerly replacement is the sand sole and the probable southerly replacement is the Cortez halibut (Figure 5).

1.4.2. Other Potential Competitors

Other fishes in the nearshore fish assemblage sometimes eat some of the same prey as the California halibut, but most are either benthic species that show a greater emphasis on benthic prey than does the halibut or are water-column fishes (most with swimbladders) that do not typically lie in wait for prey. Most sculpins (Cottidae), some rockfishes, and some basses include more decapods in their diet and hence show a greater benthic orientation in foraging. Important species here include the Pacific staghorn sculpin, Leptocottus armatus (Tasto 1975) and spotted sand bass, Paralabrax maculatofasciatus, of the bay nursery areas and barred sand bass, Paralabrax nebulifer, (Roberts et al. 1984) and California scorpionfish, Scorpaena guttata, of sandy coastal areas near rocks (M.J. Allen 1982). These species are also potential predators of small halibut.

Many species of pelagic fishes feed on mysids and northern anchovy. For instance, queenfish show a similar change in diet from mysids to northern anchovy as they grow (Roberts et al. 1981). Queenfish, however, are nocturnally active (Hobson and Chess 1976). Because mysids occur near the bottom during the day, it is primarily the benthic ambushers that take them during this time, whereas nocturnal water column fishes (e.g. queenfish and walleye surfperch) take them in the water column at night (Hobson and Chess 1976; M.J. Allen 1982). Species that feed on northern anchovy are so numerous

a) Frequency of Occurrence



b) Relative Abundance

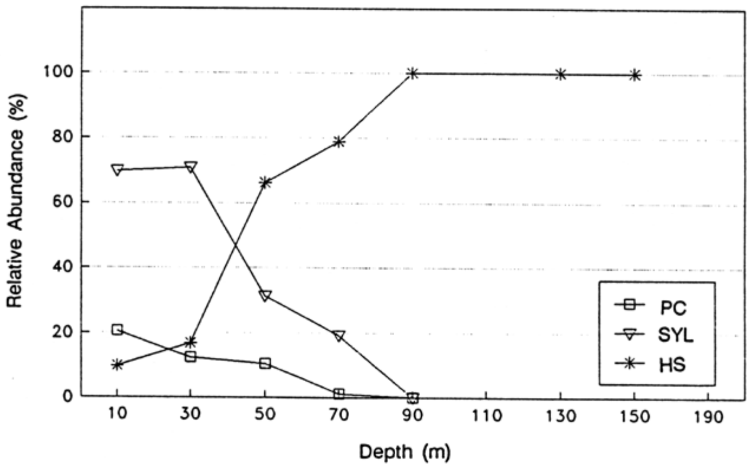


FIGURE 4. Depth distribution of benthic ambushers (pelagivores) off southern California (modified from M.J. Allen 1982). PC--California halibut, *Paralichthys californicus;* SYL—California lizardfish, *Synodus lucioceps;* HS—bigmouth sole, *Hippoglossina stomata.*

FIGURE 4. Depth distribution of benthic ambushers (pelagivores) off southern California (modified from M.J. Allen 1982). PC—California halibut, Paralichthys californicus; SYL—California lizardfish, Synodus lucioceps; HS—bigmouth sole, Hippoglossina stomata

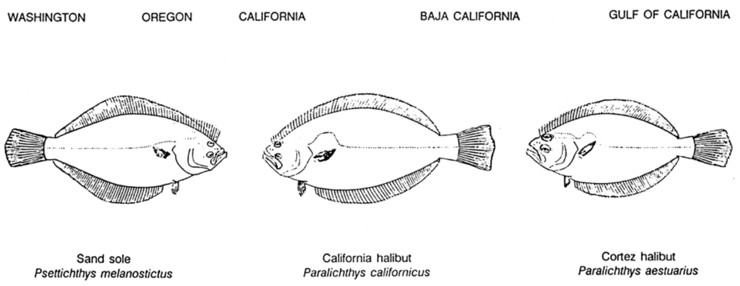


FIGURE 5. Geographic displacement series of ecological counterparts of the California halibut, *Paralichthys californicus*.

FIGURE 5. Geographic displacement series of ecological counterparts of the California halibut, Paralichthys californicus

and diverse as to not be worth listing here. Because northern anchovy are so abundant, it is doubtful that any one species would seriously affect the availability of this prey for the California halibut.

1.5. COMMUNITY ASSOCIATES

Near San Onofre, California, halibut larvae are most closely associated with larvae of the diamond turbot, Hypsopsetta guttulata, and spotted turbot, Pleuronichthys ritteri (Walker et al. 1987). In 1978–80 they were primarily members of a winter–spring assemblage of larvae (Walker et al. 1987). This assemblage also included the northern anchovy, rockfishes, white croaker, and queenfish.

Beam trawl surveys of bays and the nearshore mainland coast (at 8–13 m) of southern California (MBC 1990), indicated that young-of-the-year California halibut in bays (Anaheim Bay and Agua Hedionda Lagoon) are associated with cheekspot goby, Ilypnus gilberti; bay pipefish, Syngnathus leptorhynchus; and giant kelpfish, Heterostichus rostratus. Along the coast, California halibut were commonly associated with speckled sanddab and spotted turbot.

Bag seine and otter trawl surveys in outer Anaheim Bay indicate that juvenile California halibut are closely associated with topsmelt; Pacific staghorn sculpin; spotted sand bass; California corbina; shiner perch, Cymatogaster aggregata; pile perch, Rhacochilus vacca; black perch, Embiotoca jacksoni; walleye surfperch; white seaperch; striped mullet, Mugil cephalus; giant kelpfish; and diamond turbot (Dixon and Eckmayer 1975).

Although California halibut was not a member of a group in a recurrent group analysis of soft-bottom fishes on the southern California shelf (M.J. Allen 1982), it was closely associated (Index of Affinity = 0.35–0.40) with the white seaperch, walleye surfperch, black perch, and speckled sanddab. This strongly suggests that the California halibut is found commonly near schools of surfperches (which are possible prey).

In a habitat analysis of nearshore areas of southern California (L.G. Allen 1985), California halibut formed species groups (based upon similarities in abundance) with the shovelnose guitarfish, Rhinobatos productus; specklefin midshipman, Porichthys myriaster; kelp pipefish, Syngnathus californiensis; bay goby, Lepidogobius lepidus; and spotted turbot. off Huntington Beach, California, it is found most closely associated with speckled sanddab or spotted turbot (MBC 1987b, 1988).

California halibut was the dominant species in the Estero de Punta Banda near Ensenada, Baja California, in 1982–83, along with the spotfin croaker, Roncador stearnsii (Beltrán-Félix et al. 1986). Monthly peaks in fish abundance there were due to juvenile California halibut and diamond turbot.

1.6. PREDATORS

Although predation on California halibut has not been directly studied, nonhuman predators probably decrease in importance with increasing halibut size. Juvenile California halibut are no doubt eaten by shorebirds, water fowl, and fishes in bays, but the most important predators there have not been determined. Ford (1965) found California halibut of 7–9 mm in stomachs of thornback, Platyrhinoidis triseriata, at depths of 9 m off La Jolla. Larger California halibut in coastal areas are eaten by Pacific angel shark; Pacific electric ray, Torpedo californica; California sea lion, Zalophus californianus (and probably northern sea lion, Eumatopias jubatus) ; and bottlenose dolphin, Tursiops truncatus (Fitch and Lavenberg 1971). Large halibut sometimes eat smaller halibut (Feder et al. 1974). California halibut bury themselves in the sand and rely on cryptic coloration to avoid predators. However, as adults they may be able to escape some predators by their swimming abilities.

1.7. PARASITES

Endoparasites of the California halibut include trematodes, cestodes, and nematodes (Bane and Bane 1971; Haaker 1975). About 48% of the California halibut from Anaheim Bay had intestinal tract infestations of the nematode Spirocamallanus pereirai and 34% had infestations of the trematodes Tubulovesicula linbergi and Stephanostomum casum (Haaker 1975). About 2% were infested with the larvae of the cestode Echeneibothrum sp.

Ectoparasites of the California halibut include copepods and isopods. Copepods include Lepeophtheirus bufidis from the body, Taenicanthodes haakeri from the fin rays, and Acanthochondria solea and Holobomalochus prolixus from the gill cavity (Haaker 1975). The Pacific fish louse, Lironeca vulgaris, (a cymothoid isopod) is often found attached to the blind side of California halibut (Bane and Bane 1971).

1.8. KEY SPECIES IN THE BIOLOGICAL ENVIRONMENT OF THE CALIFORNIA HALIBUT

Important prey species of the California halibut include the mysids, Mysidopsis elongatus and Neomysis kadiakensis, which are important prey to the juveniles, and the northern anchovy, which is the most important prey to the adults.

The most important potential competitors of the California halibut are the California lizardfish, bigmouth sole, and speckled sanddab. All are diurnal, benthic species which feed heavily on nektonic prey. Because of its abundance and aggressiveness, the speckled sanddab is a potentially important competitor of small California halibut in the coastal zone. The California lizardfish and bigmouth sole are potential competitors of larger halibut; both are benthic ambushers and feed on mysids at the same size as does the California halibut. The California lizardfish similarly shifts to northern anchovy as it grows, but the bigmouth sole does not grow sufficiently large to make this shift. Small juveniles of both of these species are coastal whereas those of the California halibut reside primarily in the bays. Hence, competition among these species and juvenile halibut is remote but competition between adult California halibut and adult California lizardfish is possible. However, it should be noted that a large halibut is capable of eating a moderately sized lizardfish but because of the difference in body form, the reverse is not true.

The sand sole and Pacific halibut are the most likely replacements of the California halibut to the north (i.e. north of Tomales Bay) and the Cortez halibut to the south (i.e. south of Magdalena Bay). The relative similarities in ecology between the sand sole, Pacific halibut, and California halibut need to be better described. The sand sole is probably the best candidate for an ecological replacement because it is probably the primary soft-bottom benthic ambusher in the nearshore coastal zone north of central California. However, the Pacific halibut is obviously the replacement in the fishery. The geographic displacement series of ecological counterparts in the nearshore zone probably consists of sand sole, California halibut, and Cortez halibut in the region from Washington to the Gulf of California (Figure 5).

The most important predator on settling California halibut along the coast may be the thornback. The most important nonhuman predator of larger coastal juveniles and adults may be the California sea lion. Predation on California halibut is not well documented.

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2. Distribution And Abundance of Early Life History Stages of The California Halibut, Paralichthys californicus, And Comparison With the Fantail Sole, Xystreurys liolepis

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2.1. ABSTRACT

Temporal and spatial abundance patterns of the larvae of two paralichthyid flatfishes, California halibut, Paralichthys californicus, and fantail sole, Xystreurys liolepis, were investigated using a 30-year-long (1951–81) CalCOFI data set that included stations from central California to southern Baja California, and an 8-year-long (1978–86) nearshore data set from two sites in the vicinity of San Onofre, California.

California halibut spawn throughout the year, primarily in February–March and secondarily between July and October off California and northern Baja California. Further south, in Sebastian Viscaino Bay and off central and southern Baja California, spawning is primarily in June–August, and secondarily in February–March. Most larvae occur over the continental shelf, in the upper 30 m of the water column. The oldest larvae occur almost exclusively very near shore; at night they are neustonic. The surfaceward movement of older larvae may facilitate their movement to the shallow zone where they settle and transform to the juvenile stage.

Abundance of larval California halibut is highest off southern California, northern Baja California, and in Sebastian Viscaino Bay, and lowest off central California and southern Baja California. Interannual patterns of larval abundance and the California commercial catch have been highly concordant since 1958, suggesting that the year-to-year fluctuations in the commercial catch result largely from halibut abundance. Furthermore, this concordance of interannual patterns suggests that ichthyoplankton surveys can be used as a fishery-independent tool to assess and monitor the spawning biomass of California halibut.

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Fantail sole spawn throughout the year, with most activity in the last half of the year (August–December). Larvae occur primarily over the continental shelf, mainly off Baja California. Preflexion and flexion stage larvae occur principally in the midwater column; postflexion stage larvae settle into the moderately shallow (22–45 m) epibenthos where they transform to the juvenile stage. The different benthic recruitment strategies of fantail sole and California halibut minimize trophic competition between the young juveniles of the two species.

2.2. INTRODUCTION

The California halibut, Paralichthys californicus, is one of about 21 species belonging to the genus[2] , which occurs in subtropical and warm temperate coastal waters of the New World and northwestern Pacific Ocean. The California halibut ranges along the Pacific coast of North America from northern Washington state to southern Baja California; its distribution is centered in northern Baja California and it is uncommon north of San Francisco. The fantail sole, Xystreurys liolepis, is a somewhat more tropical species that ranges from Monterey Bay, California, to the Gulf of California (Miller and Lea 1972).

Paralichthys californicus has supported important commercial and recreational fisheries since the early twentieth century (e.g., Frey 1971); these fisheries have become increasingly regulated in response to decreasing and variable catches (Methot 1983; Barsky 1990; Jow 1990; Oliphant 1990). From the 1940s to the 1970s both the commercial and recreational fisheries were characterized by catch cycles of about 20 years length; however, in the most recent cycle the recreational party boat catch has remained depressed since the low catches of the early 1970s, while the commercial catch has greatly increased, with only relatively minor short term fluctuations. The inevitable user group conflict that resulted from this disparity in recreational and commercial catches focused attention on possible solutions to the difficult allocation problem (Reed and MacCall 1988), which in turn emphasized the need for basic information on the population dynamics and ecology of this species.

Ichthyoplankton surveys can provide information on spatial and temporal distributions of spawning, on ecology of the early life history stages, and on survival and recruitment of fish stocks (Smith and Richardson 1977). Although such surveys typically focus on wide-ranging coastal pelagic species, in recent years they also have proven effective in monitoring species restricted to the shallow continental shelf (Barnett et al. 1984; Lavenberg et al. 1986). The California Cooperative Oceanic Fisheries Investigations (CalCOFI) has conducted extensive biological/oceanographic surveys off California and Baja California since 1939; recently, a computer data base was established for a 30-year segment (1951–81) of the CalCOFI ichthyoplankton time series (Ambrose et al. 1987). Larval P. californicus occur in samples from the shoreward CalCOFI stations, and these provide fishery-independent information on abundance trends in the form of seasonal and interannual variation in

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[2] Paralichthys traditionally has been included in the family Bothidae, and this affiliation has persisted in recent literature and checklists despite extensive evidence (Amaoka 1969; Ahlstrom et al. 1984; Hensley and Ahlstrom 1984) that it, and 13 other genera, form a distinct lineage: the family Paralichthyidae.

larval numbers. A nearshore ichthyoplankton survey conducted during 1978–86 near the San Onofre Nuclear Generating Station (SONGS) afforded the opportunity to study seasonal and interannual variation in larval abundance in the habitat of adult California halibut. In this paper we use both data sets to: 1) provide new information on the early life history of P. californicus, particularly on seasonal and long-term spawning trends; 2) show that the catch cycles of the California halibut fishery may reflect availability rather than fishing effort; 3) demonstrate the potential of ichthyoplankton surveys as a means of monitoring California halibut biomass; and 4) compare temporal and spatial distributions of larval California halibut with the patterns of the sympatric fantail sole larvae. Larvae of the two species were confused until recently (Ahlstrom et al. 1984); however, subsequent reanalysis of samples allowed time series to be established for both species. The similarities of both the ontogenetic stages and the adults of these two paralichthyids suggest niche overlap, and we address this in our analysis of the X. liolepis data.

2.3. MATERIALS AND METHODS

2.3.1. CalCOFI Surveys

The CalCOFI sampling pattern consists of a series of transect lines perpendicular to the coast at 40-naut mi intervals (Figure 1). Standard stations on each line are 20 naut mi apart, except near islands where they are more closely spaced. Over the 30-year sampling period considered in this paper, the minimum bottom depth at the most shoreward stations was 15 m; most stations were over the deeper continental shelf and farther seaward. Surveys were conducted annually from 1951 to 1966 and triennially from 1966 to 1981. Seasonal coverage was essentially monthly from 1951 to 1960, quarterly from 1961 to 1965, and approximately monthly again from 1966 to 1981. The triennial surveys of 1972 through 1981 consisted of six cruises each, with most cruises in the first half of the year. Areal coverage was greatest during 1951 to 1960, with reduced coverage off southern Baja California thereafter (see Ambrose et al. [1987] and subsequent data reports in that series for details of the CalCOFI sampling coverage).

Prior to 1969, integrated oblique plankton tows were taken to a depth of 140 m using a 1-m ring net equipped with 0.55-mm mesh silk netting. In 1969 the silk netting was replaced with 0.505-mm mesh nylon netting and the integrated tows were taken to a depth of 210 m. In 1978 a 71-cm diameter bongo net (McGowan and Brown 1966) replaced the 1-m ring net. In 1981 a 15-min surface tow was added at each station using a Manta net (Brown and Cheng 1981) having a 15.5 cm deep by 86 cm wide mouth opening and 0.505-mm mesh nylon net.

Laboratory processing of these samples included sorting of the fish eggs and larvae from the plankton and identification and enumeration of all fish larvae. For this study, we reidentified all specimens previously identified as P. californicus, corrected historical errors, and measured body length of each specimen to 0.1 mm. Larval X. liolepis were distinguished from P. californicus, enumerated, and measured.

A standard haul factor (Kramer et al. 1972), calculated for each tow, was used to convert larval counts to the estimated number of larvae under 10 m^2

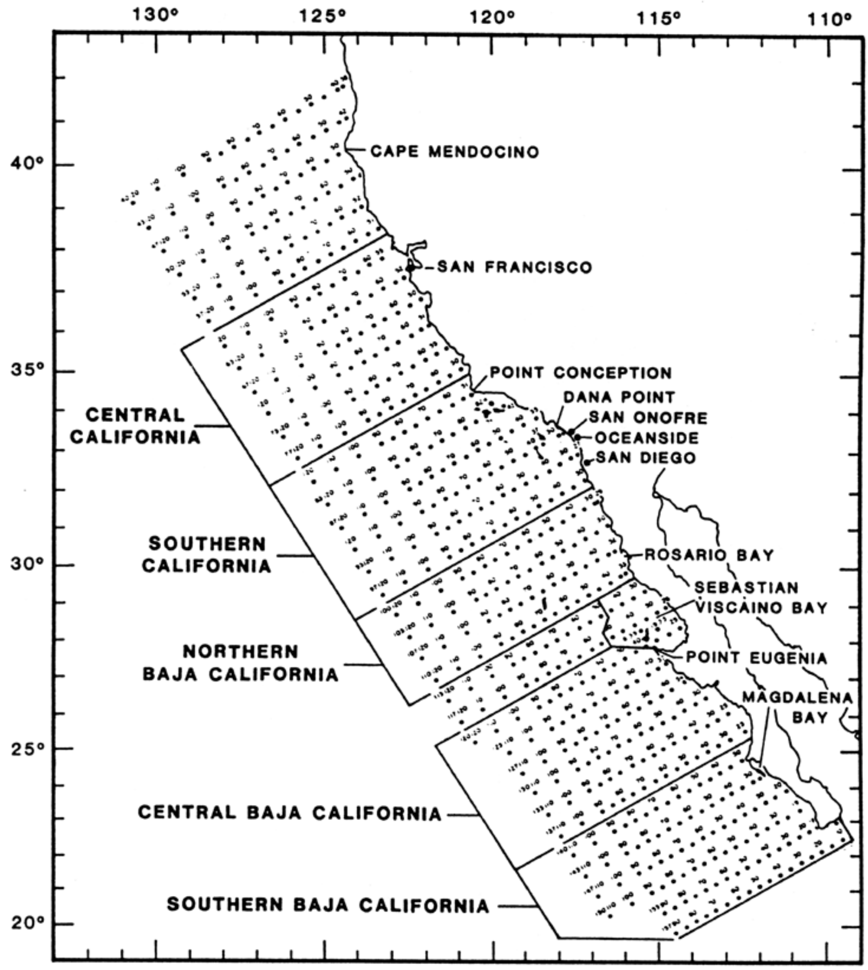

FIGURE 1. Map of the study area showing the six CalCOFI zones and geographic reference points.

FIGURE 1. Map of the study area showing the six CalCOFI zones and geographic reference points

of sea surface. To facilitate analysis, these abundance data were pooled into groups representing six coastal zones (Figure 1): central California (CalCOFI lines 60–77), southern California (lines 80–97), northern Baja California (lines 100–110), Sebastian Viscaino Bay (lines 113–120), central Baja California (lines 120–137), and southern Baja California (lines 140–157). The outer boundaries of these zones were determined by the most seaward occurrences of larval P. californicus from the overall 1951–81 time series (exclusive of three obvious outliers). These zones were the basis for computations of mean abundance under 10 m^2 of sea surface (Appendices I and II). To compensate for seasonal, areal, and interannual gaps in the time series, we employed an ANOVA predictive model developed by MacCall and Prager (1988) to fill in the missing values and produce seasonal and annual abundance indices. Details of this model and its application are given by MacCall and Prager (1988); briefly, missing values within the cells of the ANOVA model were predicted via an iterative procedure that utilized the means of the observed values in the appropriate ANOVA rows and columns (in this case, regions, months, and years) to generate estimates of the missing values. Finally, in order to estimate the average total number of larval California halibut occupying each of the six coastal zones, the mean abundance of larvae in each zone was multiplied by the total area encompassed by that zone (Appendices I and II). These areas (in thousands of km^2) are: central California 10.94, southern California 44.51, northern Baja California 39.17, Sebastian Viscaino Bay 31.40, central Baja California 71.48, and southern Baja California 20.46.

Because the data for larval X. liolepis were limited, it was not feasible to establish zones as was done for P. californicus. Analysis in this case was limited to estimation of seasonal incidence and abundance (mean number of larvae per positive tow).

Vertical distribution data were obtained from a series of 16 discrete depth tows taken off Dana Point, California at CalCOFI station 90.28 (2.4 nm from shore, 350 m bottom depth) from 29 March to 5 April 1980. The MESSHAI multiple opening-closing net system (Pommeranz and Moser 1987) was used to sample five discrete 10-m thick water column strata; the mouth opening of each net was 25 x 25 cm. A Manta net was used to obtain a surface sample during each tow. Larval density (numbers per 10 m^3) for each stratum was calculated from total numbers of larvae and total volume of filtered water summed from all tows in each stratum.

2.3.2. Nearshore Surveys

Nearshore samples were collected from January 1978 through September 1986 along a transect line perpendicular to shore approximately 1 km south of SONGS, and from August 1979 through September 1986 along a similar transect off Stuart Mesa, approximately 17 km south of the SONGS transect. Except for a limited study of daily vertical migration at the SONGS site (Barnett et al. 1984), the sampling methodology, described by Barnett et al. (1984) and Walker et al. (1987), was the same at both study sites. Briefly, a stratified random sampling design (Snedecor and Cochran 1967) was used wherein the neustonic (top 16 cm), epibenthic (bottom 67 cm), and remaining midwater layers of the water column were sampled along a randomly selected isobath within each of five blocks at each site on each survey date. These blocks were defined by bottom depth: (A) 6–9 m; (B) 9–12 m; (C) 12–22 m; (D) 22–45 m; and (E) 45–75 m. Sampling for the vertical migration study was conducted only along the 8-m and 13-m isobaths off SONGS.

Three different samplers, equipped with 0.333-mm mesh Nitex nets and flowmeters, were required to sample the entire water column. A Manta net, 88 cm wide by 16 cm deep, was used to sample the neuston; a 71-cm bongo net was used to take a stepped-oblique tow through the midwater column; and an Auriga net (MBC Applied Environmental Sciences, 947 Newhall Street, Costa

Mesa, CA 92627), 2 m wide by 0.5 m high, was used in the epibenthic stratum. All sampling on the transects was at night; both day and night sampling was included in the vertical migration study. In all cases, tows were taken along the selected isobath at ca. 1 m/s for a fixed time in order to filter a target volume of 400 m^3. All samples were preserved in the field in 10% seawater formalin.

Because the nearshore sampling was part of a study to predict, and subsequently measure, the effects on the plankton of a coastal nuclear electric generating station, the sampling frequency varied considerably, according to the changing requirements of the power plant study. Sampling frequency ranged from approximately weekly during the latter part of the predictive phase of the study to approximately quarterly during the 3-year interim between the plant pre-operational and operational phases. Most sampling was in spring and summer (March through September).

Subsamples (average 25%, range 3.1-100%) taken with a Folsom plankton splitter were sorted for fish larvae using dissecting microscopes (6–10X magnification). Each was checked to ensure that at least 90% of the fish larvae were removed. Larval California halibut and fantail sole were enumerated in four classes corresponding to developmental stages: yolk-sac (no yolk-sac stage fantail sole were identified), preflexion (exclusive of yolk-sac), notochord flexion, and postflexion. This staging was done for a subset of the 1978–79 samples (one transect per survey) and for all subsequent samples. In addition, postflexion stage larvae of California halibut were enumerated in 1-mm size classes from the 1978 samples to more closely examine the distribution of transforming larvae. From 1984 through 1986, as a result of a shift in program focus, samples collected in block E were not analyzed.

Larval California halibut count data were converted to number per 100 m^3, and for the transect sampling these density values were used to calculate larval abundance (number under 10 m^2 of sea surface) in each block. The abundance values were transformed by log (X + C), then analyzed using ANOVA and the Student-Neuman-Keuls (SNK) multiple range test (results evaluated at [a]=0.05) for offshore pattern. Most non-zero abundance values for preflexion and flexion larvae were larger than 1.0, while most for yolk-sac and postflexion larvae were larger than 0.1. Therefore, constants selected for use in the log (X + C) transformation were 1.0 for preflexion and flexion, and 0.1 for yolk-sac and postflexion. For analyses of finer-scale offshore/vertical distributions of larvae off SONGS, the log (X + 1.0) transformation of larval density data was used since values [>] 1.0 represented the majority of the non-zero data. For the ANOVA and SNK analyses of both abundance and density patterns, the 1984–86 data were excluded in order to maintain a balanced design. Results of the analyses were back-transformed and are presented in tabular form as geometric mean number of larval California halibut per 10 m^2 or per 100 m^3. Note that the geometric means are a function of the constant used in the log transformation, and are smaller than the corresponding arithmetic means. The arithmetic means are presented in figures. Since few larval fantail sole were collected, only arithmetic mean abundances and densities are given; statistical analyses were not performed.

A repeated-measures ANOVA was used for the analysis of daily vertical migration. This analysis was described by Barnett et al. (1984) and only the results are summarized here.

Seasonal abundance patterns were qualitatively examined for both species by calculating monthly mean abundance (number under 10 m^2 of sea surface) within the 6 to 75-m depth zone at each study site (Appendices III to VI). In addition, the average number of larvae occupying the coastal zone in each month was estimated for each site. This was done by multiplying each mean larval abundance value by the area represented by that transect line. The areal estimates were obtained from Lavenberg et al. (1986): the SONGS transect, corresponding approximately to CalCOFI line 90.9, was taken to represent an area of 142 km^2, while the Stuart Mesa transect, corresponding approximately to CalCOFI line 91.6, represented 105 km^2. For the 1984–86 surveys, when larval abundance data were available only for stations shoreward of the 45-m isobath, both monthly mean abundances and population estimates were extrapolated to the entire zone shoreward of the 75-m isobath. These values, given in Appendices III to VI, are within about 5% of the values that would have been obtained for population size of both species and for mean abundance of larval fantail sole if the estimates were not extrapolated beyond 45-m depth, but are only about three-quarters as large for mean abundance of larval California halibut.

2.4. RESULTS

2.4.1. CalCOFI Surveys

2.4.1.1. Paralichthys californicus

A total of 3713 larval P. californicus (9350 after adjustment for standard haul factor) were collected in 1092 of the 13,367 tows taken in the six coastal zones during 1951–81. These larvae were collected primarily between Magdalena Bay, Baja California and Point Conception, California (Figure 2), an area corresponding to the San Diegan zoogeographic province (Allen and Smith 1988). Spawning distributions often are precise estimators of zoogeographic relationships; the overall larval distribution of P. californicus clearly shows its warm-water affinity and demonstrates its limited spawning off central California. Mean incidence over the entire 1951–81 time series was highest (12.0%) in the Sebastian Viscaino Bay zone, somewhat lower in northern Baja California and southern California, and two-thirds lower off central California and central and southern Baja California (Table 1). Mean relative abundance followed a similar pattern, except that zonal differences were larger. Mean abundance in the Sebastian Viscaino Bay zone was highest (1.14 larvae/10 m^2), with northern Baja California and southern California somewhat lower. Mean abundance in southern Baja California was lower yet—about 13% that of Sebastian Viscaino Bay, while the value for central California was only about 10% of the Sebastian Viscaino Bay value. However, estimates of mean total number of larvae occupying each zone (mean larval abundance in each zone multiplied by the area encompassed by the zone) were about equal for southern California, northern Baja California, and Sebastian Viscaino Bay. These three zones combined accounted for about 80% of the total number of larval California halibut estimated to occupy the waters off California and Baja California. The estimated total was somewhat lower for the central Baja California zone, and was very low for central California and southern Baja California: these last two zones accounted for about 3% of the overall California and Baja California estimated total (Table 1). Larval California halibut clearly were concentrated at nearshore stations: 85% of all larvae occurred at stations over the continental shelf (<200 m bottom depth).

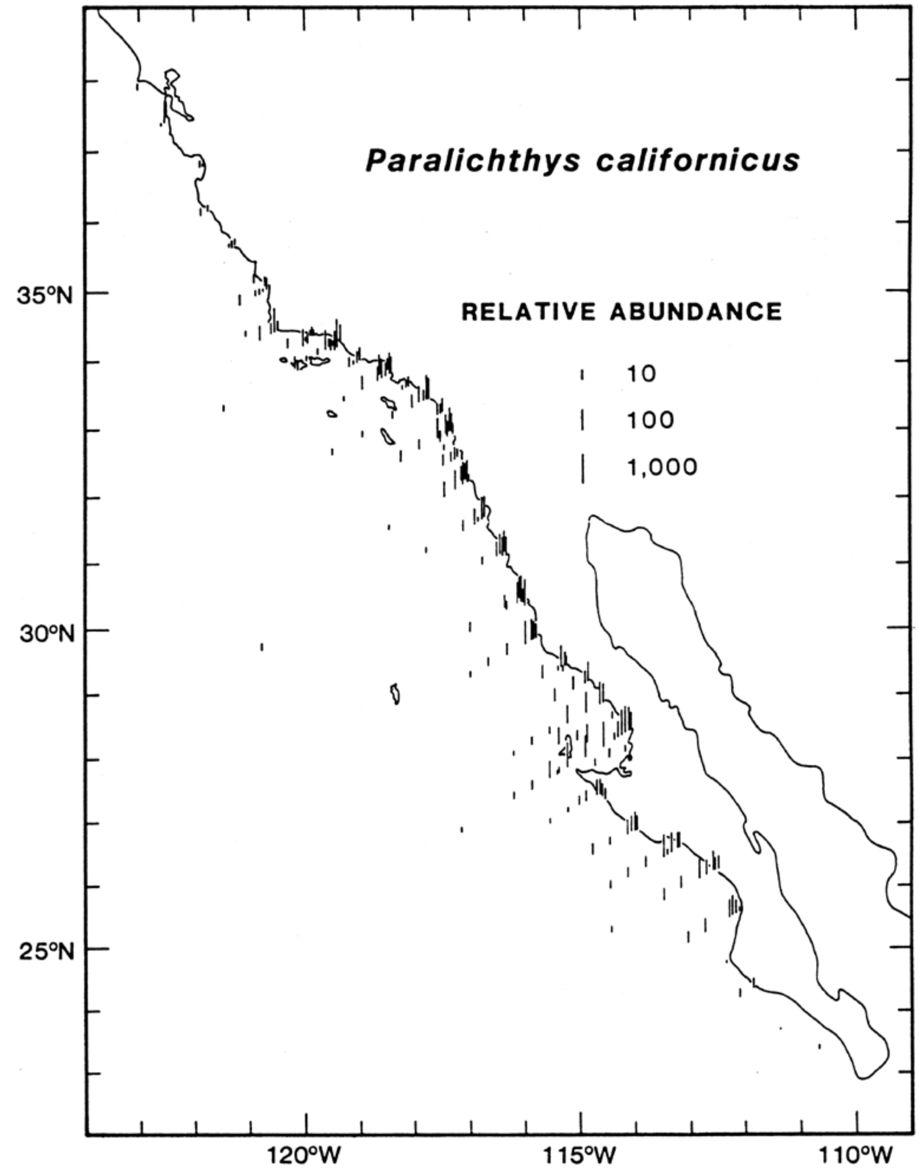

FIGURE 2. Geographic distribution and relative abundance of larval *Paralichthys californicus* collected in CalCOFI surveys, 1951–81.

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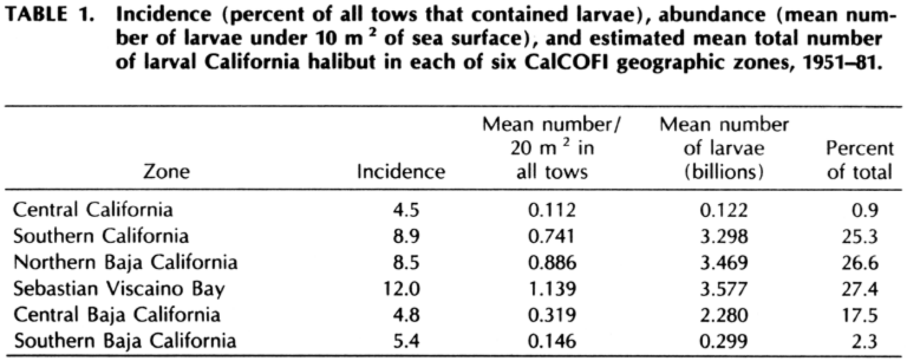


TABLE 1. Incidence (percent of all tows that contained larvae), abundance (mean number of larvae under 10 m^2 of sea surface), and estimated mean total number of larval California halibut in each of six CalCOFI geographic zones, 1951–81.

Zone	Incidence	Mean number/ 20 m^2 in all tows	Mean number of larvae (billions)	Percent of total
Central California	4.5	0.112	0.122	0.9
Southern California	8.9	0.741	3.298	25.3
Northern Baja California	8.5	0.886	3.469	26.6
Sebastian Viscaino Bay	12.0	1.139	3.577	27.4
Central Baja California	4.8	0.319	2.280	17.5
Southern Baja California	5.4	0.146	0.299	2.3

TABLE 1. ***Incidence (percent of all tows that contained larvae), abundance (mean number of larvae under 10 m^2 of sea surface), and estimated mean total number of larval California halibut in each of six CalCOFI geographic zones, 1951–81.***

Spawning occurs throughout the year in the CalCOFI survey area (Figure 3). Mean seasonal incidence and abundance, pooled for the entire time series, were similar (Figure 3a), with major peaks in February and July, minor peaks in April and October, and minima in May and November. Overall, both incidence and abundance decreased after the sharp February peak (13.3% positive tows, 1.42 larvae/10 m^2). The summer peak was weaker (9.7%, 0.92 larvae/10 m^2) but broader, extending from about June into August. When the incidence data were partitioned into California and Baja California components, there were three periods of higher incidence (Figure 3b): January–February, June–July and September–October off California, and February, April, and July–August off Baja California.

There were three peaks in larval abundance (mean number of larvae/10 m^2 in positive tows, and averaged over all tows) off California, with amplitude decreasing sequentially from the February to the July and October peaks (Figure 4). off Baja California, mean abundance also was highest in February (16 larvae/10 m^2 in positive tows, 2.2 larvae/10 m^2 in all tows), while the summer peak was smaller but much broader (June–August). Minor increases occurred off Baja California in April and October (Figure 4b).

Seasonal trends of estimated mean total number of larvae were similar off California and Baja California but the total was much larger off Baja California than off California (Figure 5a). Northern Baja California produced the largest component of the overall February peak (Figure 5b), with an ANOVA index value twice as large as the overall CalCOFI mean. Following the February peak, the total number of larvae off northern Baja California decreased abruptly, remained low through June, then increased slightly in August before declining to the annual nadir in October and November (Figure 5b). California contributed the second largest fraction of the overall February peak. Interestingly, the ANOVA model indicated three smaller peaks in California after the major February peak: in April, July, and September–October (Figure 5b). The April peak was not apparent in the arithmetic means of incidence and abundance for California (cf. Figures 3b, 4b, and 5b). The combined central and southern Baja California index value was slightly lower than that for California in February, showed a minor increase in April, a large peak in June–August, and

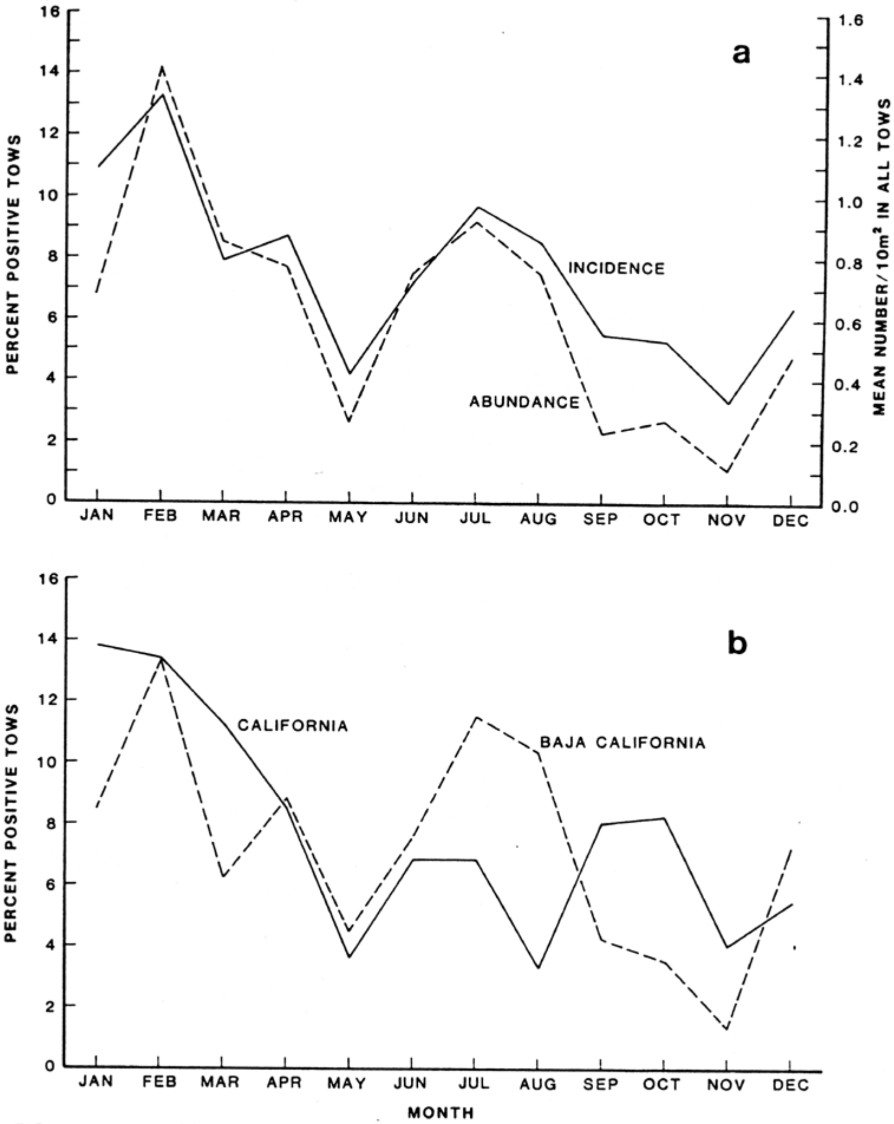


FIGURE 3. Monthly means of: (a) incidence and abundance of larval *Paralichthys californicus* collected in CalCOFI surveys, 1951–81; and (b) incidence of larval *P. californicus* at CalCOFI stations off California and off Baja California, 1951–81.

FIGURE 3. Monthly means of: (a) incidence and abundance of larval Paralichthys californicus collected in CalCOFI surveys, 1951–81; and (b) incidence of larval P. californicus at CalCOFI stations off California and off Baja California, 1951–81

declined to a minimum in November (Figure 5b). Larval production was-delayed in Sebastian Viscaino Bay, with the early peak in March, one month later than for the other areas. The total number of larvae in Sebastian Viscaino Bay was highest in July (Figure 5b); this peak, which represented the largest fraction of the overall summer peak, was ca. 1.5 times the overall CalCOFI mean.

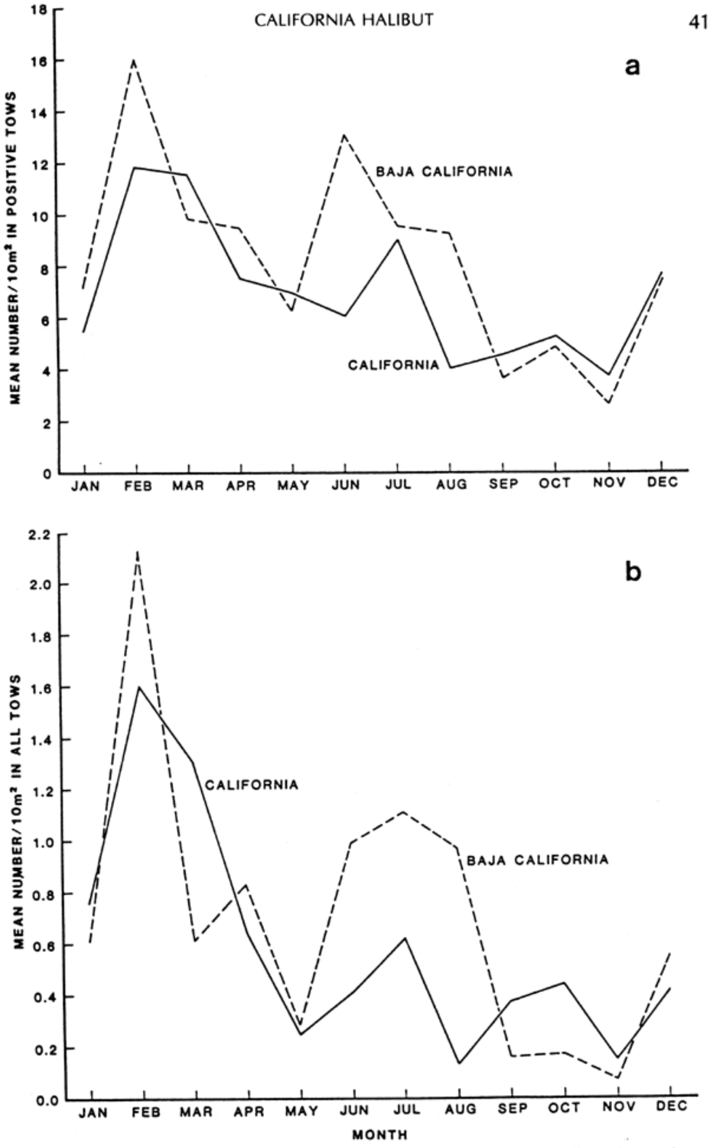


FIGURE 4. Monthly mean abundance of larval *Paralichthys californicus* collected at CalCOFI stations off California and off Baja California, 1951–81: (a) mean number per 10 m ^{2} averaged only over tows that contained *P. californicus*; and (b) mean number per 10 m ^{2} averaged over all tows.

FIGURE 4. Monthly mean abundance of larval Paralichthys californicus collected at CalCOFI stations off California and off Baja California, 1951–81: (a) mean number per 10 m^2 averaged only over tows that contained P. californicus; and (b) mean number per 10 m^2 averaged over all tows

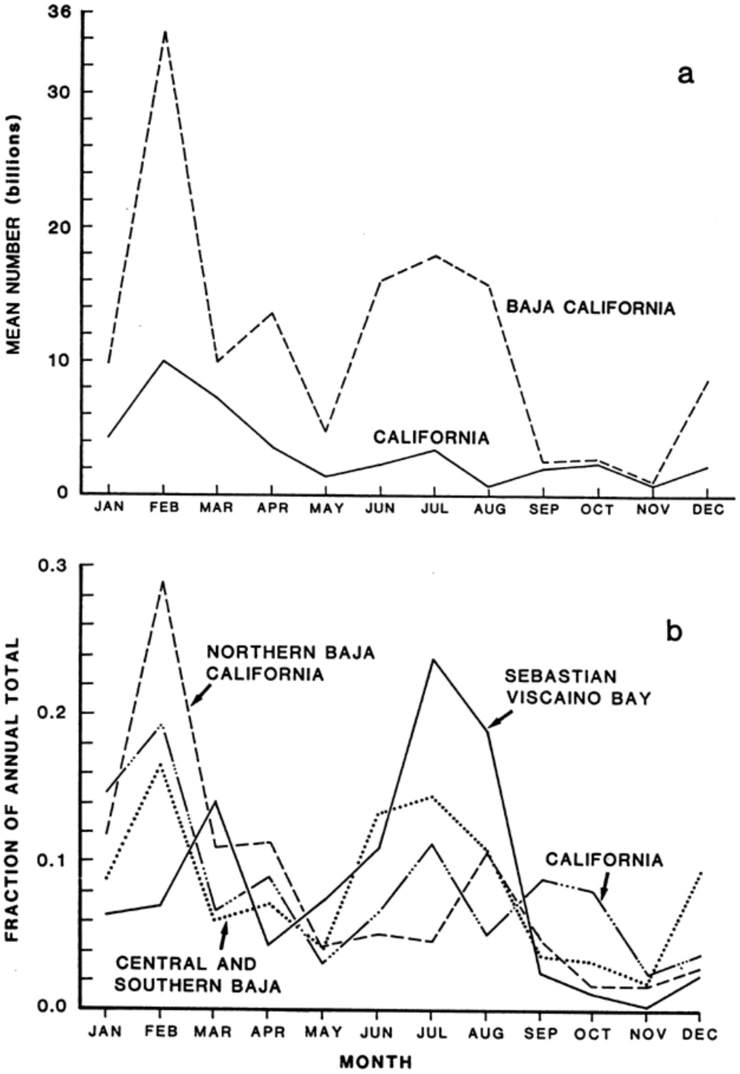


FIGURE 5. Total number of larval *Paralichthys californicus* by month and geographic zone in CalCOFI surveys, 1951–81: (a) mean total number (= monthly mean number per m ^{2} x area in m ^{2} of geographic region) present off California and off Baja California; and (b) fraction of the total present in each of four geographic zones asderived from the ANOVA analysis

FIGURE 5. Total number of larval Paralichthys californicus by month and geographic zone in CalCOFI surveys, 1951–81: (a) mean total number (= monthly mean number per m^2 x area in m^2 of geographic region) present off California and off Baja California; and (b) fraction of the total present in each of four geographic zones asderived from the ANOVA analysis

Regional differences in seasonal spawning patterns were further investigated by plotting regional maps of larval incidence and abundance data pooled by quarter (Figure 6). Larval incidence off central California was moderate only in the first quarter, and was low during the remainder of the year. off southern California, incidence was highest in the first quarter, subsided during the second quarter to a level comparable to the central California maximum, and then increased again during the third quarter. off northern Baja California, incidence was highest during the first quarter and subsequently declined gradually. In Sebastian Viscaino Bay larval incidence was moderately high during the first half of the year, then increased to its maximum level in the third quarter. Incidence off central and southern Baja California was lower during the first quarter than in any of the more northern regions; incidence was minimal in the second quarter and only a little higher subsequently. Similar patterns were evident for mean abundance, except that the third quarter increase off southern California was less apparent, while the strength and duration of the spring–summer spawning peak in Sebastian Viscaino Bay was even more apparent (Figure 6).

The major spawning peaks of P. californicus in California (February) and Sebastian Viscaino Bay (July–August) occurred during vastly different regimes of temperature and zooplankton abundance. Mean larval abundance was highest off southern California when water temperature was lowest, and when mean zooplankton volume was beginning to increase (Table 2). In contrast, in Sebastian Viscaino Bay highest mean larval abundance occurred during the period when water temperature was highest and when mean zooplankton volume was decreasing (Table 2).

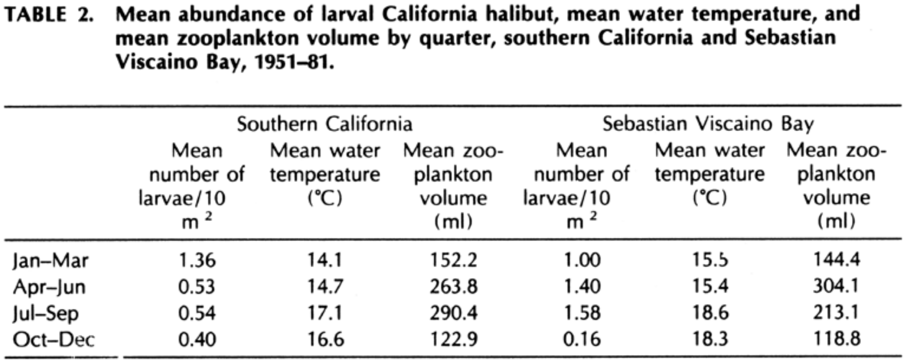


TABLE 2. Mean abundance of larval California halibut, mean water temperature, and mean zooplankton volume by quarter, southern California and Sebastian Viscaino Bay, 1951–81.

	Southern California			Sebastian Viscaino Bay		
	Mean number of larvae/10 m ^{2}	Mean water temperature (°C)	Mean zoo-plankton volume (ml)	Mean number of larvae/10 m ^{2}	Mean water temperature (°C)	Mean zoo-plankton volume (ml)
Jan–Mar	1.36	14.1	152.2	1.00	15.5	144.4
Apr–Jun	0.53	14.7	263.8	1.40	15.4	304.1
Jul–Sep	0.54	17.1	290.4	1.58	18.6	213.1
Oct–Dec	0.40	16.6	122.9	0.16	18.3	118.8

TABLE 2. ***Mean abundance of larval California halibut, mean water temperature, and mean zooplankton volume by quarter, southern California and Sebastian Viscaino Bay, 1951–81.***

Analysis of interannual variation in larval abundance is hindered by uneven regional coverage of CalCOFI surveys during 1951–81. The Southern California Bight was the most consistently occupied area, with complete coverage on about 95% of the cruises during the 30-year period. Mean larval abundance (number of larvae/10 m^2 on all tows) off southern California varied markedly during this period (Figure 7). Means ranged from extremely low values (>0.2 larvae/10 m^2) in 1951–52, 1960, and 1972, to highs of 0.9 larvae/10 m^2 in 1958, 1.8 larvae/10 m^2 in 1965, and almost 5.0 larvae/10 m^2 by 1981. Commercial landings for southern California corresponded closely to the trends in larval

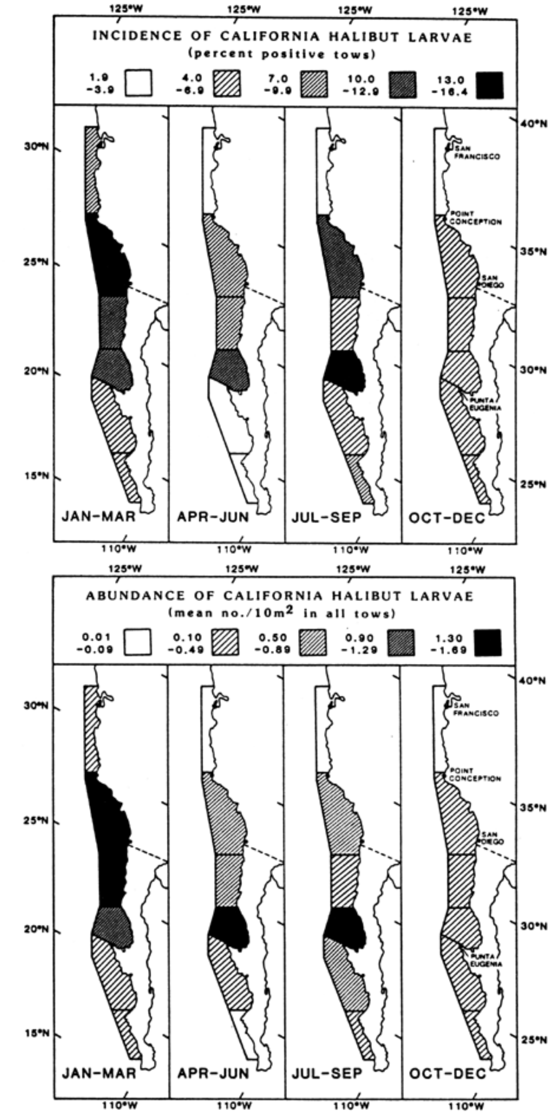


FIGURE 6. Maps of incidence (above) and mean abundance (below) of larval *Paralichthys californicus*, by quarter, in each of six geographic zones; CalCOFI surveys, 1951–81.

FIGURE 6. Maps of incidence (above) and mean abundance (below) of larval Paralichthys californicus, by quarter, in each of six geographic zones; CalCOFI surveys, 1951–81

abundance, except during 1951–58 when the trends were diametrically opposite (Figure 7). Commercial landings decreased from ca. 1 million lb in 1947 to ca. 250,000 lb by 1958, then increased sharply to 800,000 lb in 1964, decreased again to 117,000 lb by 1973, and finally increased once again to ca. 700,000 lb in 1981. The close correspondence of trends in larval abundance and landings after 1958 is remarkable. The disparity between the two time series before 1958 may be, at least in part, an artifact resulting from inadequate identifications of P. californicus larvae in those early years. Abundance values may well have been higher than the recorded values for P. californicus. However, confirmation (or refutation) of this suggestion is not presently feasible.

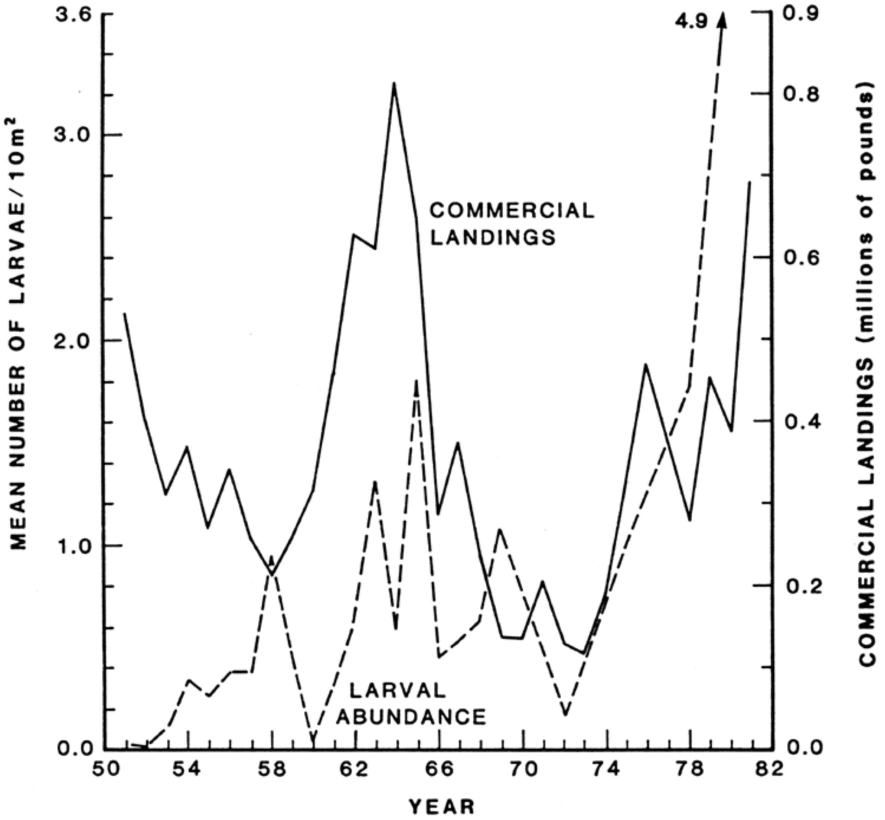


FIGURE 7. Annual mean abundance of larval Paralichthys californicus collected at CalCOFI stations off southern California from 1951–81, and annual southern California commercial landings of *P. californicus* from 1951–81.

FIGURE 7. Annual mean abundance of larval Paralichthys californicus collected at CalCOFI stations off southern California from 1951–81, and annual southern California commercial landings of P. californicus from 1951–81

The ANOVA model showed a pattern of interannual California larval abundance index values in general agreement with trends in the California commercial landings (Figure 8), and even closer agreement was obtained between California commercial landings and the larval abundance index for all six CalCOFI zones combined (Figure 8). Only the relatively low abundance indices for 1951–58 were poorly aligned with landings.

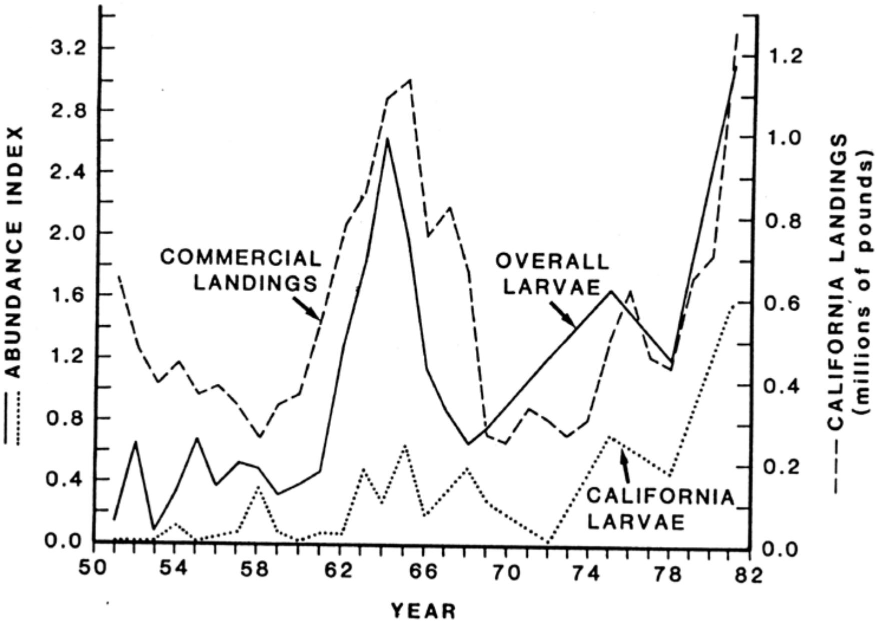


FIGURE 8. ANOVA annual abundance index values for larval *Paralichthys californicus* from all 1951–81 CalCOFI stations and from the California stations alone, and 1951–81 annual California commercial landings of *P. californicus*.

FIGURE 8. ANOVA annual abundance index values for larval Paralichthys californicus from all 1951–81 CalCOFI stations and from the California stations alone, and 1951–81 annual California commercial landings of P. californicus

The vertical distribution study of larval P. californicus in near-shelf waters showed that larvae were restricted to the upper 30 m of the water column, and were concentrated in the shallower part of that zone (Table 3 Figure 9). Overall, about half the larvae were taken in the upper 10 m and about 90% in the upper 20 m. Day/night larval density ratios of 4.9 for the upper 10 m and 0.5 for the 10 to 20-m stratum suggest a downward movement of larvae at night. Surface (Manta net) tows taken in conjunction with the discrete depth tows captured no larvae during the day, and at night contained the fewest larvae of any stratum in the upper 30 m (1.5 larvae/100 m^3).

Overall, mean lengths of larvae from the vertical distribution study were greatest in the surface samples, smallest in the 0 to 10-m stratum, and increased slightly in the 10 to 20-m and 20 to 30-m strata (Table 4). Within each stratum the mean larval length was larger at night than during the day. The disparity between day and night lengths decreased with increasing depth: day/night ratios of mean length were 0.82 for the 0 to 10-m stratum, 0.94 for 10–20 m, and 0.97 for 20–30 m. Large postflexion stage larvae were taken only in surface tows, and only at night.

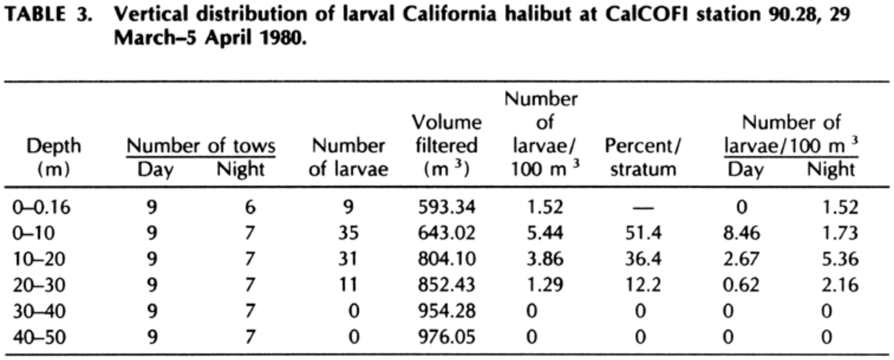


TABLE 3. Vertical distribution of larval California halibut at CalCOFI station 90.28, 29 March–5 April 1980.

Depth (m)	Number of tows		Number of larvae	Volume filtered (m^3)	Number of larvae/ 100 m^3	Percent/ stratum	Number of larvae/100 m^3	
	Day	Night					Day	Night
0–0.16	9	6	9	593.34	1.52	—	0	1.52
0–10	9	7	35	643.02	5.44	51.4	8.46	1.73
10–20	9	7	31	804.10	3.86	36.4	2.67	5.36
20–30	9	7	11	852.43	1.29	12.2	0.62	2.16
30–40	9	7	0	954.28	0	0	0	0
40–50	9	7	0	976.05	0	0	0	0

TABLE 3. ***Vertical distribution of larval California halibut at CalCOFI station 90.28, 29 March–5 April 1980.***

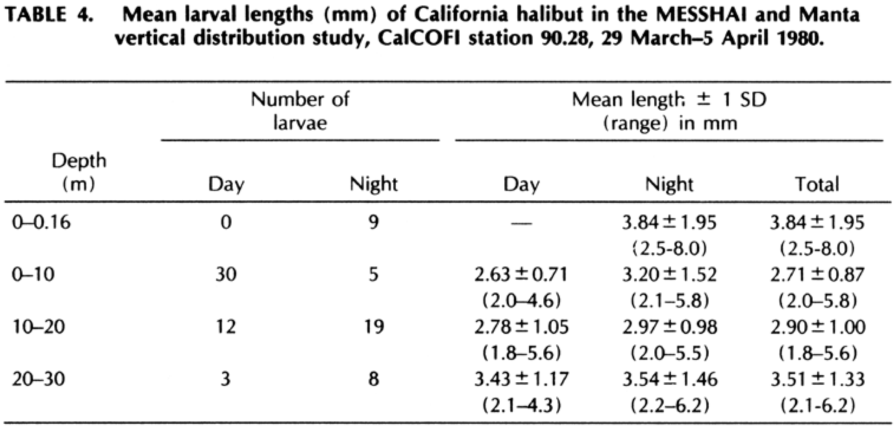


TABLE 4. Mean larval lengths (mm) of California halibut in the MESSHAI and Manta vertical distribution study, CalCOFI station 90.28, 29 March–5 April 1980.

Depth (m)	Number of larvae		Mean length ± 1 SD (range) in mm		
	Day	Night	Day	Night	Total
0–0.16	0	9	—	3.84 ± 1.95 (2.5-8.0)	3.84 ± 1.95 (2.5-8.0)
0–10	30	5	2.63 ± 0.71 (2.0–4.6)	3.20 ± 1.52 (2.1–5.8)	2.71 ± 0.87 (2.0–5.8)
10–20	12	19	2.78 ± 1.05 (1.8–5.6)	2.97 ± 0.98 (2.0–5.5)	2.90 ± 1.00 (1.8–5.6)
20–30	3	8	3.43 ± 1.17 (2.1–4.3)	3.54 ± 1.46 (2.2–6.2)	3.51 ± 1.33 (2.1-6.2)

TABLE 4. ***Mean larval lengths (mm) of California halibut in the MESSHAI and Manta vertical distribution study, CalCOFI station 90.28, 29 March–5 April 1980.***

Comparison of larval lengths of P. californicus taken in Manta and bongo tows in the 1981 CalCOFI survey supported the results of the vertical distribution study in that mean larval length overall was about 1.5 times larger in the Manta samples than in the bongo samples (Table 5). The overall length-frequency distribution in Manta samples was bimodal about the 2.25-mm and 8.25-mm length classes, while the overall pattern for bongo samples was unimodal about the 3.25-mm length class (Table 6). The bimodal length frequency distribution of total Manta net catches resulted from opposite day and night distributions (Table 6). Mean larval length in night Manta samples was twice that of day Manta samples, while mean larval length in night bongo samples was only slightly larger than that of day bongo samples (Table 5). More than 80% of all day-caught larvae at the surface were in the two smallest size classes, while over 50% of the night-caught surface larvae were in the four largest size classes. In the bongo samples, frequency of occurrence declined with increasing larval length (except that the 2.25-mm size class was underrepresented), and the largest size classes were absent, both day and night.

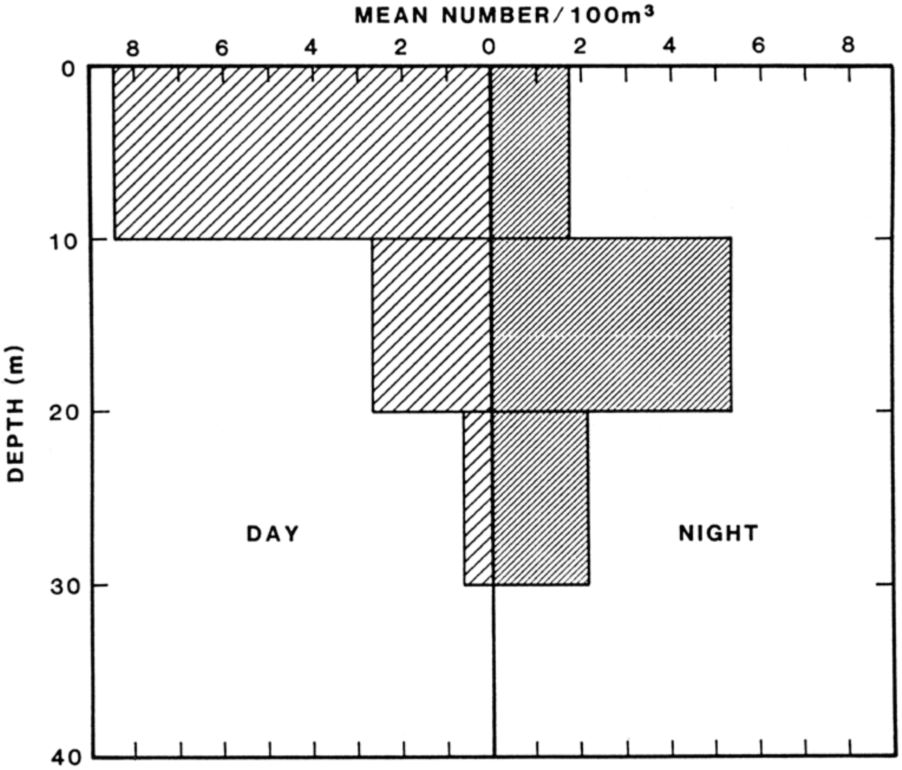
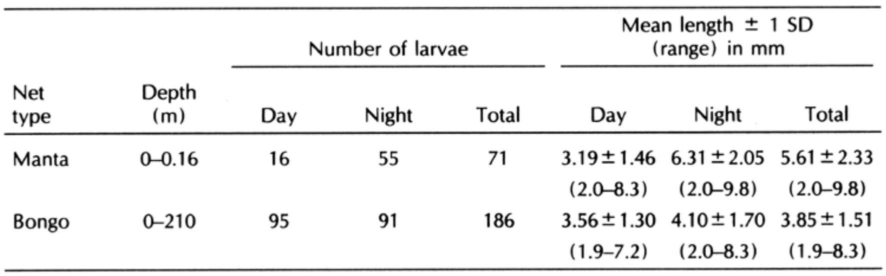


FIGURE 9. Mean vertical distribution of larval *Paralichthys californicus* at CalCOFI station 90.28, 29 March–5 April 1980.

FIGURE 9. Mean vertical distribution of larval Paralichthys californicus at CalCOFI station 90.28, 29 March–5 April 1980

TABLE 5. Mean larval lengths (mm) of California halibut collected in the 1981 CalCOFI survey.



Net type	Depth (m)	Number of larvae Day	Number of larvae Night	Number of larvae Total	Mean length ± 1 SD (range) in mm Day	Mean length ± 1 SD (range) in mm Night	Mean length ± 1 SD (range) in mm Total
Manta	0–0.16	16	55	71	3.19 ± 1.46 (2.0–8.3)	6.31 ± 2.05 (2.0–9.8)	5.61 ± 2.33 (2.0–9.8)
Bongo	0–210	95	91	186	3.56 ± 1.30 (1.9–7.2)	4.10 ± 1.70 (2.0–8.3)	3.85 ± 1.51 (1.9–8.3)

TABLE 5. ***Mean larval lengths (mm) of California halibut collected in the 1981 CalCOFI survey.***

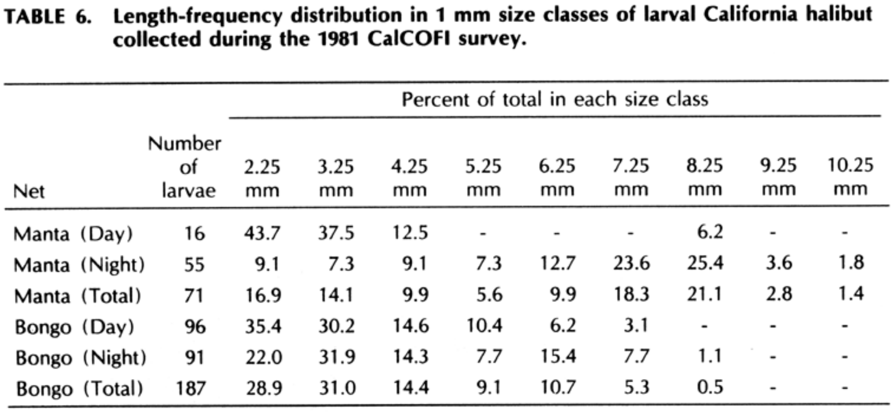


TABLE 6. Length-frequency distribution in 1 mm size classes of larval California halibut collected during the 1981 CalCOFI survey.

Net	Number of larvae	Percent of total in each size class 2.25 mm	3.25 mm	4.25 mm	5.25 mm	6.25 mm	7.25 mm	8.25 mm	9.25 mm	10.25 mm
Manta (Day)	16	43.7	37.5	12.5	-	-	-	6.2	-	-
Manta (Night)	55	9.1	7.3	9.1	7.3	12.7	23.6	25.4	3.6	1.8
Manta (Total)	71	16.9	14.1	9.9	5.6	9.9	18.3	21.1	2.8	1.4
Bongo (Day)	96	35.4	30.2	14.6	10.4	6.2	3.1	-	-	-
Bongo (Night)	91	22.0	31.9	14.3	7.7	15.4	7.7	1.1	-	-
Bongo (Total)	187	28.9	31.0	14.4	9.1	10.7	5.3	0.5	-	-

TABLE 6. ***Length-frequency distribution in 1 mm size classes of larval California halibut collected during the 1981 CalCOFI survey.***

Size frequency distributions in CalCOFI samples differed little between larvae collected over the continental shelf and those collected farther seaward (Figure 10). The offshore larvae contributed slightly smaller proportions of the 2.25-mm, 6.25-mm, and 7.25-mm length classes, and slightly larger proportions of the 3.25-mm, 4.25-mm, 5.25-mm, and 8.25-mm length classes, than the larvae collected at shallower stations. A more striking feature of the size frequency distribution is the paucity of large larvae in the CalCOFI samples: ca. 80% of the larvae were in the preflexion stage (Figure 10). In addition to the small catches of large larvae, the 2.25-mm size class was under- represented in the CalCOFI samples because of extrusion of the larvae through the 0.5-mm mesh. Yolk-sac larvae were rare in CalCOFI samples, again because their small size and fragility make them highly vulnerable to extrusion.

2.4.1.2. Xystreurys liolepis

A total of 529 larval fantail sole (1272 after adjustment for standard haul factor) were taken in CalCOFI samples between 1951 and 1981, less than one-seventh the number of P. californicus larvae collected. Few larval fantail sole occurred north of Sebastian Viscaino Bay, and none was taken north of Point Conception (Figure 11). Larvae were relatively abundant in Sebastian Viscaino Bay and south of Punta Eugenia to Magdalena Bay. Larvae of X. liolepis were more coastal than larval P. californicus.

Like P. californicus, X. liolepis apparently spawns throughout the year, but its peak activity is shifted to the second half of the year. Mean larval incidence usually was less than 1% from January to June, increased to a maximum of 4% in August, then decreased gradually to 3% by December (Figure 12). Mean abundance (number of larvae/10 m^2 in positive tows) was lowest between February and May (ca. 4 larvae/10 m^2), increased to a maximum of ca. 10 larvae/10 m^2 in August, then declined sharply back to the ca. 4 larvae/10 m^2 level before once again irregularly increasing to ca. 8 larvae/10 m^2 in December (Figure 12).

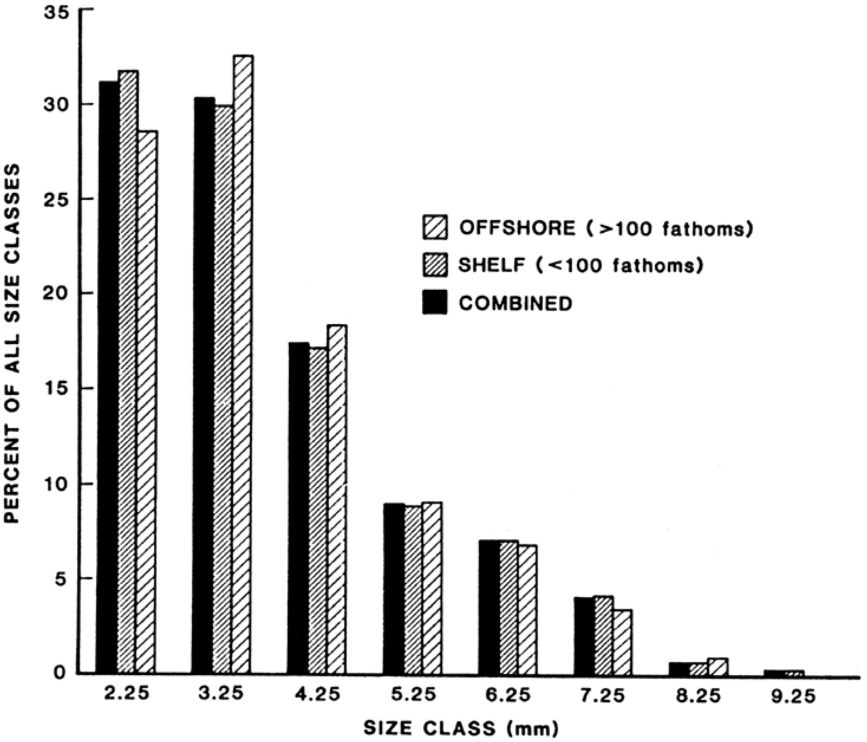


FIGURE 10. Length-frequency distributions of larval *Paralichthys californicus* collected at CalCOFI stations over the continental shelf (< 100 fm bottom depth) and seaward of the shelf (> 100 fm bottom depth), 1951–81. The 2.25 to 4.25-mm size classes correspond approximately to preflexion larval stage, the 5.25-mm class approximately to flexion stage, and the 6.25 to 9.25-mm classes approximately to postflexion stage.

FIGURE 10. Length-frequency distributions of larval Paralichthys californicus collected at CalCOFI stations over the continental shelf (< 100 fm bottom depth) and seaward of the shelf (> 100 fm bottom depth), 1951–81. The 2.25 to 4.25-mm size classes correspond approximately to preflexion larval stage, the 5.25-mm class approximately to flexion stage, and the 6.25 to 9.25-mm classes approximately to postflexion stage

Maps of mean larval incidence and abundance, pooled by quarter, show that incidence was low throughout the year north of Sebastian Viscaino Bay, except for a slight increase off southern California during October–December (Figure 13). Highest incidence in Sebastian Viscaino Bay and off central Baja California occurred during the second half of the year, with a third-quarter peak for the former and a fourth-quarter peak for the latter. Regional abundance patterns were similar to the incidence patterns, except that the increase off southern California extended over both the third and fourth quarters, and the highest value for central Baja California occurred during the third quarter, rather than the fourth quarter.

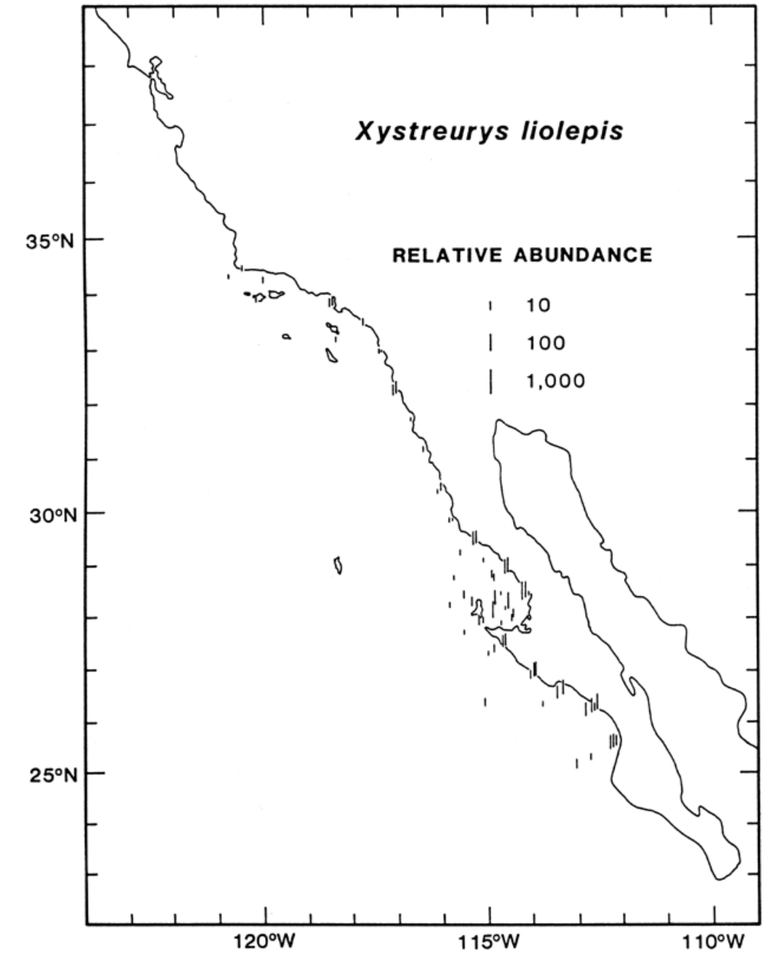


FIGURE 11. Geographic distribution and relative abundance of larval *Xystreurys liolepis* collected in CalCOFI surveys, 1951–81.

FIGURE 11. Geographic distribution and relative abundance of larval Xystreurys liolepis collected in CalCOFI surveys, 1951–81

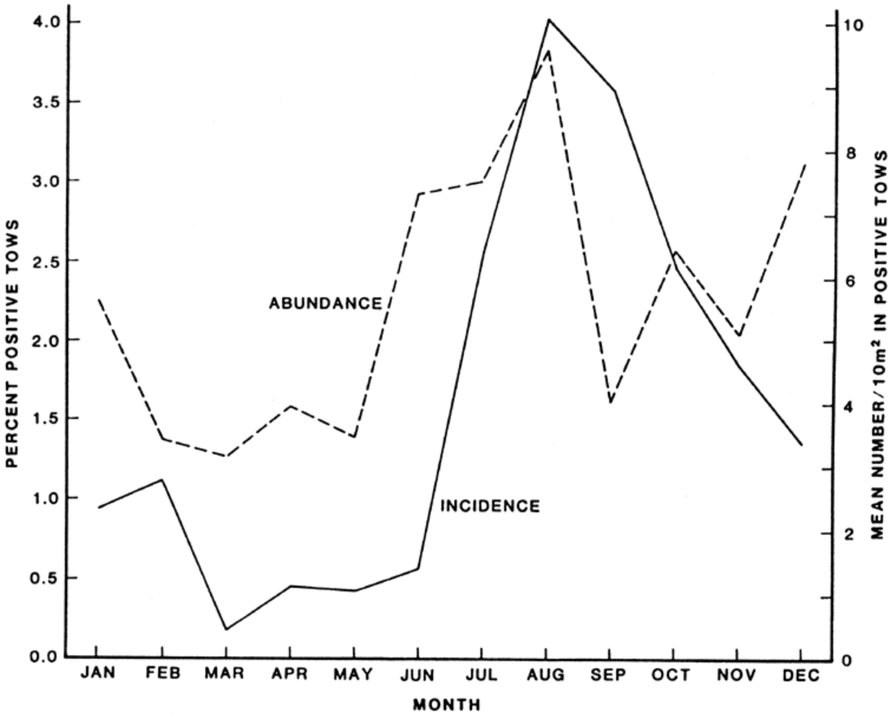


FIGURE 12. Monthly mean incidence and abundance (mean number of larvae per 10 m^2 in positive tows only) of larval *Xystreurys liolepis* in CalCOFI surveys, 1951–81.

FIGURE 12. Monthly mean incidence and abundance (mean number of larvae per 10 m^2 in positive tows only) of larval Xystreurys liolepis in CalCOFI surveys, 1951–81

2.4.2. Nearshore Surveys

2.4.2.1. Paralichthys californicus

Larval California halibut occurred throughout the year near shore, typically with abundance maxima in spring and in late summer–fall, and with a minimum in mid-winter (Figure 14, Appendices III, IV). The spring peak usually occurred in March and April each year, while the summer–fall peak was more variable, occurring anytime between about July and November. Abundance was consistently low in December and January.

This bimodal annual abundance pattern largely reflects preflexion stage larvae, which accounted for approximately 84% of the total collected. Yolk-sac larvae, which were much less abundant than expected (about 5% of the total) displayed much the same pattern, with abundance typically higher in March and/or April, and often again during 1 or 2 months between July and November; none was collected in December. The small catches of yolk-sac larvae probably reflected extrusion of these small, delicate larvae through the net mesh and damage that precluded identification of many of the specimens retained. Both flexion stage larvae (about 9% of the total) and postflexion stage larvae (about 2% of the total) were collected in every month except January, and both tended to display spring and summer–fall abundance maxima more-or-less concurrently with the younger larvae.

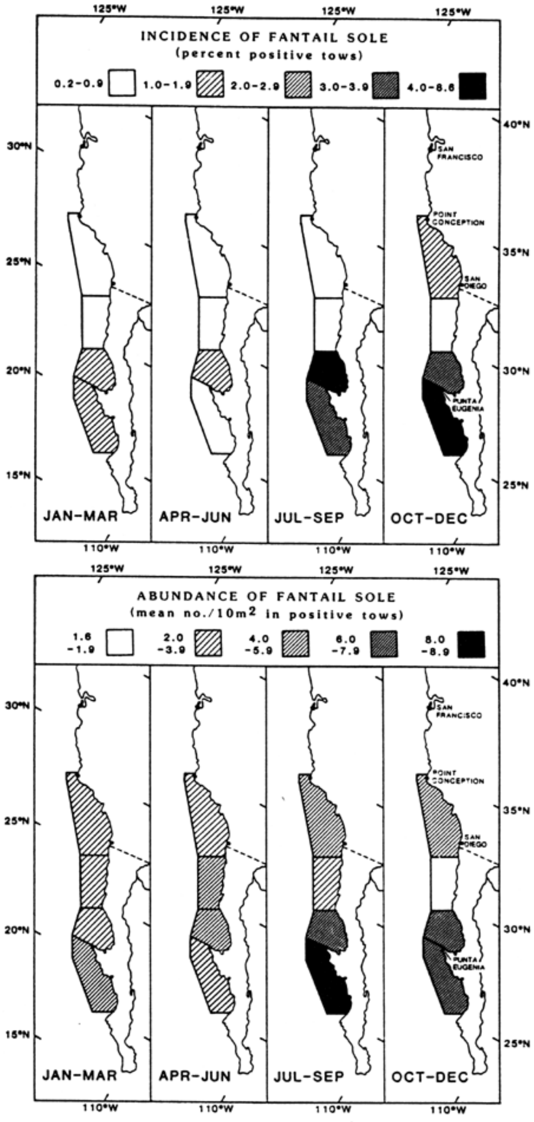


FIGURE 13. Maps of incidence (above) and mean abundance in positive tows (below) of larval *Xystreurys liolepis*, by quarter, in each of four geographic zones; CalCOFI surveys, 1951–81.

FIGURE 13. Maps of incidence (above) and mean abundance in positive tows (below) of larval Xystreurys liolepis, by quarter, in each of four geographic zones; CalCOFI surveys, 1951–81

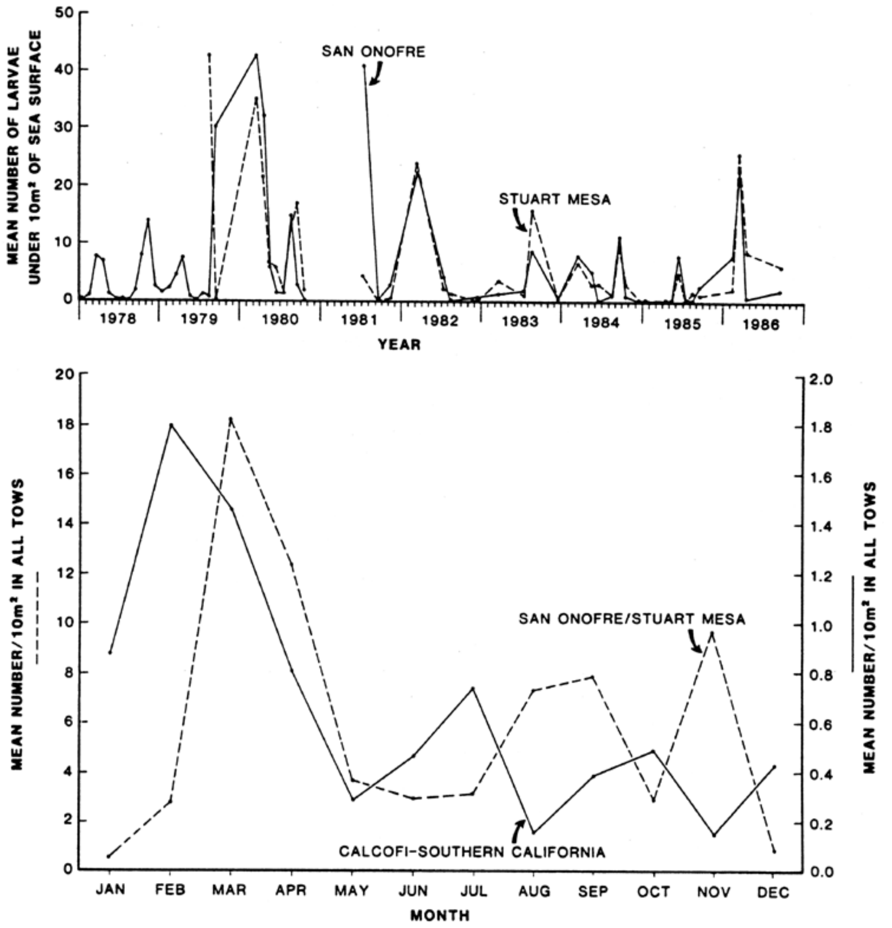


FIGURE 14. Interannual and seasonal abundance patterns (mean number of larvae per 10 m ^{2} between the 6-m and 75-m isobaths) of larval *Paralichthys californicus* (exclusive of yolk-sac larvae) off San Onofre and Stuart Mesa, California, 1978–86. Sampling began at the Stuart Mesa site in August 1979. Top: monthly mean abundance at each site; bottom: monthly mean abundance averaged over all surveys pooled from both sites. Monthly means from the southern California CalCOFI zone are also shown below for comparison.

FIGURE 14. Interannual and seasonal abundance patterns (mean number of larvae per 10 m^2 between the 6-m and 75-m isobaths) of larval Paralichthys californicus (exclusive of yolk-sac larvae) off San Onofre and Stuart Mesa, California, 1978–86. Sampling began at the Stuart Mesa site in August 1979. Top: monthly mean abundance at each site; bottom: monthly mean abundance averaged over all surveys pooled from both sites. Monthly means from the southern California CalCOFI zone are also shown below for comparison

Examination of the 1980 catch data, when samples were taken at weekly intervals, indicated a strong concordance of temporal abundance patterns for all four larval stages. During that time, minor abundance peaks typically occurred at approximately biweekly intervals for all larval stages.

Average monthly abundance ranged from <0.1 to 42.3 larvae per 10 m^2 off San Onofre, and from 0 to 43/10 m^2 off Stuart Mesa. Monthly mean larval abundances typically were similar at both sites, except that during 1981 larvae consistently were less abundant off Stuart Mesa, while during 1983 they usually were less abundant off San Onofre (Figure 14). Larval abundances increased dramatically at both sites beginning in late summer–fall of 1979 and remained elevated through much of 1980 (Figure 14; Appendices III, IV). Subsequently, abundance declined to levels more comparable to 1978-early 1979: average annual abundance declined steadily through 1985, then began another marked increase in 1986. During the year(s) of high larval abundance, approximately 10^8 larvae (nearly 10^9 in March 1980) were estimated to occupy the area (ca. 247 km^2) shoreward of the 75-m isobath between about Dana Point and Oceanside, California. During lower abundance years, estimated totals more commonly were on the order of 10^6–10^7 larvae (Appendices III, IV).

Mean abundance (number under 10 m^2 of sea surface) and density (number per 100 m^3) of larval California halibut were highest between the 12-m and 45-m isobaths (Figure 15). Cross-shelf abundance patterns differed little between the San Onofre and Stuart Mesa sites (e.g., Table 7), and differed only slightly more between larval stages. Yolk-sac larvae tended to be most abundant in block D (22 to 45-m depth) and least abundant in blocks A and E, generally in accord with the overall pattern; however, abundances within each of the five blocks were statistically indistinguishable from one another at both study sites owing to the small and highly variable catches. Preflexion larvae were significantly more abundant in blocks C and D than elsewhere, and tended to be least abundant in blocks A and B (Table 7). Flexion stage larvae were distributed similarly, except that only the relatively high abundance in block D was statistically distinguishable from the very low abundances in blocks A and B (Table 7). Abundances of postflexion larvae also tended to be higher in blocks C and D, but were statistically indistinguishable between blocks (Table 7). At both sites, abundance in block A was ranked higher for postflexion larvae than it was for most younger stages.

In addition to the small differences in cross-shelf abundance between ontogenetic stages, densities within vertical zones (neuston, midwater, epibenthos) also differed ontogenetically. Overall, the highest average density of larval California halibut was in midwater, and the lowest was in the epibenthos. This was the case for yolk-sac through flexion stages; postflexion larvae tended to be most abundant in the neuston (Figures 16, 17).

To further examine the stage-specific differences in cross-shelf and vertical distributions, the SONGS data were analyzed statistically for patterns of larval density in the 15 cross-shelf strata (5 blocks x 3 water-column layers per block) sampled. For both preflexion and flexion stage larvae, most of the highest-ranked densities were, as expected, in midwater. Densities of preflexion stage larvae were significantly higher in the blocks C and D midwater than in any of the remaining strata (Table 8). The density of flexion larvae in block D midwater was significantly higher than those in any other stratum except block C midwater (Table 8). In contrast, most of the highest-ranked densities for postflexion larvae were in the neuston, with block A neuston ranked significantly higher than all epibenthic and most midwater strata (Table 8).

An examination of the cross-shelf distributions by 1-mm size class of the postflexion larvae collected at San Onofre in 1978 further demonstrated the shoreward and surfaceward shift of older larvae (Figure 17). Densities of the 7 to 8-mm size classes were highest near shore and in the neuston, and transforming larvae (>8 mm) were exclusively near shore, primarily in the neuston.

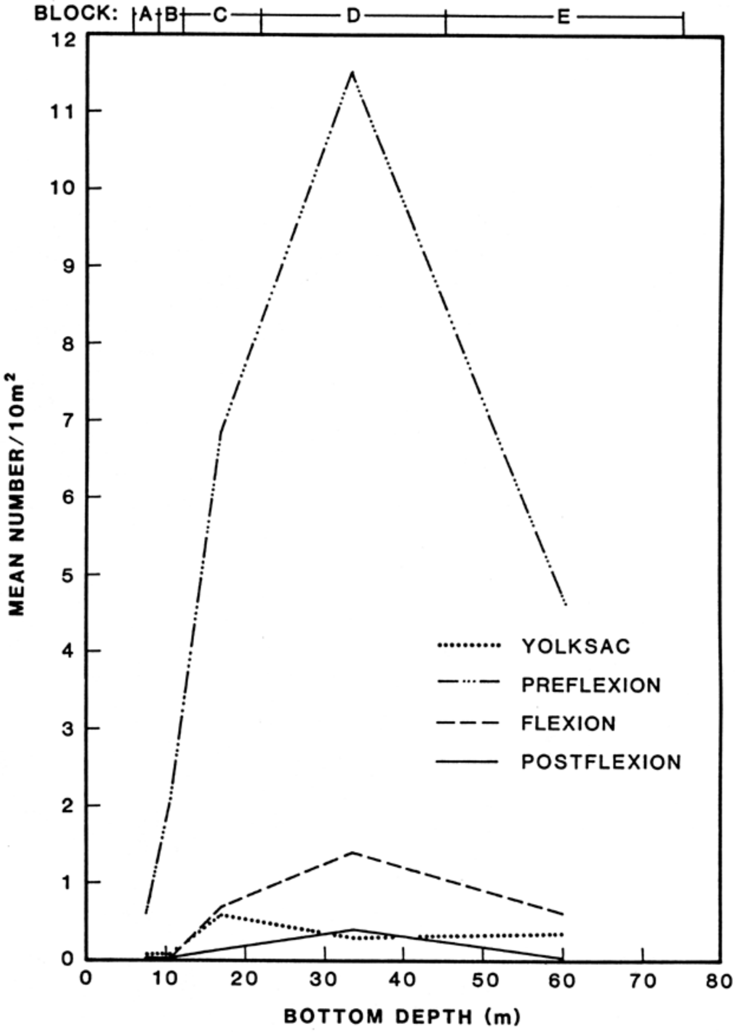


FIGURE 15. Mean abundance of larval *Paralichthys californicus* in each sampling block of the San Onofre study site, 1978–85 (*N*=86 for blocks A–D; *N*=70 for block E). Each mean is plotted at the mid-depth of its block.

FIGURE 15. Mean abundance of larval Paralichthys californicus in each sampling block of the San Onofre study site, 1978–85 (N=86 for blocks A–D; N=70 for block E). Each mean is plotted at the mid-depth of its block

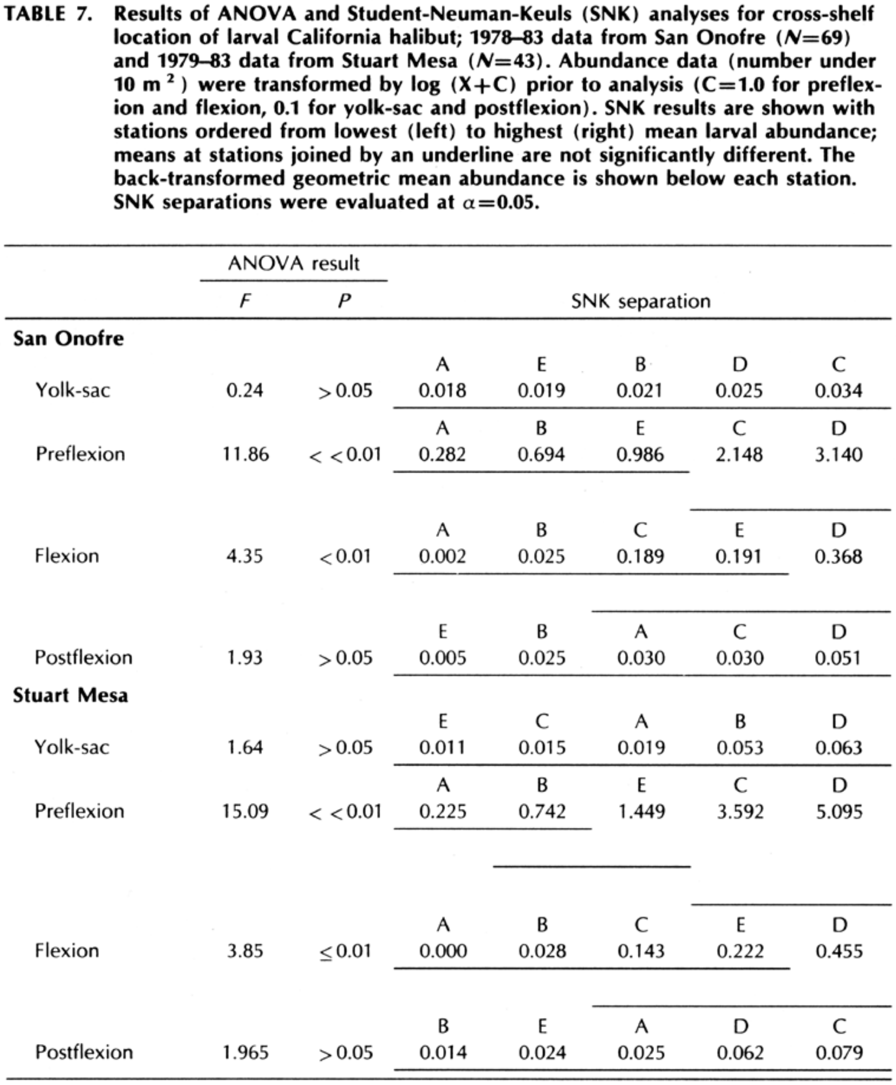


TABLE 7. Results of ANOVA and Student-Neuman-Keuls (SNK) analyses for cross-shelf location of larval California halibut; 1978–83 data from San Onofre (N=69) and 1979–83 data from Stuart Mesa (N=43). Abundance data (number under 10 m^2) were transformed by log (X+C) prior to analysis (C=1.0 for preflexion and flexion, 0.1 for yolk-sac and postflexion). SNK results are shown with stations ordered from lowest (left) to highest (right) mean larval abundance; means at stations joined by an underline are not significantly different. The back-transformed geometric mean abundance is shown below each station. SNK separations were evaluated at α=0.05.

	ANOVA result		SNK separation				
	F	*P*					
San Onofre							
			A	E	B	D	C
Yolk-sac	0.24	>0.05	0.018	0.019	0.021	0.025	0.034
			—	—	—	—	—
			A	B	E	C	D
Preflexion	11.86	$<<0.01$	0.282	0.694	0.986	2.148	3.140
			—	—	—		
						—	—
			A	B	C	E	D
Flexion	4.35	<0.01	0.002	0.025	0.189	0.191	0.368
			—	—	—	—	
					—	—	—
			E	B	A	C	D
Postflexion	1.93	>0.05	0.005	0.025	0.030	0.030	0.051
			—	—	—	—	—
Stuart Mesa							
			E	C	A	B	D
Yolk-sac	1.64	>0.05	0.011	0.015	0.019	0.053	0.063
			—	—	—	—	—
			A	B	E	C	D
Preflexion	15.09	$<<0.01$	0.225	0.742	1.449	3.592	5.095
			—	—			
				—	—		
						—	—
			A	B	C	E	D
Flexion	3.85	≤ 0.01	0.000	0.028	0.143	0.222	0.455
			—	—	—	—	
					—	—	—
			B	E	A	D	C
Postflexion	1.965	>0.05	0.014	0.024	0.025	0.062	0.079
			—	—	—	—	—

TABLE 7. ***Results of ANOVA and Student-Neuman-Keuls (SNK) analyses for cross-shelf location of larval California halibut; 1978–83 data from San Onofre (N=69) and 1979–83 data from Stuart Mesa (N=43). Abundance data (number under 10 m^2) were transformed by log (X+C) prior to analysis (C=1.0 for preflexion and flexion, 0.1 for yolk-sac and postflexion). SNK results are shown with stations ordered from lowest (left) to highest (right) mean larval abundance; means at stations joined by an underline are not significantly different. The back-transformed geometric mean abundance is shown below each station. SNK separations were evaluated at [a]=0.05.***

2.4.2.2. Xystreurys liolepis

Larval fantail sole occurred infrequently, usually in small numbers, in the nearshore samples. Larvae displayed a strong unimodal seasonal pattern, with occurrences only from July through December. Typically, incidence was highest in September, and abundance was highest in August or September (Figure 18). This largely reflects preflexion stage larvae, which accounted for nearly three-quarters (74.7%) of the total, although seasonal trends for flexion (24.8% of the total) and postflexion (0.5% of the total) stages differed little from the preflexion pattern. No yolk-sac larvae were identified in the samples.

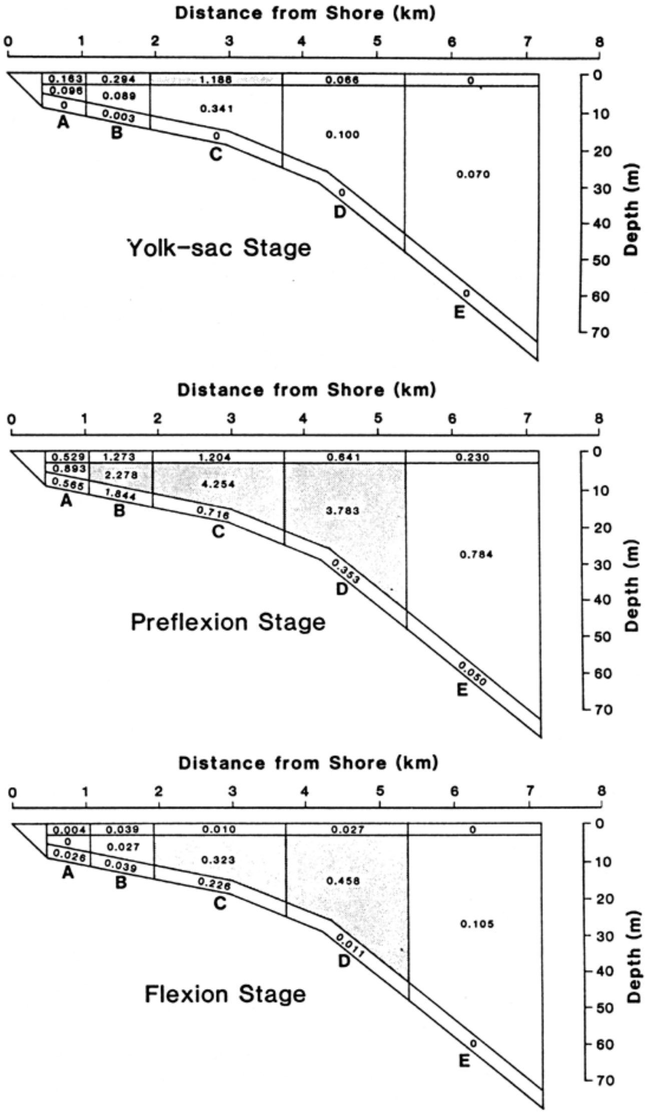


FIGURE 16. Mean density (number per 100 m ^{3}) of yolk-sac, preflexion, and flexion stage larvae of *Paralichthys californicus* in each cross-shelf stratum, San Onofre, 1978–85. Shading highlights the strata (subjectively selected) with highest larval densities.

FIGURE 16. Mean density (number per 100 m^3) of yolk-sac, preflexion, and flexion stage larvae of Paralichthys californicus in each cross-shelf stratum, San Onofre, 1978–85. Shading highlights the strata (subjectively selected) with highest larval densities

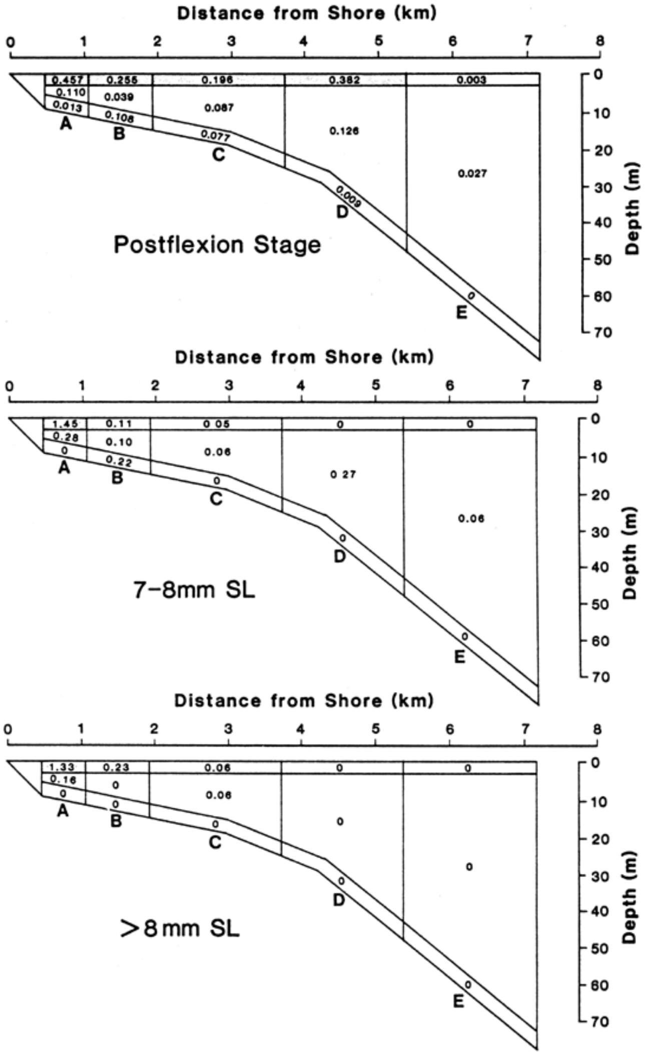


FIGURE 17. Mean density (number per 100 m^3) of postflexion stage larvae of *Paralichthys californicus* in each cross-shelf stratum, San Onofre. Shading highlights the strata (subjectively selected) with highest larval densities. Top: all postflexion larvae, 1978–85 (the relatively high mean density in block D neuston was attributable to a large catch on 7 July 1981; without that datum the mean would have been 0.062 larvae per 100 m^3); middle: larvae 7–8 mm long, 1978; bottom: transforming larvae (>8 mm long), 1978.

FIGURE 17. Mean density (number per 100 m^3) of postflexion stage larvae of Paralichthys californicus in each cross-shelf stratum, San Onofre. Shading highlights the strata (subjectively selected) with highest larval densities. Top: all postflexion larvae, 1978–85 (the relatively high mean density in block D neuston was attributable to a large catch on 7 July 1981; without that datum the mean would have been 0.062 larvae per 100 m^3); middle: larvae 7–8 mm long, 1978; bottom: transforming larvae (>8 mm long), 1978

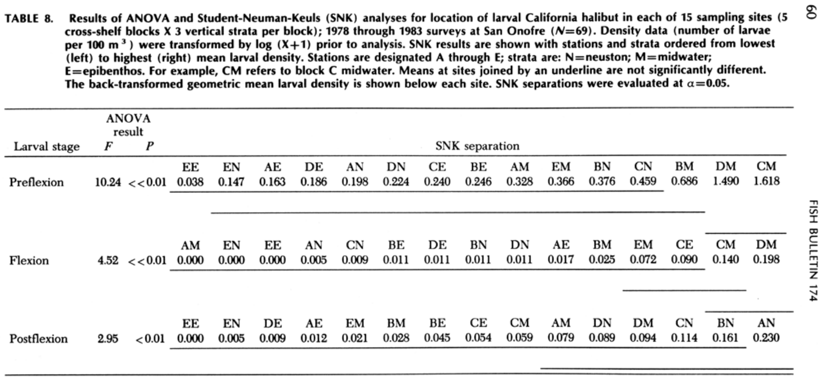


TABLE 8. Results of ANOVA and Student-Neuman-Keuls (SNK) analyses for location of larval California halibut in each of 15 sampling sites (5 cross-shelf blocks X 3 vertical strata per block); 1978 through 1983 surveys at San Onofre (*N*=69). Density data (number of larvae per 100 m^3) were transformed by log (X+1) prior to analysis. SNK results are shown with stations and strata ordered from lowest (left) to highest (right) mean larval density. Stations are designated A through E; strata are: N=neuston; M=midwater; E=epibenthos. For example, CM refers to block C midwater. Means at sites joined by an underline are not significantly different. The back-transformed geometric mean larval density is shown below each site. SNK separations were evaluated at $\alpha=0.05$.

Larval stage	ANOVA result *F*	*P*	SNK separation														
			EE	EN	AE	DE	AN	DN	CE	BE	AM	EM	BN	CN	BM	DM	CM
Preflexion	10.24	<<0.01	0.038	0.147	0.163	0.186	0.198	0.224	0.240	0.246	0.328	0.366	0.376	0.459	0.686	1.490	1.618
			AM	EN	EE	AN	CN	BE	DE	BN	DN	AE	BM	EM	CE	CM	DM
Flexion	4.52	<<0.01	0.000	0.000	0.000	0.005	0.009	0.011	0.011	0.011	0.011	0.017	0.025	0.072	0.090	0.140	0.198
			EE	EN	DE	AE	EM	BM	BE	CE	CM	AM	DN	DM	CN	BN	AN
Postflexion	2.95	<0.01	0.000	0.005	0.009	0.012	0.021	0.028	0.045	0.054	0.059	0.079	0.089	0.094	0.114	0.161	0.230

TABLE 8. ***Results of ANOVA and Student-Neuman-Keuls (SNK) analyses for location of larval California halibut in each of 15 sampling sites (5 cross-shelf blocks X 3 vertical strata per block); 1978 through 1983 surveys at San Onofre (N=69). Density data (number of larvae per 100 m^3) were transformed by log (X+1) prior to analysis. SNK results are shown with stations and strata ordered from lowest (left) to highest (right) mean larval density. Stations are designated A through E; strata are: N=neuston; M=midwater; E=epibenthos. For example, CM refers to block C midwater. Means at sites joined by an underline are not significantly different. The back-transformed geometric mean larval density is shown below each site. SNK separations were evaluated at [a]=0.05.***

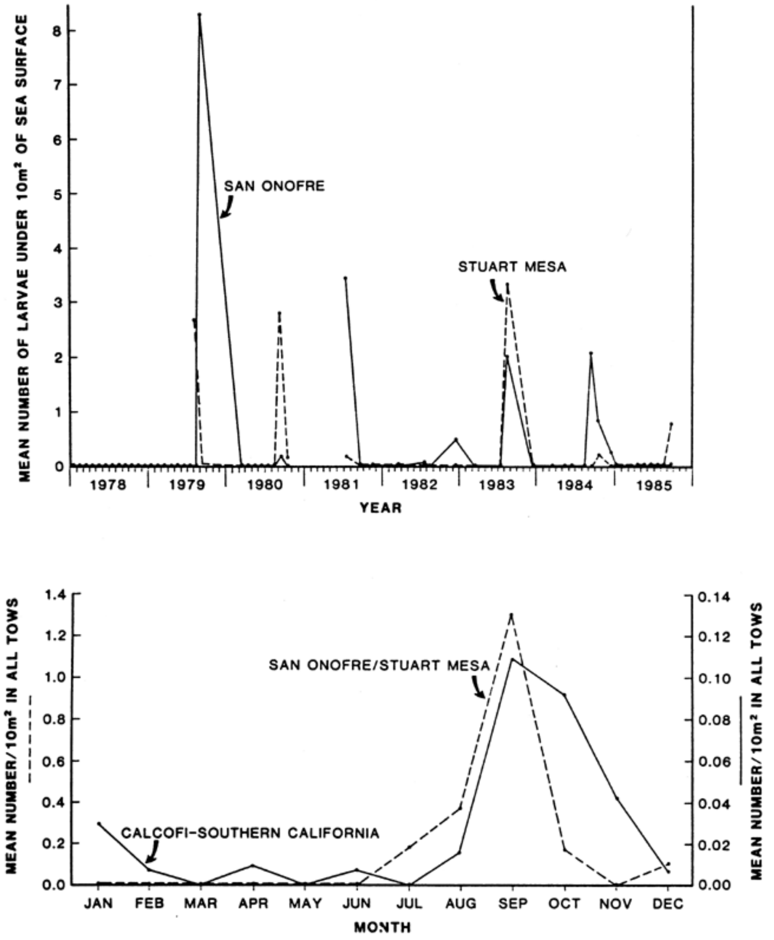


FIGURE 18. Interannual and seasonal abundance patterns (mean number of larvae per 10 m ^{2} between the 6-m and 75-m isobaths) of larval *Xystreurys liolepis* off San Onofre and Stuart Mesa, California, 1978–85. Sampling began at the Stuart Mesa site in August 1979. Top: monthly mean abundance at each site; bottom: monthly mean abundance averaged over all surveys pooled from both sites. Monthly means from the southern California CalCOFI zone are also shown below for comparison.

FIGURE 18. Interannual and seasonal abundance patterns (mean number of larvae per 10 m^2 between the 6-m and 75-m isobaths) of larval Xystreurys liolepis off San Onofre and Stuart Mesa, California, 1978–85. Sampling began at the Stuart Mesa site in August 1979. Top: monthly mean abundance at each site; bottom: monthly mean abundance averaged over all surveys pooled from both sites. Monthly means from the southern California CalCOFI zone are also shown below for comparison

Monthly average abundance during July–December ranged from 0 to 8.3 larvae/10 m^2 at San Onofre (Appendix V) and from 0 to 3.4 larvae/10 m^2 at Stuart Mesa (Appendix VI); typically, average abundance was less than 1 larva/10 m^2 at both sites. None was collected in 1978 or in the first half of 1979, but a large collection was made off San Onofre in September 1979. This corresponded with the beginning of the dramatic abundance increase noted for larval P. californicus.

The estimated number of larval X. liolepis occupying the 247 km^2 shoreward of the 75-m isobath between about Dana Point and Oceanside, California, ranged as high as 118 million in September 1979, but more commonly was much smaller (Appendices V, VI). Typically, larval fantail sole were less than one-quarter as abundant as larval California halibut.

The highest abundance and highest density of larval fantail sole occurred in block D (22 to 45-m depth) at both the San Onofre and Stuart Mesa study sites. No larvae were collected near shore in block A, and very few occurred in block B. Cross-shelf distributions were similar for all three larval stages: all were most abundant in block D, less abundant both seaward and shoreward, and absent or nearly absent very near shore (Figure 19). The concentration in block D was more pronounced at San Onofre than off Stuart Mesa for preflexion larvae, but was equally marked at both sites for the older stages.

Larval fantail sole were collected primarily in midwater and epibenthic samples; very few were taken in the neuston (Figure 20). Vertical distributions shifted downward in the water column ontogenetically: preflexion larvae occurred most frequently (62% of all occurrences) and usually in highest density in midwater samples, flexion larvae were predominantly epibenthic (63% of all occurrences), and postflexion larvae were exclusively epibenthic. Cross-shelf distributions contracted concurrently with settlement, so that most postflexion larvae occurred in the block D epibenthos (Figure 20).

2.5. DISCUSSION

The information on reproduction and early life history of the California halibut provided by the CalCOFI and SONGS time series has important implications for management of this species. The broad areal coverage during the first three decades of CalCOFI surveys reveals the extensive distribution of P. californicus along the coast of Baja California and demonstrates the international character of the management problems. Our estimate that more than two-thirds of the larval California halibut production occurs in Mexican waters places this species in a well-known group of transboundary species that includes northern anchovy, Engraulis mordax; Pacific sardine, Sardinops sagax; yellowtail, Seriola lalandi; white seabass, Atractoscion nobilis; Pacific bonito, Sarda chiliensis; and ocean whitefish, Caulolatilus princeps. Effective management of these species will require close cooperation between the United States and Mexico. CalCOFI provides a focus for the research needed to support this management effort and our study emphasizes the need for continuance of the CalCOFI surveys, and expansion of the present survey design.

The CalCOFI and SONGS time series have provided definitive coast-wide information on spawning seasonality of P. californicus—information not previously available to fishery managers. Although this species historically was

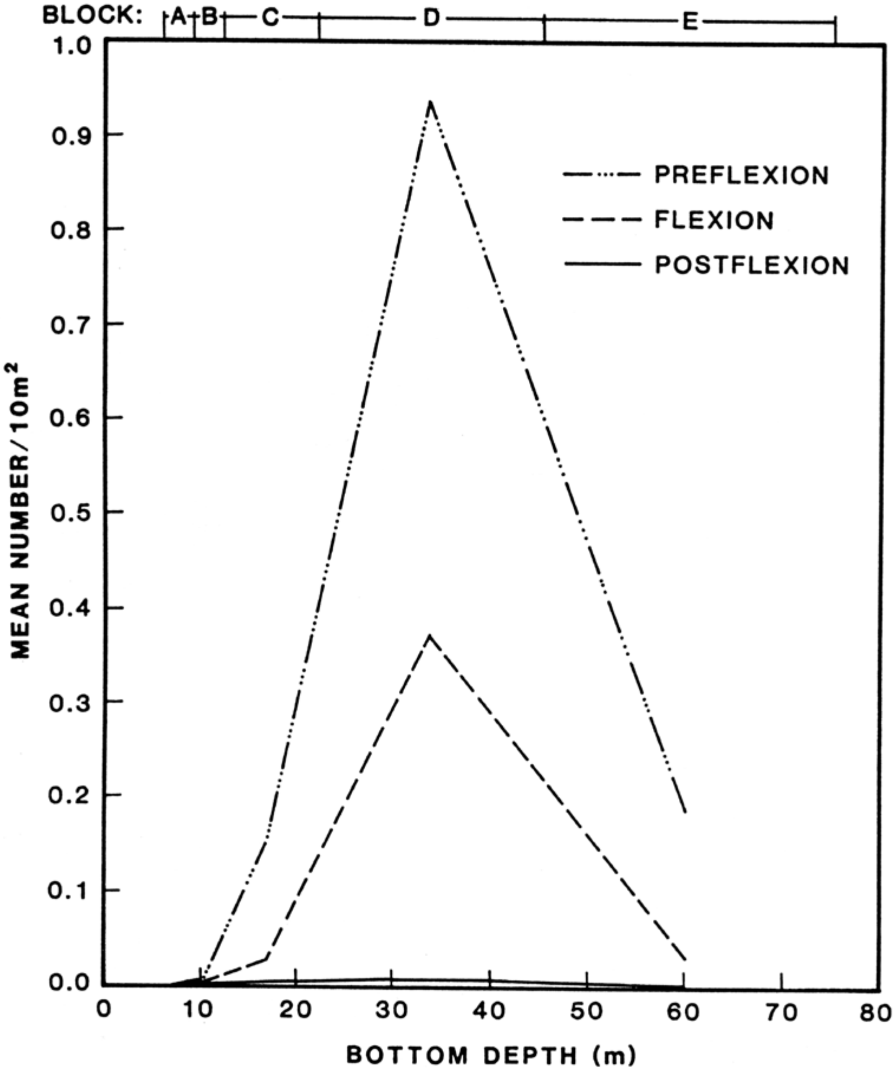


FIGURE 19. Mean abundance of larval *Xystreurys liolepis* in each sampling block of the San Onofre study site, 1978–85, July–December surveys only (*N*=44 for blocks A–D; *N*=36 for block E). Each mean is plotted at the mid-depth of its block.

FIGURE 19. Mean abundance of larval Xystreurys liolepis in each sampling block of the San Onofre study site, 1978–85, July–December surveys only (N=44 for blocks A–D; N=36 for block E). Each mean is plotted at the mid-depth of its block

considered a late spring–early summer spawner off California, the CalCOFI time series clearly showed an overall February peak with minor peaks in July and October, while the SONGS time series showed that nearer shore off southern California the major peak typically was a little later, in March. In central California waters, little spawning occurs after the first quarter of the year. Previous regulations, such as the closure of commercial fishing during the second quarter of the year to protect "spawning" fish (Schott 1977), clearly must have been ineffective since the closures were after the main spawning period, and before the secondary spawning peak.

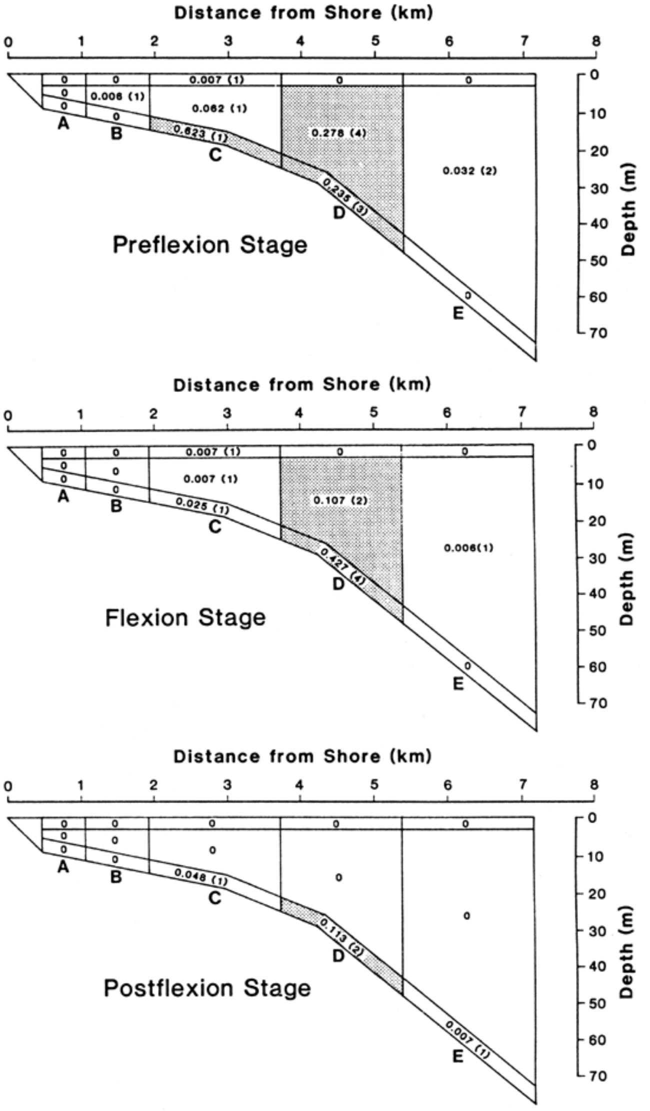


FIGURE 20. Mean density (number per 100 m ³) of larval *Xystreurys liolepis* in each cross-shelf stratum, San Onofre, 1978–85 (July–December surveys only). Shading highlights the strata (subjectively selected) with highest larval densities. The number of occurrences of larvae is given in parentheses for each stratum.

FIGURE 20. Mean density (number per 100 m^3) of larval Xystreurys liolepis in each cross-shelf stratum, San Onofre, 1978–85 (July–December surveys only). Shading highlights the strata (subjectively selected) with highest larval densities. The number of occurrences of larvae is given in parentheses for each stratum

The February spawning peak off California is unexpected since it is generally thought that a species with warm-water affinity residing in temperate waters should spawn later in the year when water temperature is higher. The seasonal pattern of larval abundance off northern Baja California is similar to that off California; however, in Sebastian Viscaino Bay and off central and southern Baja California, where spawning would be expected to occur mainly earlier in the year, the minor spawning peak occurs in February and March and the major larval production is in June–August. Thus, P. californicus is separable into two geographic groups with respect to spawning seasonality: north of Rosario Bay, Baja California, peak larval abundance is in February–March, while to the south peak abundance is in June–September.

Presumably, the northern stock of California halibut was derived from an ancestral southern population. A shift in spawning emphasis off California and northern Baja California from summer to late winter–spring to coincide with the peak in microzooplankton production may have been an adaptation critical to survival north of the ancestral range. A more general question concerning the seasonal spawning patterns is why does P. californicus exhibit bimodal spawning seasonality in the northern and southern populations? This pattern of year-round spawning with late winter–spring and summer–fall peaks is seen in other prominent California Current species such as northern anchovy, Pacific sardine, and several sanddab (Citharichthys spp.) species (Moser et al. 1987), and could be interpreted as a strategy for maximizing egg production and larval survival. The coincidence of the late winter–spring spawning peak with the microzooplankton production peak off California and northern Baja California should enhance larval growth and survival by providing increased food resources. Furthermore, during this period the offshore coastal winds tend to weaken and the onshore winds tend to strengthen (Dorman 1982), which may aid in retaining the planktonic eggs and larvae within the relatively productive coastal zone. For example, Barnett and Jahn (1987) described a shoreward shift of zooplankton distributions off San Onofre from February to early April, which generally coincides with the spring peak of larval California halibut abundance.

Following the late winter–spring spawning peak, low reproductive output coupled with intensive feeding by the adults could provide the energy reserves for another spawning pulse in summer–fall. This summer–fall period follows the major part of the upwelling "season" and is characterized by weak offshore winds and strong onshore winds, which again should aid in retaining the planktonic eggs and larvae in the coastal zone where zooplankton abundance is relatively high (e.g. Beers and Stewart 1970; Barnett 1974; Petersen et al. 1986). A period of relative reproductive quiescence following the summer–fall spawning peak could once again allow the build-up of energy reserves for the main reproductive pulse.

Alternatively, the two peaks may represent egg production from different age groups in the population. The possibility that large halibut behave differently from small and intermediate age classes is intriguing. These large fish may represent a substantial deep-water segment of the population that undergoes extensive longshore migrations with brief periods of nearshore residence (M. McCorkle, in Golden 1990). Larval production from this segment of the population may be proportionately large and may, in part, explain the bimodal nature of spawning and the one-month lag in peak spawning indicated by offshore (CalCOFI) and nearshore (SONGS) ichthyoplankton data. Generally, larger females in fish populations spawn earlier and longer than smaller size groups and the earlier spring peak indicated by the CalCOFI survey may represent larval production of large, deep-living females. Clearly, future research should focus on the spawning contribution and seasonality of all age segments of California halibut populations.

The concordance of interannual patterns of larval abundance in the CalCOFI samples and commercial landings since 1958 is remarkable and reveals the value of ichthyoplankton time series as a fishery-independent analytical tool. The California halibut fishery has followed the usual trend of stock depletion typical of other fisheries, except that periods of increased abundance are recognizable at approximately 20-year intervals (Methot 1983; Barsky 1990). The long-standing question of whether these cycles are a phenomenon of fishery effort or population abundance may be resolved by the close fit between larval abundance and the commercial catch. Larval P. californicus taken in the CalCOFI surveys were predominantly small, recently-spawned (no more than several days old) individuals that can be considered indicators of spawning biomass. The extraordinary concurrence between the interannual abundance cycles of the larvae and those of the commercial catch suggests that the catch cycles primarily reflect halibut abundance (assuming that effort was relatively constant; historical fishery effort data that would allow evaluation of this assumption are unavailable), and further suggests that ichthyoplankton surveys can be used to assess and monitor the spawning biomass of P. californicus. The CalCOFI survey design, which was intended to sample the eggs and larvae of wide-ranging coastal pelagic species with little sampling effort over the continental shelf, nevertheless is suitable for this use. This is demonstrated by the fact that the seasonal larval abundance signal for P. californicus from these offshore samples is strong and closely tracks the seasonal signals from surveys specifically designed to sample the shelf habitat (SONGS analysis in this paper, Lavenberg et al. 1986). This coherence emphasizes the inherent robustness of the ichthyoplankton survey method.

Larval P. californicus seaward of the continental shelf are restricted to the upper 30 m (largely the upper 20 m) of the water column, where they apparently settle or migrate from the 0 to 10-m stratum to the 10 to 20-m stratum at night. This nocturnal relocation may be passive, resulting from a cessation of daytime feeding activity, or it may be an adaptive behavior that reduces losses to invertebrate predators in the surface zone, analagous to the avoidance mechanisms suggested by Ohman (1988) for invertebrate prey. Over the shallow shelf (13-m bottom depth) larval P. californicus tend to move downward during the day (Barnett et al. 1984). Whether the apparent difference in vertical redistribution between the two studies reflects different larval behaviors in the two different habitats studied, or merely reflects the different vertical scales of the studies is unknown.

Yolk-sac through flexion stage California halibut are distributed similarly over the continental shelf, both within the water column and with respect to distance from shore. During postflexion, larval distribution over the shelf as well as seaward of the shelf shifts upward in the water column. The oldest larvae are concentrated nearshore, in the neuston at night and in the epibenthos during the day (S.H. Kramer, NMFS Southwest Fisheries Science Center, pers. comm.).

Shanks (1983, 1988) described a mechanism by which neustonic organisms can be transported shoreward across the continental shelf in surface slicks that form at the convergence zones over internal wave troughs. The internal waves propagate across the shelf on the rising tide when the water column is stratified (Winant and Bratkovich 1981), as it typically becomes, beginning in late spring each year. In southern California, the internal waves have a fortnightly cycle, with the largest waves occurring during spring tides and smaller waves occurring during neap tides (Cairns 1968). During spring tides the internal waves may break and cross the shelf as a near-bottom tidal bore with accompanying surface seaward flow, while during neap tides the internal waves do not break and the accompanying surface slicks may move shoreward (Cairns 1968; Winant and Bratkovich 1981; Shanks 1983). Given this scenario, it would be predicted that organisms using the internal wave slicks as a shoreward transport mechanism should be neustonic and have an approximately fortnightly (neap tide) abundance cycle (Shanks 1983). The approximately fortnightly periodicity of larval halibut catches in 1980, coupled with the predominantly neustonic nocturnal distribution of the older postflexion stage larvae, is in general accord with this prediction. However, support for the internal wave transport mechanism is weak since only about half (53%) of the 1980 surveys in which postflexion stage larvae were collected from the neuston were made on a neap tide (another 32% were on, or near, spring tides), and only half the neap tide collections were made on a rising tide (but all the spring tide collections were on the rising tide). This support would be stronger if spring tide internal waves usually do not break on the shelf near San Onofre.

Whatever the mechanism(s) involved in the shoreward movement of the older California halibut larvae, they clearly do become concentrated in the very nearshore zone. This presumably is in preparation for settlement as transforming juveniles along the shallow open coast and in adjacent bays (Kramer 1990). The epibenthic diurnal distribution of the older larvae in the nearshore zone might be interpreted as habitat sampling in preparation for assumption of the benthic juvenile mode.

Larval fantail sole employ a much different strategy. Rather than moving into the very nearshore zone, larval fantail sole settle into the epibenthos farther seaward on the shelf, with the postflexion stage concentrated near the bottom in the 22 to 45-m depth range. Transformation to the juvenile presumably occurs there. For example, Love et al. (1986), reporting on otter trawl collections in the 6.1 to 18.3-m depth range along the southern California shelf, noted that juvenile fantail sole recruited to the deepest stations.

The vastly different benthic recruitment strategies of P. californicus and X. liolepis preclude potential competition between the early juveniles of these species. Early benthic juveniles of both are morphologically similar and have potentially overlapping feeding habits (M. J. Allen, MBC Applied Environmental Sciences, pers. comm.; Allen 1988). Transforming larvae of P. californicus settle in the immediate nearshore zone and the juveniles utilize embayments and lagoons as nursery areas (Allen 1988; Kramer 1990), while X. liolepis recruits to deeper shelf waters and does not utilize estuarine nursery areas. Thus, the early juveniles of these two species are spatially separated and potential trophic competition is avoided by effective partitioning of the nearshore habitat. Older juveniles of the two species do co-occur after P. californicus juveniles leave the estuarine nurseries and move onto the shelf; however, by this time they have diverged trophically, with X. liolepis becoming specialized to feed on the bottom, primarily on slow-moving crustaceans, while P. californicus preys above the bottom, primarily on fish and fast-moving crustaceans (Allen 1982; Plummer et al. 1983).

2.6. ACKNOWLEDGMENTS

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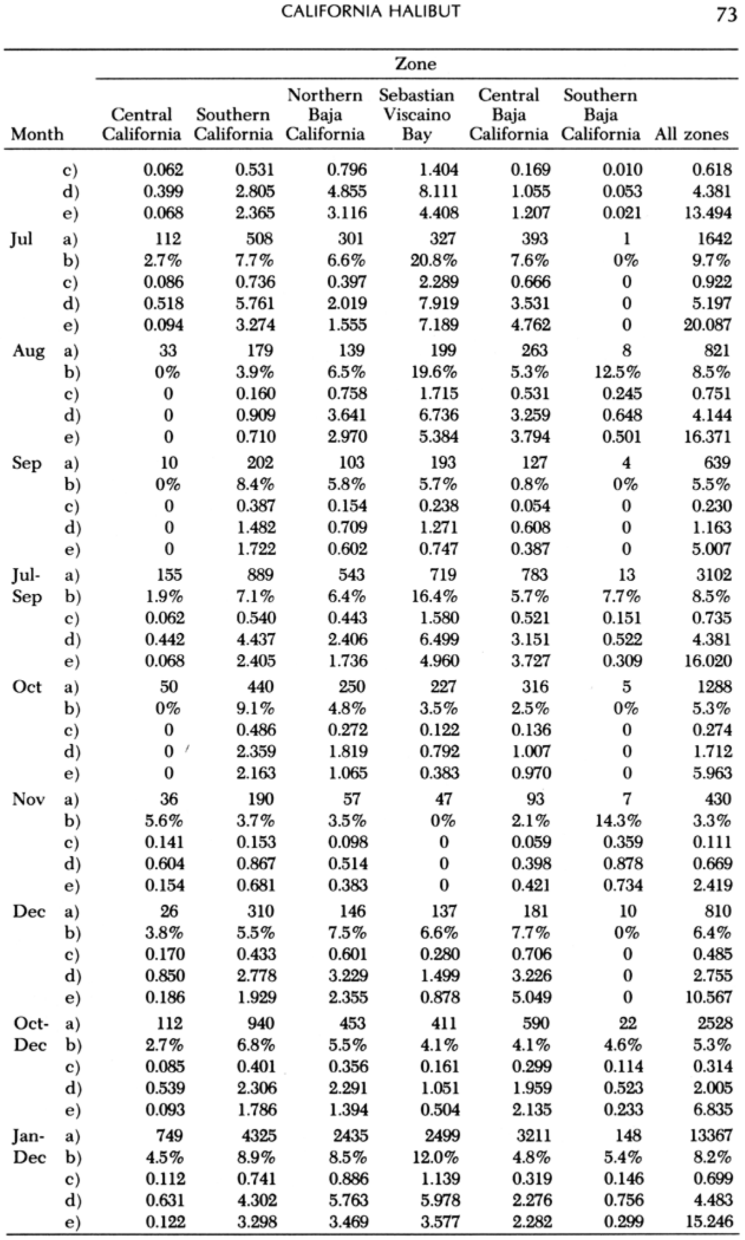
APPENDICES

APPENDIX I

Month		Zone						
		Central California	Southern California	Northern Baja California	Sebastian Viscaino Bay	Central Baja California	Southern Baja California	All zones
Jan	a)	125	470	243	202	205	35	1280
	b)	15.2%	13.4%	11.9%	9.9%	3.4%	5.7%	10.9%
	c)	0.337	0.879	0.702	1.036	0.131	0.238	0.680
	d)	1.136	3.191	2.539	4.457	0.785	1.016	2.907
	e)	0.369	3.914	2.749	3.252	0.939	0.486	14.824
Feb	a)	57	419	259	261	403	33	1432
	b)	3.5%	14.8%	16.6%	16.9%	9.4%	6.1%	13.3%
	c)	0.114	1.802	3.141	0.854	0.558	0.200	1.417
	d)	0.662	7.832	14.001	2.790	3.497	1.018	7.698
	e)	0.125	8.018	12.301	2.680	3.987	0.409	30.881
Mar	a)	42	349	176	222	329	18	1136
	b)	0%	12.6%	8.5%	10.4%	2.1%	5.6%	7.9%
	c)	0	1.464	0.939	1.138	0.111	0.109	0.852
	d)	0	6.835	4.463	5.547	1.162	0.449	4.197
	e)	0	6.515	3.679	3.573	0.796	0.223	18.564
Jan-Mar	a)	224	1238	678	685	937	86	3848
	b)	9.4%	13.6%	12.8%	12.7%	5.5%	5.8%	10.9%
	c)	0.217	1.356	1.695	1.000	0.308	0.196	1.005
	d)	0.923	6.160	9.147	4.337	2.443	0.928	5.666
	e)	0.237	6.036	6.639	3.139	2.199	0.402	21.918
Apr	a)	121	429	297	284	387	19	1537
	b)	4.1%	9.8%	12.8%	11.6%	4.1%	0%	8.7%
	c)	0.085	0.814	1.544	1.074	0.157	0	0.770
	d)	0.450	3.783	7.237	7.936	0.850	0	5.121
	e)	0.093	3.622	6.046	3.373	1.125	0	16.790
May	a)	62	405	195	200	287	2	1151
	b)	0%	4.2%	3.1%	8.5%	2.4%	50.0%	4.2%
	c)	0	0.294	0.172	0.642	0.121	0.140	0.274
	d)	0	1.735	1.210	3.057	0.909	0.140	1.781
	e)	0	1.308	0.672	2.015	0.863	0.286	5.979
Jun	a)	75	424	269	200	227	6	1201
	b)	2.7%	7.5%	5.6%	14.0%	4.4%	0%	7.2%
	c)	0.077	0.472	0.422	2.633	0.249	0	0.752
	d)	0.466	2.420	2.601	11.135	1.459	0	6.664
	e)	0.084	2.102	1.653	8.268	1.782	0	16.384
Apr-Jun	a)	258	1258	761	684	901	27	3889
	b)	2.7%	7.2%	7.7%	11.4%	3.7%	3.7%	6.9%

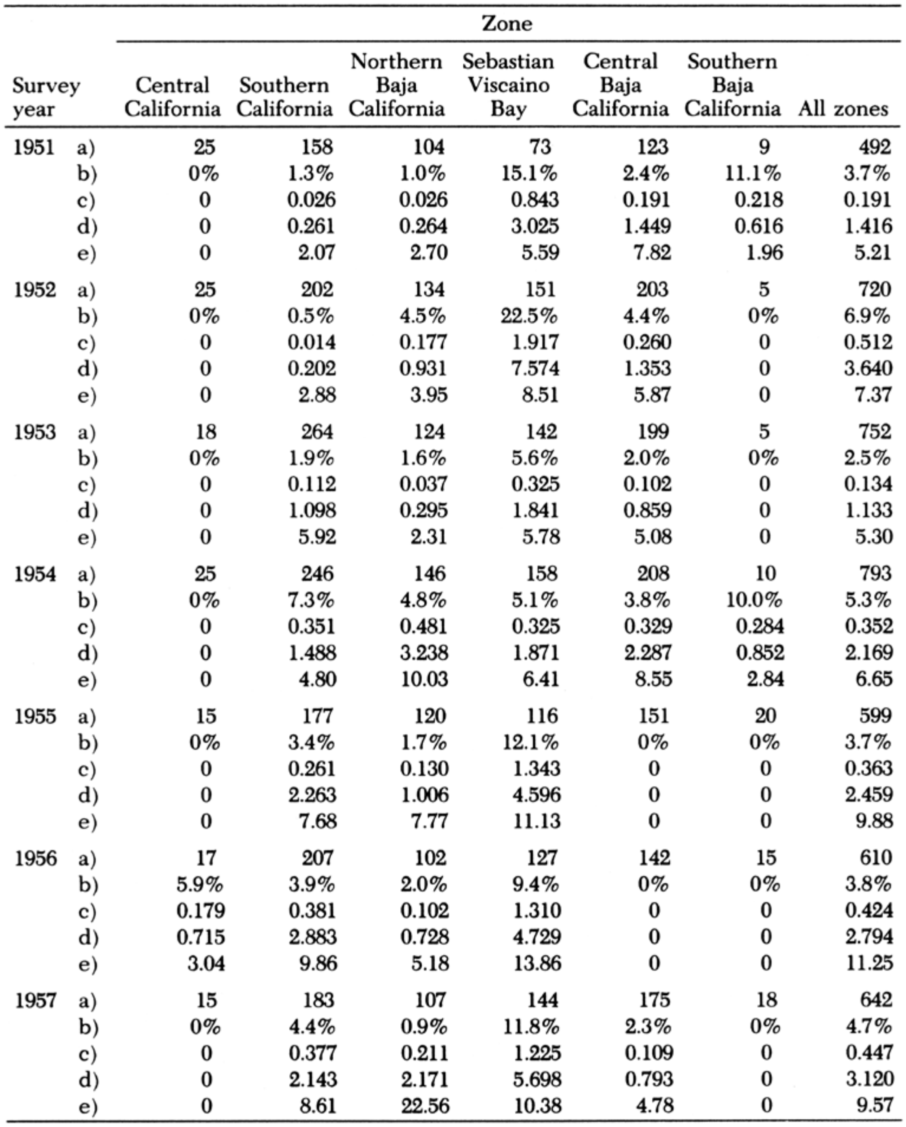
APPENDIX I—Cont'd.



Month		Zone						
		Central California	Southern California	Northern Baja California	Sebastian Viscaino Bay	Central Baja California	Southern Baja California	All zones
	c)	0.062	0.531	0.796	1.404	0.169	0.010	0.618
	d)	0.399	2.805	4.855	8.111	1.055	0.053	4.381
	e)	0.068	2.365	3.116	4.408	1.207	0.021	13.494
Jul	a)	112	508	301	327	393	1	1642
	b)	2.7%	7.7%	6.6%	20.8%	7.6%	0%	9.7%
	c)	0.086	0.736	0.397	2.289	0.666	0	0.922
	d)	0.518	5.761	2.019	7.919	3.531	0	5.197
	e)	0.094	3.274	1.555	7.189	4.762	0	20.087
Aug	a)	33	179	139	199	263	8	821
	b)	0%	3.9%	6.5%	19.6%	5.3%	12.5%	8.5%
	c)	0	0.160	0.758	1.715	0.531	0.245	0.751
	d)	0	0.909	3.641	6.736	3.259	0.648	4.144
	e)	0	0.710	2.970	5.384	3.794	0.501	16.371
Sep	a)	10	202	103	193	127	4	639
	b)	0%	8.4%	5.8%	5.7%	0.8%	0%	5.5%
	c)	0	0.387	0.154	0.238	0.054	0	0.230
	d)	0	1.482	0.709	1.271	0.608	0	1.163
	e)	0	1.722	0.602	0.747	0.387	0	5.007
Jul-Sep	a)	155	889	543	719	783	13	3102
	b)	1.9%	7.1%	6.4%	16.4%	5.7%	7.7%	8.5%
	c)	0.062	0.540	0.443	1.580	0.521	0.151	0.735
	d)	0.442	4.437	2.406	6.499	3.151	0.522	4.381
	e)	0.068	2.405	1.736	4.960	3.727	0.309	16.020
Oct	a)	50	440	250	227	316	5	1288
	b)	0%	9.1%	4.8%	3.5%	2.5%	0%	5.3%
	c)	0	0.486	0.272	0.122	0.136	0	0.274
	d)	0	2.359	1.819	0.792	1.007	0	1.712
	e)	0	2.163	1.065	0.383	0.970	0	5.963
Nov	a)	36	190	57	47	93	7	430
	b)	5.6%	3.7%	3.5%	0%	2.1%	14.3%	3.3%
	c)	0.141	0.153	0.098	0	0.059	0.359	0.111
	d)	0.604	0.867	0.514	0	0.398	0.878	0.669
	e)	0.154	0.681	0.383	0	0.421	0.734	2.419
Dec	a)	26	310	146	137	181	10	810
	b)	3.8%	5.5%	7.5%	6.6%	7.7%	0%	6.4%
	c)	0.170	0.433	0.601	0.280	0.706	0	0.485
	d)	0.850	2.778	3.229	1.499	3.226	0	2.755
	e)	0.186	1.929	2.355	0.878	5.049	0	10.567
Oct-Dec	a)	112	940	453	411	590	22	2528
	b)	2.7%	6.8%	5.5%	4.1%	4.1%	4.6%	5.3%
	c)	0.085	0.401	0.356	0.161	0.299	0.114	0.314
	d)	0.539	2.306	2.291	1.051	1.959	0.523	2.005
	e)	0.093	1.786	1.394	0.504	2.135	0.233	6.835
Jan-Dec	a)	749	4325	2435	2499	3211	148	13367
	b)	4.5%	8.9%	8.5%	12.0%	4.8%	5.4%	8.2%
	c)	0.112	0.741	0.886	1.139	0.319	0.146	0.699
	d)	0.631	4.302	5.763	5.978	2.276	0.756	4.483
	e)	0.122	3.298	3.469	3.577	2.282	0.299	15.246

APPENDIX I—Cont'd.

APPENDIX II



		Zone						
Survey year		Central California	Southern California	Northern Baja California	Sebastian Viscaino Bay	Central Baja California	Southern Baja California	All zones
1951	a)	25	158	104	73	123	9	492
	b)	0%	1.3%	1.0%	15.1%	2.4%	11.1%	3.7%
	c)	0	0.026	0.026	0.843	0.191	0.218	0.191
	d)	0	0.261	0.264	3.025	1.449	0.616	1.416
	e)	0	2.07	2.70	5.59	7.82	1.96	5.21
1952	a)	25	202	134	151	203	5	720
	b)	0%	0.5%	4.5%	22.5%	4.4%	0%	6.9%
	c)	0	0.014	0.177	1.917	0.260	0	0.512
	d)	0	0.202	0.931	7.574	1.353	0	3.640
	e)	0	2.88	3.95	8.51	5.87	0	7.37
1953	a)	18	264	124	142	199	5	752
	b)	0%	1.9%	1.6%	5.6%	2.0%	0%	2.5%
	c)	0	0.112	0.037	0.325	0.102	0	0.134
	d)	0	1.098	0.295	1.841	0.859	0	1.133
	e)	0	5.92	2.31	5.78	5.08	0	5.30
1954	a)	25	246	146	158	208	10	793
	b)	0%	7.3%	4.8%	5.1%	3.8%	10.0%	5.3%
	c)	0	0.351	0.481	0.325	0.329	0.284	0.352
	d)	0	1.488	3.238	1.871	2.287	0.852	2.169
	e)	0	4.80	10.03	6.41	8.55	2.84	6.65
1955	a)	15	177	120	116	151	20	599
	b)	0%	3.4%	1.7%	12.1%	0%	0%	3.7%
	c)	0	0.261	0.130	1.343	0	0	0.363
	d)	0	2.263	1.006	4.596	0	0	2.459
	e)	0	7.68	7.77	11.13	0	0	9.88
1956	a)	17	207	102	127	142	15	610
	b)	5.9%	3.9%	2.0%	9.4%	0%	0%	3.8%
	c)	0.179	0.381	0.102	1.310	0	0	0.424
	d)	0.715	2.883	0.728	4.729	0	0	2.794
	e)	3.04	9.86	5.18	13.86	0	0	11.25
1957	a)	15	183	107	144	175	18	642
	b)	0%	4.4%	0.9%	11.8%	2.3%	0%	4.7%
	c)	0	0.377	0.211	1.225	0.109	0	0.447
	d)	0	2.143	2.171	5.698	0.793	0	3.120
	e)	0	8.61	22.56	10.38	4.78	0	9.57

APPENDIX II—Cont'd.

		Zone						
Survey year		Central California	Southern California	Northern Baja California	Sebastian Viscaino Bay	Central Baja California	Southern Baja California	All zones
1958	a)	27	250	129	149	186	20	761
	b)	3.7%	10.8%	9.3%	3.4%	1.6%	0%	6.3%
	c)	0.100	0.923	0.657	0.477	0.090	0	0.533
	d)	0.508	4.480	2.771	3.728	0.842	0	3.304
	e)	2.69	8.54	7.06	14.22	5.56	0	8.45
1959	a)	34	255	146	156	210	14	815
	b)	0%	5.1%	6.2%	8.3%	0.9%	0%	4.5%
	c)	0	0.436	0.406	0.466	0.024	0	0.305
	d)	0	2.675	1.801	1.898	0.248	0	1.888
	e)	0	8.56	6.59	5.59	2.55	0	6.71
1960	a)	35	206	139	164	184	11	739
	b)	0%	2.4%	9.3%	6.7%	4.3%	9.1%	5.3%
	c)	0	0.059	0.782	0.222	0.123	0.498	0.255
	d)	0	0.400	3.355	0.928	0.737	1.575	1.614
	e)	0	2.44	8.36	3.31	2.83	5.48	4.82
1961	a)	16	98	60	62	85	0	321
	b)	0%	8.2%	6.7%	8.1%	4.7%		6.5%
	c)	0	0.316	0.181	0.364	0.258		0.269
	d)	0	1.438	0.681	1.457	1.401		1.287
	e)	0	3.87	2.72	4.52	5.48		4.11
1962	a)	12	91	60	64	79	0	306
	b)	0%	9.9%	15.0%	18.7%	8.9%		12.1%
	c)	0	0.633	0.561	0.650	0.703		0.615
	d)	0	2.337	1.566	1.531	3.714		2.485
	e)	0	6.40	3.74	3.47	7.93		5.09
1963	a)	26	129	75	82	123	2	437
	b)	7.7%	17.0%	16.0%	11.0%	8.9%	50.0%	13.0%
	c)	0.195	1.320	0.885	0.532	0.863	0.140	0.897
	d)	0.675	5.268	2.978	2.356	5.105	0.140	4.269
	e)	2.53	7.74	5.53	4.85	9.65	0.28	6.87
1964	a)	64	175	80	90	138	2	549
	b)	12.5%	14.3%	17.5%	32.2%	13.8%	0%	17.5%
	c)	0.268	0.592	4.674	3.063	1.025	0	1.667
	d)	1.172	2.270	20.716	13.875	4.370	0	10.151
	e)	2.15	4.15	26.71	9.51	7.45	0	9.53
1965	a)	56	138	80	93	144	4	515
	b)	12.5%	29.7%	18.7%	28.0%	11.1%	50.0%	20.8%
	c)	0.146	1.788	0.681	2.173	0.811	0.660	1.225
	d)	0.476	4.717	1.847	5.638	4.347	0.800	4.244
	e)	1.17	6.02	3.63	7.77	7.30	1.32	5.89
1966	a)	59	271	177	170	205	6	888
	b)	6.8%	9.2%	7.9%	15.9%	4.9%	16.7%	9.1%
	c)	0.198	0.459	0.699	1.333	0.156	0.418	0.587
	d)	0.738	2.047	6.195	4.723	0.731	0.935	3.679
	e)	2.92	4.98	8.84	8.39	3.19	2.51	6.43

APPENDIX II—Cont'd.

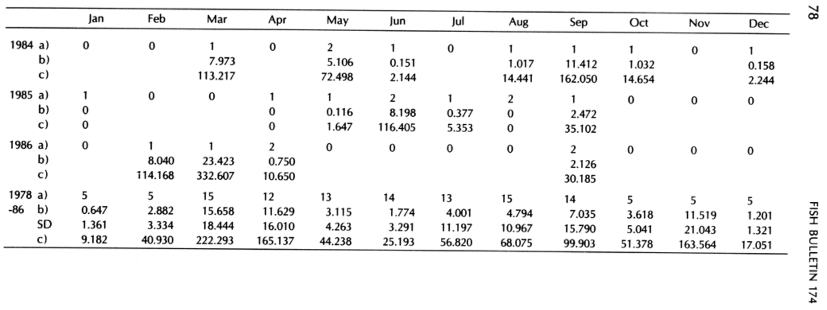
Survey year		Zone						
		Central California	Southern California	Northern Baja California	Sebastian Viscaino Bay	Central Baja California	Southern Baja California	All zones
1967	a)	0	27	28	36	40	0	131
	b)		14.8%	10.7%	11.1%	5.0%		9.9%
	c)		0.540	0.340	0.664	0.082		0.392
	d)		1.486	1.088	2.497	0.384		1.588
	e)		3.64	3.18	5.97	1.64		3.94
1968	a)	17	56	26	18	25	0	142
	b)	17.6%	14.3%	7.7%	0%	0%		9.1%
	c)	0.703	0.634	0.148	0	0		0.361
	d)	1.618	2.049	0.553	0	0		1.455
	e)	3.98	4.44	1.92	0	0		3.95
1969	a)	77	230	144	145	178	0	774
	b)	6.5%	11.3%	13.2%	3.4%	2.8%		7.7%
	c)	1.185	1.083	1.322	0.179	0.097		0.642
	d)	0.773	4.584	6.043	1.332	0.684		3.716
	e)	2.84	9.58	10.02	5.19	3.46		8.28
1972	a)	47	123	79	83	105	7	444
	b)	0%	3.2%	11.4%	16.9%	8.6%	14.3%	8.3%
	c)	0	0.198	0.629	2.346	0.435	0.846	0.722
	d)	0	1.251	2.051	10.795	2.113	2.072	4.974
	e)	0	6.07	5.52	13.91	5.08	5.92	8.66
1975	a)	50	474	154	152	178	0	1008
	b)	2.0%	13.7%	11.7%	15.1%	13.5%		13.0%
	c)	0.034	1.003	1.115	3.390	1.074		1.345
	d)	0.241	3.454	4.164	12.930	3.839		6.072
	e)	1.70	7.32	9.54	22.40	1.07		10.35
1978	a)	50	253	119	76	89	0	587
	b)	0%	11.5%	8.4%	11.8%	3.4%		8.7%
	c)	0	1.776	0.933	1.598	0.218		1.195
	d)	0	6.305	3.640	6.711	1.278		5.133
	e)	0	15.49	11.10	13.50	6.47		13.75
1981	a)	39	112	102	48	41	0	342
	b)	5.1%	25.0%	21.6%	8.3%	7.3%		17.5%
	c)	0.208	4.928	5.442	0.535	1.118		3.485
	d)	0.898	17.751	13.838	2.073	4.353		12.968
	e)	4.05	19.71	25.23	6.42	15.30		19.85

APPENDIX II—Cont'd.

APPENDIX III

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1978	a)	2	12	6	4	4	4	4	4	2	2	4	2
	b)	0.153	0.984	7.845	6.737	1.092	0.085	0.136	0.009	1.917	8.262	13.718	2.588
	c)	2.173	13.977	111.394	95.669	15.506	1.201	1.932	0.121	27.221	117.317	194.799	36.749
1979	a)	2	2	2	2	2	2	1	2	2	0	0	0
	b)	1.540	2.206	4.037	7.168	0.914	0.004	1.149	0.545	30.512			
	c)	21.867	31.325	57.320	101.792	12.979	0.054	16.312	7.739	433.270			
1980	a)	0	0	3	3	4	5	4	4	5	2	0	0
	b)			42.316	32.257	5.994	1.589	1.027	15.277	3.076	0.267		
	c)			600.887	458.049	85.118	22.567	14.579	216.937	43.686	3.796		
1981	a)	0	0	0	0	0	0	1	0	1	0	1	0
	b)							40.989		0.120		2.720	
	c)							582.044		1.704		38.624	
1982	a)	0	0	1	0	0	0	1	1	0	0	0	1
	b)			22.729				3.500	0.010				0.630
	c)			322.752				49.700	0.142				8.946
1983	a)	0	0	1	0	0	0	1	1	0	0	0	1
	b)			1.222				1.352	8.650				0.040
	c)			17.352				19.198	122.830				0.568

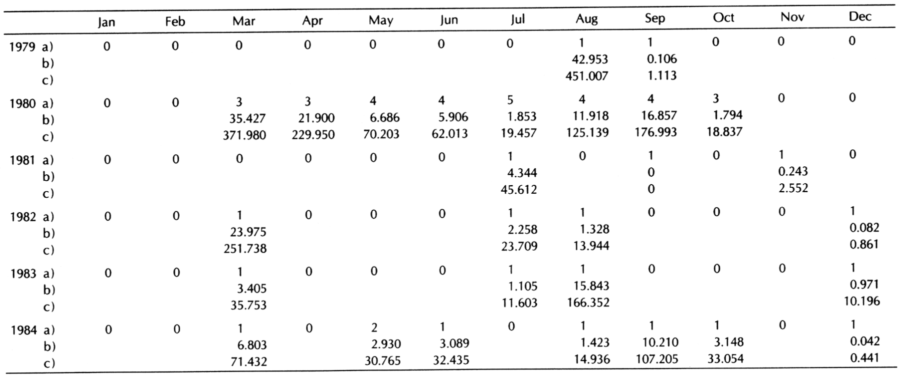
APPENDIX III—Cont'd.



		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1984	a)	0	0	1	0	2	1	0	1	1	1	0	1
	b)			7.973		5.106	0.151		1.017	11.412	1.032		0.158
	c)			113.217		72.498	2.144		14.441	162.050	14.654		2.244
1985	a)	1	0	0	1	1	2	1	2	1	0	0	0
	b)	0			0	0.116	8.198	0.377	0	2.472			
	c)	0			0	1.647	116.405	5.353	0	35.102			
1986	a)	0	1	1	2	0	0	0	0	2	0	0	0
	b)		8.040	23.423	0.750					2.126			
	c)		114.168	332.607	10.650					30.185			
1978	a)	5	5	15	12	13	14	13	15	14	5	5	5
-86	b)	0.647	2.882	15.658	11.629	3.115	1.774	4.001	4.794	7.035	3.618	11.519	1.201
	SD	1.361	3.334	18.444	16.010	4.263	3.291	11.197	10.967	15.790	5.041	21.043	1.321
	c)	9.182	40.930	222.293	165.137	44.238	25.193	56.820	68.075	99.903	51.378	163.564	17.051

APPENDIX III—Cont'd.

APPENDIX IV



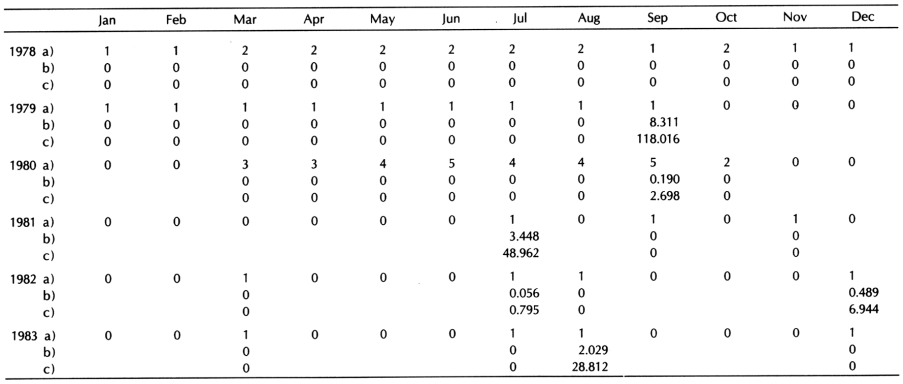
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1979	a)	0	0	0	0	0	0	0	1	1	0	0	0
	b)								42.953	0.106			
	c)								451.007	1.113			
1980	a)	0	0	3	3	4	4	5	4	4	3	0	0
	b)			35.427	21.900	6.686	5.906	1.853	11.918	16.857	1.794		
	c)			371.980	229.950	70.203	62.013	19.457	125.139	176.993	18.837		
1981	a)	0	0	0	0	0	0	1	0	1	0	1	0
	b)							4.344		0		0.243	
	c)							45.612		0		2.552	
1982	a)	0	0	1	0	0	0	1	1	0	0	0	1
	b)			23.975				2.258	1.328				0.082
	c)			251.738				23.709	13.944				0.861
1983	a)	0	0	1	0	0	0	1	1	0	0	0	1
	b)			3.405				1.105	15.843				0.971
	c)			35.753				11.603	166.352				10.196
1984	a)	0	0	1	0	2	1	0	1	1	1	0	1
	b)			6.803		2.930	3.089		1.423	10.210	3.148		0.042
	c)			71.432		30.765	32.435		14.936	107.205	33.054		0.441

APPENDIX IV—Cont'd.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985 a)	1	0	0	1	1	2	1	2	1	0	0	0
b)	0			0	0.072	5.253	0	1.369	1.110			
c)	0			0	0.756	55.157	0	14.375	11.655			
1986 a)	0	1	1	2	0	0	0	0	2	0	0	0
b)		2.250	25.933	8.955					6.454			
c)		23.625	272.297	94.033					67.764			
1979 a)	1	1	7	6	7	7	9	10	10	4	1	3
—86 b)	0	2.250	23.771	13.935	4.668	5.317	1.886	11.196	9.176	2.133	0.243	0.365
SD	-	-	16.092	18.396	3.971	4.681	1.810	15.091	12.554	2.202	-	0.525
c)	0	23.625	249.594	146.319	49.017	55.823	19.803	117.555	96.347	22.394	2.552	2.833

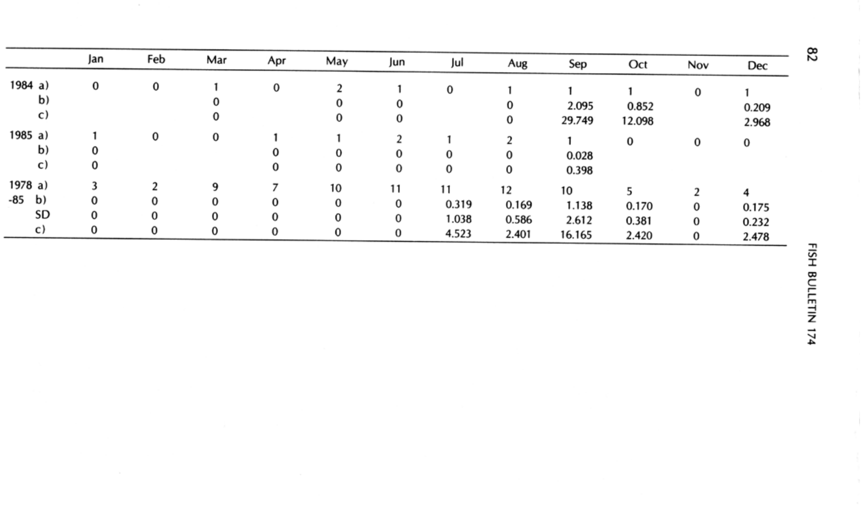
APPENDIX IV—Cont'd.

APPENDIX V



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1978 a)	1	1	2	2	2	2	2	2	1	2	1	1
b)	0	0	0	0	0	0	0	0	0	0	0	0
c)	0	0	0	0	0	0	0	0	0	0	0	0
1979 a)	1	1	1	1	1	1	1	1	1	0	0	0
b)	0	0	0	0	0	0	0	0	8.311			
c)	0	0	0	0	0	0	0	0	118.016			
1980 a)	0	0	3	3	4	5	4	4	5	2	0	0
b)			0	0	0	0	0	0	0.190	0		
c)			0	0	0	0	0	0	2.698	0		
1981 a)	0	0	0	0	0	0	1	0	1	0	1	0
b)							3.448		0		0	
c)							48.962		0		0	
1982 a)	0	0	1	0	0	0	1	1	0	0	0	1
b)			0				0.056	0				0.489
c)			0				0.795	0				6.944
1983 a)	0	0	1	0	0	0	1	1	0	0	0	1
b)			0				0	2.029				0
c)			0				0	28.812				0

APPENDIX V—Cont'd.



		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1984	a)	0	0	1	0	2	1	0	1	1	1	0	1
	b)			0		0	0		0	2.095	0.852		0.209
	c)			0		0	0		0	29.749	12.098		2.968
1985	a)	1	0	0	1	1	2	1	2	1	0	0	0
	b)	0			0	0	0	0	0	0.028			
	c)	0			0	0	0	0	0	0.398			
1978	a)	3	2	9	7	10	11	11	12	10	5	2	4
-85	b)	0	0	0	0	0	0	0.319	0.169	1.138	0.170	0	0.175
	SD	0	0	0	0	0	0	1.038	0.586	2.612	0.381	0	0.232
	c)	0	0	0	0	0	0	4.523	2.401	16.165	2.420	0	2.478

APPENDIX V—Cont'd.

APPENDIX VI

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1979 a)	0	0	0	0	0	0	0	1	1	0	0	0
b)								2.671	0.024			
c)								28.046	0.252			
1980 a)	0	0	3	3	4	4	5	4	4	3	0	0
b)			0	0	0	0	0	0	2.827	0.166		
c)			0	0	0	0	0	0	29.684	1.743		
1981 a)	0	0	0	0	0	0	1	0	1	0	1	0
b)							0.159		0		0	
c)							1.670		0		0	
1982 a)	0	0	1	0	0	0	1	1	0	0	0	1
b)			0				0	0				0
c)			0				0	0				0
1983 a)	0	0	1	0	0	0	1	1	0	0	0	1
b)			0				0	3.356				0
c)			0				0	35.238				0
1984 a)	0	0	1	0	1	1	0	1	1	1	0	1
b)			0		0	0		0	0	0.208		0.017
c)			0		0	0		0	0	2.184		0.179

APPENDIX VI—Cont'd.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985 a)	1	0	0	1	1	2	1	2	1	0	0	0
b)	0			0	0	0	0	0	0.771			
c)	0			0	0	0	0	0	8.096			
1979– a)	1	0	6	4	6	7	9	10	8	4	1	3
85 b)	0		0	0	0	0	0.018	0.603	1.513	0.177	0	0.006
SD	–		0	0	0	0	0.053	1.281	2.530	0.236	–	0.010
c)	0		0	0	0	0	0.185	6.328	15.887	1.856	0	0.059

APPENDIX VI—Cont'd.

GROWTH AND DEVELOPMENT OF LARVAL AND JUVENILE CALIFORNIA HALIBUT, PARALICHTHYS CALIFORNICUS, REARED IN THE LABORATORY

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ABSTRACT

California halibut, Paralichthys californicus, were reared for 2 months after hatching in 300-L tanks with flow-through seawater systems to observe development and test culture techniques. Larvae were subjected to two temperatures (16°C and 20°C) and two feeding levels (low and high rotifer densities). Growth was significantly greater at the higher temperature and the higher food density; the largest juveniles (mean standard length of 14.8 mm) were the result of a combination of high temperature and high food density. Development was also faster at 20°C than 16°C, resulting in metamorphosis occurring sooner.

INTRODUCTION

The California halibut, Paralichthys californicus: Paralichthyidae, is one of the most economically important fish species off southern California. Since the early 1900s, however, sport and commercial catches have fluctuated greatly and undergone an overall reduction (Methot 1983). Although the adult population is monitored through catch data (Reed and MacCall 1988), relatively little is known about the early life history of halibut. Coastal ichthyoplankton surveys indicate that spawning occurs year-round in the nearshore area (1–20 km) of southern California, with peaks of larval abundance in winter and spring (Lavenberg et al. 1986). High densities of newly settled halibut larvae and juveniles have been collected in shallow inshore areas (Allen 1988; Kramer 1990), indicating that shoreward transport or migration occurs at some point during early development.

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Since the year-class strength of a fish cohort may be strongly affected by survival during the first few months of life (Hjort 1914, 1926; Hunter 1976), knowledge of influencing factors during this period is important in effectively managing a fishery. Thus, one of our primary objectives was to gather basic information concerning the development of halibut early life history stages. An additional long-term goal of interest to the California Department of Fish and Game was to develop methodology to rear larval halibut with the ultimate purpose of enhancing ocean populations through juvenile release.

This paper describes halibut culture from eggs to 2-month-old juveniles. Larval and juvenile fish growth and survival can be affected by a variety of factors, such as temperature (Laurence 1975; Buckley 1982; McMullen and Middaugh 1985), food quality and availability (Houde 1978; Ablett and Richards 1980; Benavente and Gatesoupe 1988), daylength (Tandler and Helps 1985; Duray and Kohno 1988), container size (Blaxter 1962; Theilacker 1980), fish density (Gadomski and Petersen 1988) and water quality (Brownell 1980a, 1980b). If all other environmental parameters are adequate, however, temperature and food probably have the greatest influence; thus, we examined the effects of these two factors on growth and, additionally, noted how developmental rates were temperature dependent.

METHODS

Egg Collection

Fertilized halibut eggs were obtained from fish spawning naturally in an outdoor 5-m diameter, 2.5-m deep redwood tank with a coastal seawater source. Drain water was strained through a 333-[u]m mesh net system to collect floating eggs from brood stock spawns. Under ambient daylength and temperature conditions, spawning periodicity varied yearly; for a more detailed description of spawning, see Caddell et al. (1990).

Larval and Juvenile Rearing

The following set of larval rearing procedures, determined from preliminary experiments, was defined as our control. Eggs were stocked in black fiberglass 300-L tanks (diameter: 1.25 m; depth: 0.25 m) at densities of 60–70/L. At 16°C, halibut larvae begin to feed 4–5 d after hatching (after complete eye pigmentation), and at the age of about 1 month, metamorphosing larvae settle to the bottom. At first-feeding, rotifers, Brachionus plicatilis, were added at densities of 15–20/ml. Rotifer densities were determined daily in the rearing tanks and replenished to 15–20/ml. To determine rotifer density in a rearing tank, the water was gently stirred and nine 10 ml samples were extracted using a pipette from locations spaced evenly throughout the tank. The resulting 90 ml was mixed; 10 ml was subsampled and rotifer numbers counted under a compound microscope. Since larvae are visual feeders, food was added to tanks early in the day to maximize feeding potential. At 3 weeks after hatching, newly hatched brine shrimp, Artemia sp., nauplii were added to excess (a tank density of about 5/ml) along with rotifers. At this time, rotifer density was gradually decreased, although larvae will continue to ingest rotifers until larval settlement.

Ambient water was pumped from a coastal intake with a salinity of about 34–35 [o/oo]. Before water entered the larval rearing tanks, it was circulated through a pressurized sand filter, an oyster-shell and activated-carbon biofilter, a 15 [u]m mechanical filter, ultraviolet sterilization, and a small chiller. Tank drains were covered with 333 [u]m mesh plastic netting to avoid losing eggs and larvae; netting with mesh small enough to filter out rotifers (about 50–100 [u]m) was found to be impractical due to rapid clogging. To avoid damaging eggs and yolk-sac larvae, water was not changed in larval tanks until first-feeding except to siphon out detritus. After first-feeding, water was changed for 2 h in the morning (at a flow rate of about 1 L/min) before feeding to avoid flushing newly added rotifers out of the tank. About 2 weeks after hatching, water input increased to continuous overnight flow, with no flow during daylight to minimize food loss; a month after hatching, flow was constant. Water quality measurements of ammonia, dissolved oxygen, and salinity were conducted at least weekly to assure that normal conditions were maintained. Initially (eggs and young larvae) air was slowly bubbled through an air stone; air flow was increased with larval development. Light was supplied by fluorescent bulbs (0.3 x 10^{15} quanta/[sec.cm^{2}]) in cycles simulating natural conditions (14 h light, 10 h dark).

Halibut were cultured in four tanks for 2 months (61–63 d) after hatching. Rearing conditions were as outlined for the control tank except for the parameters being studied. We tested two temperatures, 16°C and 20°C, and two feeding regimes at each temperature, defined as "high" and "low" food levels. At high food levels, rotifers were replenished to 15–20/ml daily during the first 3 weeks. After this period (or slightly sooner at the high temperature, due to faster larval development), brine shrimp nauplii were also added to excess and rotifer densities were gradually decreased. At low food levels, rotifers were replenished every 2 d to 10/ml, and brine shrimp nauplii were first added 4 instead of 3 weeks after hatching; rotifer densities were gradually decreased at this time. Higher water temperatures were established using small aquarium heaters. After tanks were stocked with eggs, temperatures were raised 1.0–2.0°C/d from ambient values of about 16°C. Experimental temperatures, 16°C and 20°C, were maintained within 0.5°C.

To determine growth, 15–30 larvae or juveniles were removed approximately weekly from each tank, and notochord, flexion, or standard lengths of live anesthetized specimens were measured. Dry weight was determined by air drying specimens 7 d on filter paper and weighing them as a group on an electrical beam balance. Development rates at 16°C and 20°C were determined by daily observations of larvae or juveniles in 300-L tanks with "high" feeding levels. Additionally, we noted the development of specimens removed weekly for growth studies. Significant developmental stages were defined using criteria of eye pigmentation, yolk utilization, notochord flexion, dorsal ray elongation, eye migration, and scale formation.

Growth equations for each tank were derived using least-squares regression analysis. Final lengths were compared between food and temperature treatments using two-way analysis of variance (ANOVA).

RESULTS

Development

Halibut eggs are buoyant and about 0.80 mm in diameter (SD = 0.03; *N* = 131) with one 0.14 mm oil globule. Development rates of eggs, larvae, and juveniles are temperature dependent. At 16° and 20°C, eggs hatch in 50 and 34 h, respectively (Gadomski and Caddell 1991). Newly hatched larvae are 1.8–2.0 mm notochord length with large yolk sacs, unpigmented eyes, and undeveloped mouths. Upon hatching, larvae are positively buoyant for about 0.5 d until their yolk is partially utilized. They then begin to sink downward, but remain dispersed throughout the water column by swimming toward the surface. At 16°C, eyes are completely pigmented 4 d after hatching, full yolk depletion occurs 6 d after hatching, and at about 1 month, metamorphosing larvae begin settling to the bottom. Nine significant stages in development during the first 2 months after hatching were defined (Figure 1):

(I). Full eye pigmentation.
(II). Yolk depletion.
(III). Beginning of dorsal ray elongation.
(IV). Beginning of notochord flexion.
(V). (a). Full notochord flexion (standard length); and (b). Settled behavior.
(VI). Beginning of eye migration.
(VII). Reduction in elongated dorsal rays.
(VIII). Majority metamorphosed (settled, with fully migrated eyes and elongated dorsal rays fully reduced).
(IX). Beginning of scale formation.

Many of the above events are specific to flatfish development. Dorsal ray elongation is characteristic of larvae of many pleuronectiform fishes (Ahlstrom et al. 1984). Dorsal ray elongation of larval halibut begins with the second dorsal ray and progresses until five rays are elongated. Larval eye migration occurs in all species of flatfish, which hatch with an eye on each side of the head. Halibut can be either left or right eyed—we have observed about 50% of each in laboratory-spawned larvae. When a larva had achieved full notochord flexion (standard length), a more settled behavior pattern was exhibited, with the larva lying on the tank bottom for intervals (although often swimming up to feed). Eye migration began a few days later, and by the time an eye was on the top of the head, elongated dorsal rays were noticeably reduced. By approximately 8 mm standard length (SL), larvae had completely migrated eyes, normal length dorsal rays, and a primarily benthic lifestyle.

Scale formation was not evident until after settlement, when fish were about 12 mm SL. Scales were first formed on the midline of the caudal peduncle and along the lateral line. After settlement, many fish developed pigmentation abnormalities, resulting in a partial or almost total white appearance instead of the normal dark dorsal coloration (Figure 2). Although pigmentation abnormalities in cultured flatfishes are often termed "albinism," melanophores were present in the epidermis of halibut, but at a much lower density than normal.

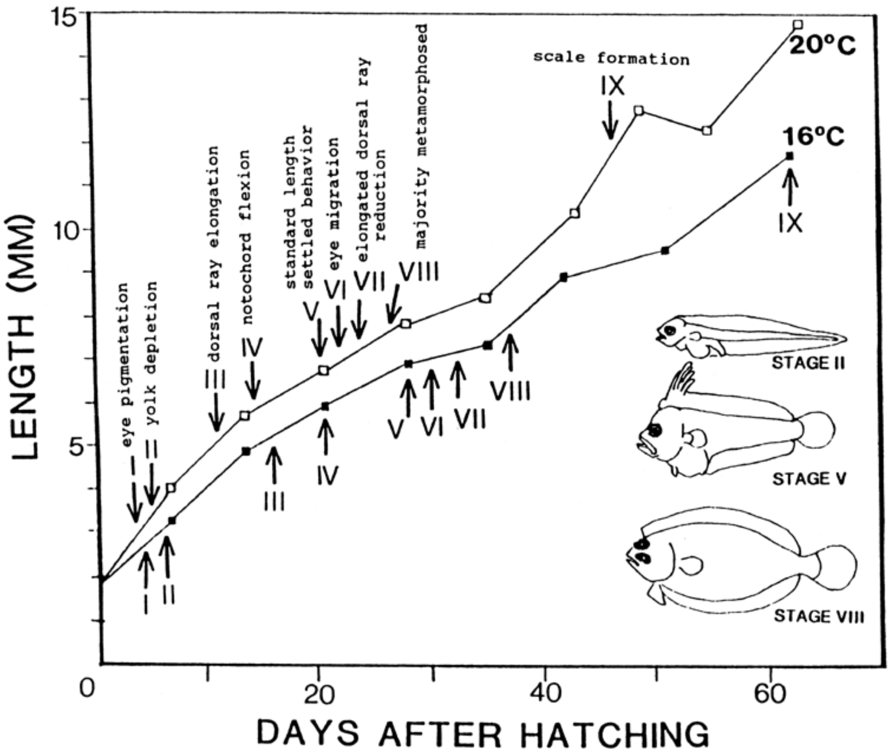

FIGURE 1. Development of halibut for two months after hatching at two temperatures (16°C and 20°C). Mean notochord, flexion, and standard lengths ($N = 20–30$) are presented. For a more complete description of developmental stages, see text. It should be noted that the length that corresponds to a developmental stage is the mean length when a majority of larvae in the tank were at that stage, not the length of an individual larva. For example, a larva completed metamorphosis at about 8 mm SL, but the mean length when a majority of larvae had metamorphosed is slightly shorter.

FIGURE 1. Development of halibut for two months after hatching at two temperatures (16°C and 20°C). Mean notochord, flexion, and standard lengths (N = 20–30) are presented. For a more complete description of developmental stages, see text. It should be noted that the length that corresponds to a developmental stage is the mean length when a majority of larvae in the tank were at that stage, not the length of an individual larva. For example, a larva completed metamorphosis at about 8 mm SL, but the mean length when a majority of larvae had metamorphosed is slightly shorter

Both growth and development were faster at 20°C than at 16°C; thus, larval size at a developmental stage was similar at both temperatures (Figure 1). Faster development at the higher temperature was evident even in early stages; eye pigmentation and yolk depletion occurred about 1 d sooner. By the age of 1 month, most larvae at 20°C had completed settlement, whereas a majority had not settled until about 10 d later at 16°C (Figure 1). At 20°C, scale formation started a few weeks after settlement, while at 16°C, scales were only evident on a small percentage of fish by the end of the 2-month grow-out period.

Growth

Both temperature and feeding significantly affected halibut growth (Table 1); final mean standard lengths of 2-month-old halibut were greater at 20°C than at 16°C and at the high versus the low food level. There was no significant

FIGURE 2. Pigmentation patterns of 3-month-old halibut. The upper fish has normal dark dorsal coloration, while the lower is very lightly pigmented.

FIGURE 2. Pigmentation patterns of 3-month-old halibut. The upper fish has normal dark dorsal coloration, while the lower is very lightly pigmented

interaction between the temperature and food treatments (Table 1). The largest 2-month-old halibut (mean standard length of 14.80 mm [SD = 2.16, *N* = 30]) were reared at 20°C and fed at the high food level (Figures 3 and 4).

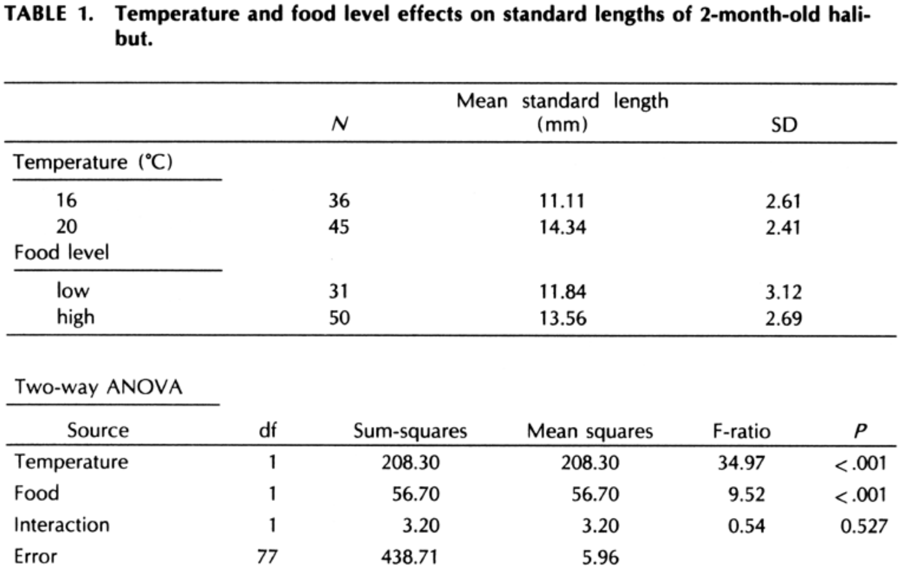

TABLE 1. Temperature and food level effects on standard lengths of 2-month-old halibut.

	N	Mean standard length (mm)	SD
Temperature (°C)			
16	36	11.11	2.61
20	45	14.34	2.41
Food level			
low	31	11.84	3.12
high	50	13.56	2.69

Two-way ANOVA

Source	df	Sum-squares	Mean squares	F-ratio	*P*
Temperature	1	208.30	208.30	34.97	< .001
Food	1	56.70	56.70	9.52	< .001
Interaction	1	3.20	3.20	0.54	0.527
Error	77	438.71	5.96		

TABLE 1. ***Temperature and food level effects on standard lengths of 2-month-old halibut.***

Within a tank some fish grew faster than others resulting in greater variability in size and developmental stage with time. For all four tanks, coefficients of variation of length were greater on the last few days of measurements (12–28%) than on previous days, when coefficients of variation were 3–10%. Growth at 20°C and the high food level was greater than all other treatments throughout the grow-out period (Figures 3 and 4), although on day 55, mean size decreased slightly, possibly due to a sampling bias. In contrast, fish at 20°C and the low food level initially grew fairly slowly, but final mean size was significantly greater than at 16°C and high food (t-test, $P < .05$).

Based on comparisons of R-squared values, larval growth was better described by exponential relationships (presented in Figures 3 and 4) than by simple linear equations. R-squared values for natural log transformed length versus time were 1–9% higher than for fits of untransformed length. R-squared values for natural log transformed weight versus time were 10–34% higher than linear fits, except for the treatment of high food and 20°C, where R-squared values were the same (93%) for both transformed and untransformed weight versus time.

DISCUSSION

Survival of larval fishes is dependent upon the availability of food at adequate concentrations; survival is greater at higher food densities (Houde 1978; Werner and Blaxter 1980). Larger larvae can eat larger food items such as brine shrimp nauplii and copepods, and the minimum necessary concentration is relatively

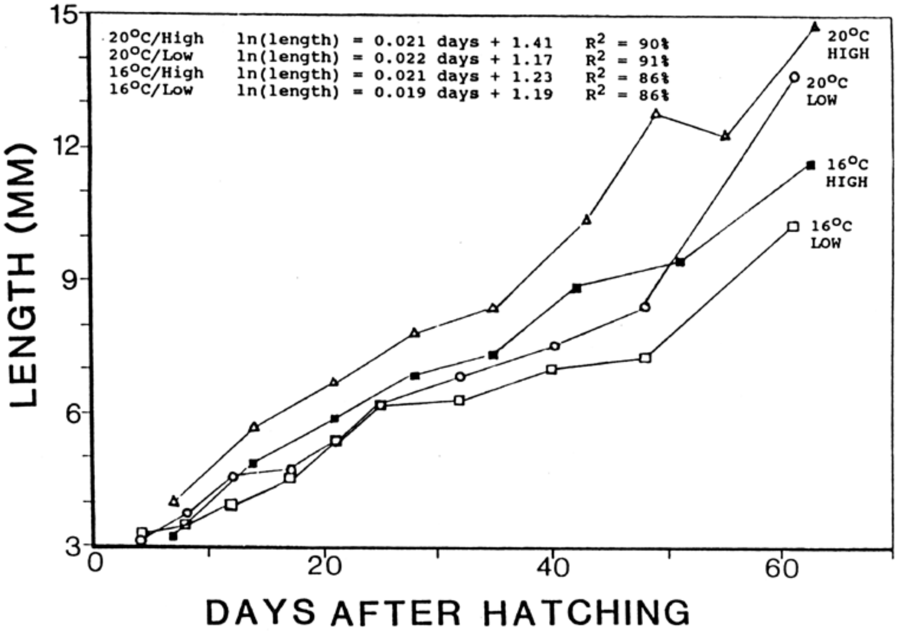

FIGURE 3. Growth of halibut for 2 months after hatching at two temperatures (16°C and 20°C) and two feeding regimes ("Low" and "High" food levels: see text). Mean notochord, flexion, and standard lengths (*N*=15–30) are presented. Growth equations and R-squared values were derived using lengths of individuals.

FIGURE 3. Growth of halibut for 2 months after hatching at two temperatures (16°C and 20°C) and two feeding regimes ("Low" and "High" food levels: see text). Mean notochord, flexion, and standard lengths (N = 15–30) are presented. Growth equations and R-squared values were derived using lengths of individuals

low (Wyatt 1972; Houde 1978; Werner and Blaxter 1980). Larvae ingesting small prey types such as rotifers, however, may require high densities for best survival (Lasker et al. 1970; Theilacker and McMaster 1971; Hunter and Kimbrell 1980). Preliminary feeding experiments we conducted in 3-L containers (with an initial stocking density of 25 halibut eggs/L) resulted in a significantly higher mean survival 18 d post-hatching at 10 rotifers/ml (47.3% survival) than 5 rotifers/ml (14.7% survival; t-test, $P < .01$; Gadomski and Caddell, unpublished data). Although not rigorously quantified in the current study, survival of halibut larvae in 300-L tanks appeared greater at the higher tested rotifer density; we visually estimated about 50% survival soon after larval settlement at 15–20 rotifers/ml versus only 10% survival at 10 rotifers/ml. It should be noted, however, that reported tank food densities are means of the initially replenished densities. In reality, distributions of both rotifers and brine shrimp nauplii were patchy, with aggregations often in the brightest section of a tank. Additionally, mean tank food densities dropped as ingestion proceeded and as food was flushed out during water changes.

Faster growth at higher food densities has been demonstrated for larvae of many fish species, among them bay anchovy, Anchoa mitchilli; lined sole, Achirus lineatus; sea bream, Archosargus rhomboidalis, (Houde 1978); herring, Clupea harengus, (Werner and Blaxter 1980); and silversides, Menidia peninsulae,

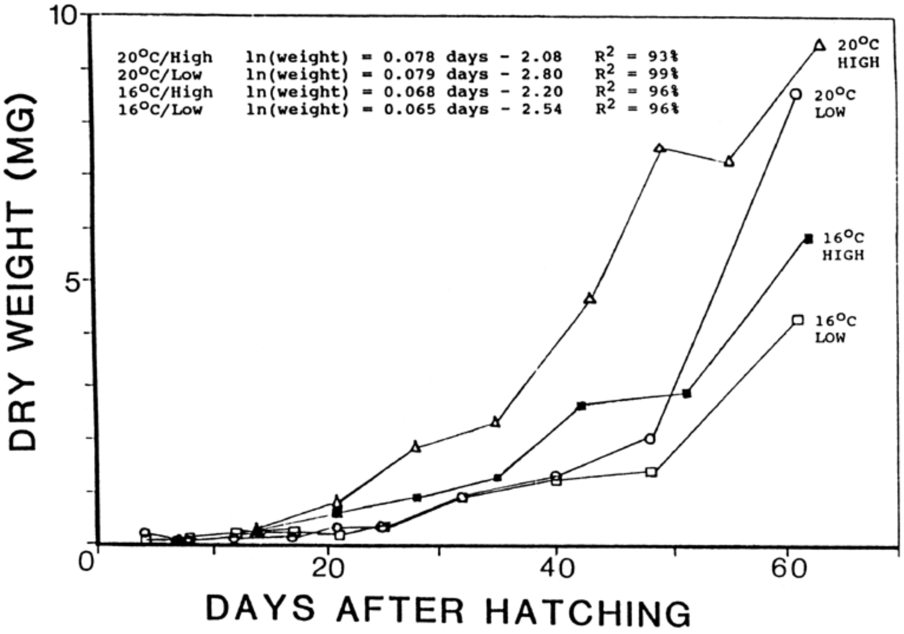

FIGURE 4. Growth of halibut for 2 months after hatching at two temperatures (16°C and 20°C) and two feeding regimes ("Low" and "High" food levels: see text). Mean dry weights (N=15–30) are presented. Growth equations and R-squared values were derived using mean weights instead of individual weights because (due to small individual size) specimens in a sample were weighed as a group.

FIGURE 4. Growth of halibut for 2 months after hatching at two temperatures (16°C and 20°C) and two feeding regimes ("Low" and "High" food levels: see text). Mean dry weights (N = 15–30) are presented. Growth equations and R-squared values were derived using mean weights instead of individual weights because (due to small individual size) specimens in a sample were weighed as a group

(McMullen and Middaugh 1985). A complicating factor in our study, however, was that with time fish density in a tank decreased due to mortalities and sampling, which resulted in more food per larva and perhaps affected growth rates. A possible example of this was at 20°C and the low food level. Growth was initially slow, probably as a result of inadequate food due to higher metabolic demands at the higher temperature (Laurence 1975; McMullen and Middaugh 1985); eventually many larvae died and growth appeared to increase. Recovery growth of food-deprived larvae has been reported for diamond turbot, Hypsopsetta guttulata (Gadomski and Petersen 1988); whitefish, Coregonus lavaretus; and peled, Coregonus peled (Dabrowski et al. 1986a, b); although seemingly faster growth may be an artifact of size-selective mortality of smaller, less robust individuals (Rosenberg and Haugen 1982). An additional factor was the introduction of a different food type, brine shrimp nauplii, during the last month, which might have alleviated a food-limiting situation.

Halibut larvae grew faster at 20°C than at 16°C. Both temperatures are within ranges encountered in the field. Halibut eggs and larvae are abundant from winter through spring when surface temperatures are usually 13–17°C, but spawning can occur in summer when surface waters may reach 22°C (Lavenberg et al. 1986; Petersen et al. 1986). Juveniles in inshore waters during summer months commonly experience temperatures above 20°C, and shallow areas may be as warm as 24°C (Kramer 1990). Temperature-induced faster growth rates in our study resulted in larvae metamorphosing sooner; most fish at 20°C had settled by 1 month at a standard length of about 8 mm, whereas at 16°C, settlement (at about the same size) took approximately 10 d longer. Increased developmental rates at higher temperatures have been shown for other flatfish species, among them winter flounder, Pseudopleuronectes americanus, (Laurence 1975) and summer flounder, Paralichthys dentatus, (Johns et al. 1981). Similarly to our studies on halibut, variations in length at a developmental stage of laboratory-reared winter flounder were low and were less than variations in age (Chambers et al. 1988).

Halibut length-versus-time growth curves level out somewhat during metamorphosis, and slightly higher growth is again evident after this period (Figure 1). This growth pattern was also reported for the flatfish Limanda yokohamae by Fukuhara (1988), who noted that although growth as measured by length had slowed, body height increased, and many other morphological changes were occurring. Similarly to halibut, L. yokohamae exhibit settled behavior before complete metamorphosis, which Fukuhara attributed to "a strategic behavior for avoiding predators and to compensate for poor swimming capability in the late pelagic stages of larval life."

Many juvenile halibut had abnormally light pigmentation. Pigment abnormalities have been documented in other reared flatfish, such as plaice, Pleuronectes platessa, (Shelbourne 1965) and turbot, Scophthalmus maximum, (Heap and Thorpe 1987). Abnormal pigmentation is not necessarily detrimental; in fact, malpigmented juvenile turbot were reported by Heap and Thorpe (1987) to grow faster than normally pigmented turbot. The interaction between chromatophore development and environmental conditions is poorly understood. Parameters that may affect pigmentation include unnatural light levels (DeVeen 1969), stocking density (Klein-Macphee 1981), temperature (Shelbourne 1964; Dawson 1967; Moore and Posey 1974) and the lack of suitable substrata (Stickney and White 1975).

Inadequate nutrition might also have influenced both chromatophore development and growth. Although halibut larvae in the laboratory settled at the same size (8 mm SL) and at about the same age (1 month) as those in the field, field growth after metamorphosis is faster than laboratory growth, about 1–2 cm/month (Allen 1988) versus our fastest post-settlement growth rate of 0.7 cm/month. Additionally, mortality rate in the laboratory increased after settlement, and greatly accelerated when fish were a few months old (Gadomski, unpublished data). This was probably largely due to the inadequate size of brine shrimp as juveniles grew, but poor nutrition during both the larval and juvenile stages may also have been a factor. For normal development of laboratory-reared fish, it may be necessary to supplement a diet of rotifers and brine shrimp with other food sources (Lasker et al. 1970; Kuhlman et al. 1981). At this time, however, we have not found other foods larval and juvenile halibut will readily accept that are also feasible to use in a large-scale hatchery operation.

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DISTRIBUTION AND ABUNDANCE OF JUVENILE CALIFORNIA HALIBUT, PARALICHTHYS CALIFORNICUS, IN SHALLOW WATERS OF SAN DIEGO COUNTY

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ABSTRACT

The size-specific distribution and abundance of juvenile California halibut, Paralichthys californicus, were determined for bay and open-coast habitats using a random sampling design stratified by depth. The pattern of settlement differed over the two-year study. Halibut settled in the bays in 1987 and primarily on the open coast in 1988. Although there was settlement on the open coast in 1988, nearly all juveniles between 60 and 100 mm standard length (SL) were in the bays. This suggests that juveniles that settled on the open coast eventually moved into bays or died. The density of juvenile halibut was greatest in the bays with highest recorded densities in the shallow shoreline habitats where depth was [<] m. Nearly all juveniles > 220 mm SL occurred on the open coast with movement of juveniles from the bays to the open coast beginning at about 140 mm SL. These results suggest that the bays are probably essential habitats for juvenile growth and survival.

INTRODUCTION

Processes used by flatfishes to select and settle in appropriate juvenile nursery areas are not known. The larvae of flatfishes that live on the continental shelf as adults are widely distributed over the shelf. The oldest and largest larvae are found closest to the area where settlement occurs (Weinstein et al. 1980; Barnett et al. 1984; Roper 1986; Boehlert and Mundy 1988).

Utilization of shallow water nursery areas by juvenile flatfishes is common (Edwards and Steele 1968; Weinstein et al. 1980; Roper and Jillett 1981; Poxton

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et al. 1982; Krygier and Pearcy 1986; Rogers et al. 1989). Evolution of complex life histories involving the selection of specialized juvenile nursery areas suggests that these habitats present greater potential for increased fitness by increasing growth opportunities, decreasing the risk of mortality, or both (Werner and Gilliam 1984; Werner 1986). Density of individuals within these habitats reflects habitat preference with highest densities considered to be indicative of optimal habitats (Fretwell 1972).

California halibut, Paralichthys californicus, is a commercially important flatfish off southern California that utilizes embayments as nursery areas (Haaker 1975; Allen 1988). Adults inhabit coastal waters less than 100 m deep with greatest abundance at depths less than 30 m (Miller and Lea 1972; Allen 1982). Adults spawn throughout the year with peak spawning in spring (Lavenberg et al. 1986; Walker et al. 1987).

Eggs and larvae occur over the shelf with greatest densities in waters less than 75 m deep and within 6 km of shore (Frey 1971; Ahlstrom and Moser 1975; Gruber et al. 1982; Barnett et al. 1984; Lavenberg et al. 1986; Walker et al. 1987). California halibut have a relatively short pelagic larval stage, transforming and settling to the bottom at a smaller size (7.5–9.4 mm) than most coastal flatfish (Ahlstrom et al. 1984). The planktonic stage probably lasts less than one month; laboratory reared halibut begin to settle to the bottom 20 d after hatching when they are 7–8 mm standard length (SL) (Gadomski and Petersen 1988).

Newly settled and larger juvenile halibut are frequently taken in shallow water embayments (Haaker 1975; Allen 1988) but not on the open coast (Allen 1982; Plummer et al. 1983). However, nearly all of the sampling on the open coast has been at depths greater than 10 m and with mesh too large to catch newly settled halibut (Plummer et al. 1983; Allen 1988). In southern California, shallow coastal areas comprise a much larger fraction of the potential nursery habitat than do embayments. The objectives of this paper are to determine the extent of the dependency of juvenile halibut on embayments relative to shallow coastal habitats, and to describe the habitats where most juveniles are found and how habitat preference changes over time.

MATERIALS AND METHODS

Collections were taken with bottom trawls on the open coast and in bays to determine time and location of settlement and to estimate habitat-specific density and abundance of juvenile California halibut. I used a random sampling design stratified by depth. Open coast sampling areas were four blocks representing 40 naut mi of coastline; two blocks were adjacent to bays and two were distant from bays (Figure 1).

The two bays sampled were Mission Bay and Agua Hedionda Lagoon, each divided into blocks of similar habitat type, resulting in five blocks in Mission Bay and three in Agua Hedionda Lagoon (Figure 1). Blocks were numbered according to their distance from the opening of the bay; the lowest numbered block (1) was the farthest from the opening of the bay to the sea (Figure 1).

Sample locations were assigned randomly within three depth strata for each block. On the open coast, the depth strata sampled were: 5 m (near the first breaker line) to 8 m; 9–11 m; and the deepest stratum, 12–14 m. In bays, the

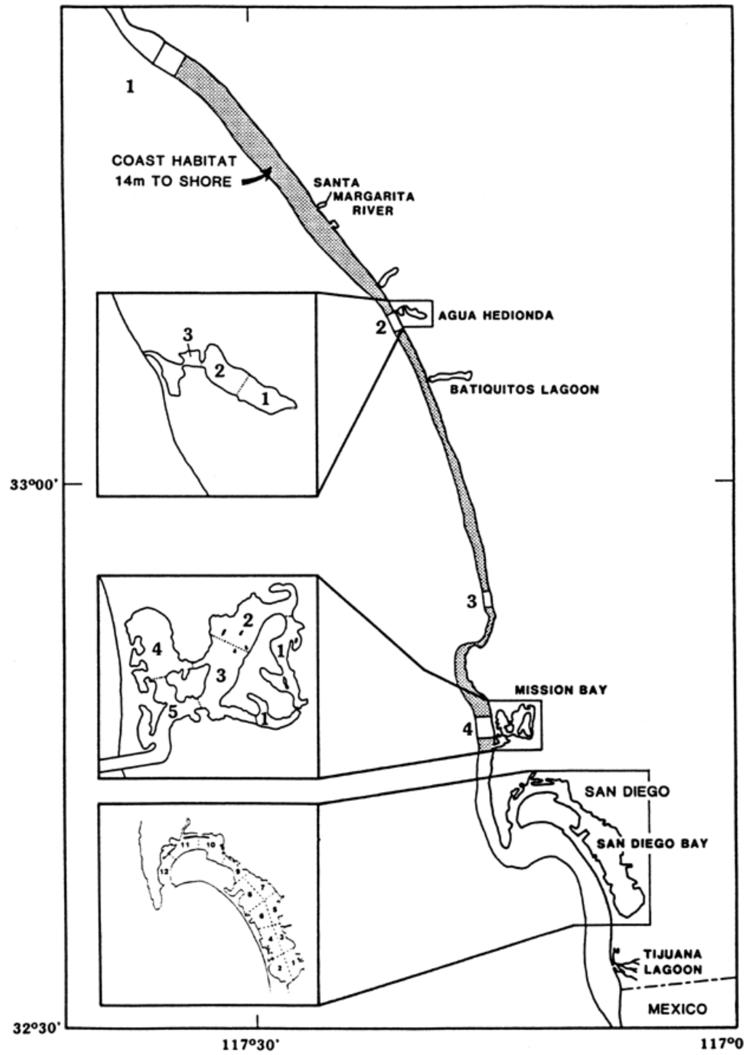

FIGURE 1. Map of location of sampling blocks. Open coast blocks are 1) San Onofre, 2) adjacent to Agua Hedionda Lagoon, 3) Torrey Pines, and 4) adjacent to Mission Bay. The two bays sampled are Agua Hedionda Lagoon and Mission Bay with sampling blocks denoted.

FIGURE 1. Map of location of sampling blocks. Open coast blocks are 1) San Onofre, 2) adjacent to Agua Hedionda Lagoon, 3) Torrey Pines, and 4) adjacent to Mission Bay. The two bays sampled are Agua Hedionda Lagoon and Mission Bay with sampling blocks denoted

depth strata ranged from < 1 m ("shoreline"); to 1–2 m ("open water," close to shore where it was possible to sample with a skiff); and to 2–4 m (near the center of the block). Three to four trawls were taken per depth stratum each month. Collections were taken monthly for 2 years beginning in September 1986 in Mission Bay and on the open coast and in March 1987 in Agua Hedionda Lagoon; last collections were taken in September 1988. Over 3300 collections were taken (Table 1).

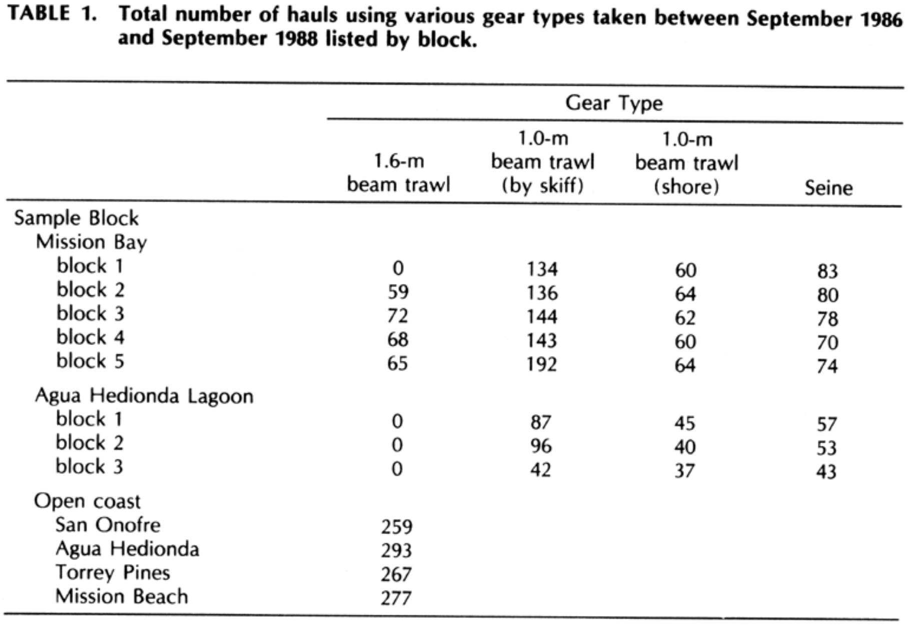

TABLE 1. Total number of hauls using various gear types taken between September 1986 and September 1988 listed by block.

	Gear Type			
	1.6-m beam trawl	1.0-m beam trawl (by skiff)	1.0-m beam trawl (shore)	Seine
Sample Block				
Mission Bay				
block 1	0	134	60	83
block 2	59	136	64	80
block 3	72	144	62	78
block 4	68	143	60	70
block 5	65	192	64	74
Agua Hedionda Lagoon				
block 1	0	87	45	57
block 2	0	96	40	53
block 3	0	42	37	43
Open coast				
San Onofre	259			
Agua Hedionda	293			
Torrey Pines	267			
Mission Beach	277			

TABLE 1. ***Total number of hauls using various gear types taken between September 1986 and September 1988 listed by block.***

I used beam trawls lined with 3-mm mesh netting for all collections on the open coast and many of those in bays, since these trawls have a fixed mouth opening allowing quantitative assessment of fish density (Krygier and Pearcy 1986). Two trawls were used: a 1.6-m wide beam trawl fished from a small research vessel (15 m) and a 1-m wide beam trawl fished from a 6-m skiff or pulled by two people in shallow water ([<] 1 m). Most bay sampling was conducted from the skiff with the 1-m beam trawl, and coastal collections were taken with the 1.6-m beam trawl (Table 1). Beam trawls were calibrated by comparing overlapping monthly samples taken in Mission Bay.

Trawls were fitted with a wheel and revolution counter to determine the distance travelled by the trawl on the bottom (Krygier and Horton 1975). Tow speed was approximately 1.5 knots; duration was 5 min in bays and 10 min on the coast. Tows were taken during daylight hours. No collections were made on the open coast in November 1987 or by skiff in bays in December 1987.

A 1-m by 6-m beach seine with 3-mm mesh was also used in shallow water (depth [<] 1 m). The beach seine was pulled parallel to shore along a measured distance of 20–50 m while maintaining a constant mouth opening (a 4-m line was stretched between the brails).

All flatfishes taken in trawls and seines were measured (standard length in mm) and the station depth, surface and bottom temperatures, and salinity (bays only) recorded. Salinity was not taken on the open coast because the refractometer was accurate to only 1 ppt.

To describe the relationship between size and density of halibut and habitat type, halibut were grouped by 20-mm length classes for all analyses. These are denoted as follows: "20" refers to fish [<]20 mm; "40" refers to fish 21–40 mm; continuing up to "> 220" which refers to all halibut > 220 mm. Densities are in number of halibut per hectare. Analysis of variance (ANOVA) with an accepted significance level of p[<]0.05 was used to analyze the data except where noted.

The area of each block or habitat type was calculated by digitizing navigation charts or maps. Only areas designated as "fine grey sand" or "sand" on coastal charts were used in the area estimates.

The largest bay in southern California, San Diego Bay, is about 5 mi south of the study area and is severely modified by dredging and pollution (Figure 1). For purposes of comparison, San Diego Bay was sampled in July 1988 and results compared to Mission Bay and Agua Hedionda Lagoon.

Gear Comparison

To compare the catch of California halibut taken in the 1.6-m beam trawl, the 1.0-m beam trawl, or the beach seine, it was necessary to weight the data for differences in the selectivity between these gear types. To compute the weighting coefficients, I used the densities of California halibut in 20-mm length classes when hauls using more than one type of gear were taken in the same block. The 1.6-m beam trawl and 1.0-m beam trawl densities were compared over the common trawling stations sampled within a 1-week period in Mission Bay (blocks 2–5). The 1.0-m beam trawl and 4.0-m beach seine densities were compared by sampling over common areas (shoreline areas in both Agua Hedionda Lagoon and Mission Bay) and were sampled on the same day.

Weighting coefficients and their variances were determined using a three-way ANOVA (Sokal and Rohlf 1981). I corrected all density (number of halibut/hectare) and abundance estimates of California halibut for the differences in gear efficiency by weighting the mean density and variance for each length class where significant differences in catchability were found. The weighted mean density (number/hectare) was calculated as $d_w = (d_1 + gd_2) / (1 + g)$ where d_1=unweighted density, d_2=weighted density, and g=weighting coefficient.

Estimated variance of the weighted mean d_w was calculated as $V(d_w) = V(d_1) + g^2V(d_2) + d_2{}^2V(g) + V(g)V(d_2)$ where $V(d_1)$=variance of unweighted density, $V(d_2)$=variance of weighted density, and $V(g)$=variance of weighting coefficient. Variance estimates were underestimated because the covariance terms were not included. Resampling techniques to estimate variance were impractical because of the large size of the database.

In addition to the beam trawl and beach seine, a catch comparison was also made between the 1.6-m beam trawl and a standard otter trawl (foot rope length 7.5 m with 1.3-cm stretch mesh cod-end liner; Mearns and Allen 1978) in San Diego Bay in June and July 1988. This otter trawl has been used extensively in studies of southern California shallow water habitats, whereas the beam trawl had never been used before. Estimation of weighting coefficients for the otter trawl provides information on the upper size limits of halibut captured by the beam trawl. Weighting coefficients were determined for 50-mm length classes by summing the total catch over the total area sampled for each gear type.

RESULTS

Description of Habitats

Open Coast

The southern California shelf is relatively steep and narrow with an average width of 6.5 km (Emery 1960) throughout the region sampled, compared to the shelf along the east coast of the U.S. which averages 100 km (Emery 1960). Only 10–20% of the Pacific coast consists of estuaries and lagoons compared to 80–90% on the Atlantic coast (Emery 1967). Although narrow, the southern California shelf is a much larger fraction (89%) of the shallow water habitat (depth [<] 14 m) than bays, which are relatively few and small (11%; Table 2).

On the shallow open coast (depth [<] 14 m), temperatures were coldest in the winter and spring, with highest temperatures in the fall (Figure 2). Dense accumulations of drift algae in shallow water outside the surf line were common on the bottom after large storms or high surf events.

Bays

The two bays sampled, Mission Bay and Agua Hedionda Lagoon, are open to the ocean throughout the year. Salinity in the bays was about the same as seawater (annual mean salinity at the Scripps Institution of Oceanography pier was 33.48 ppt in 1986 and 33.47 ppt in 1987) except during heavy rainfall when runoff decreased salinity to as low as 26 ppt (Figure 3). The occasional declines in salinity were short in duration and were most marked in the blocks that were farthest from the entrance to the sea.

The shoreline habitat (depth [<] 14 m) of bays was the most variable in temperature and salinity and was strongly affected by runoff (Figure 3). Eelgrass, Zostera sp., beds bound the outer edge of the shoreline habitat and the bottom is composed of sand or sandy mud.

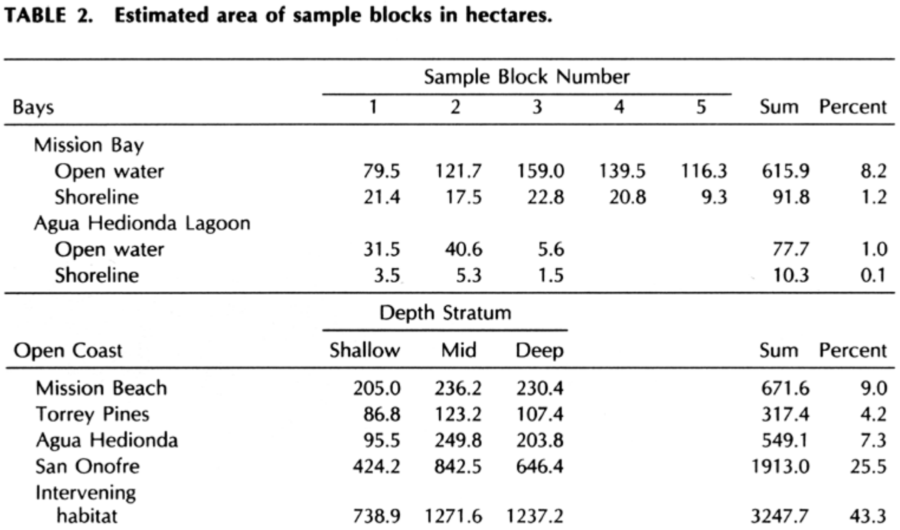

TABLE 2. Estimated area of sample blocks in hectares.

Bays	Sample Block Number 1	2	3	4	5	Sum	Percent
Mission Bay							
Open water	79.5	121.7	159.0	139.5	116.3	615.9	8.2
Shoreline	21.4	17.5	22.8	20.8	9.3	91.8	1.2
Agua Hedionda Lagoon							
Open water	31.5	40.6	5.6			77.7	1.0
Shoreline	3.5	5.3	1.5			10.3	0.1

Open Coast	Depth Stratum Shallow	Mid	Deep	Sum	Percent
Mission Beach	205.0	236.2	230.4	671.6	9.0
Torrey Pines	86.8	123.2	107.4	317.4	4.2
Agua Hedionda	95.5	249.8	203.8	549.1	7.3
San Onofre	424.2	842.5	646.4	1913.0	25.5
Intervening habitat	738.9	1271.6	1237.2	3247.7	43.3

TABLE 2. **Estimated area of sample blocks in hectares.**

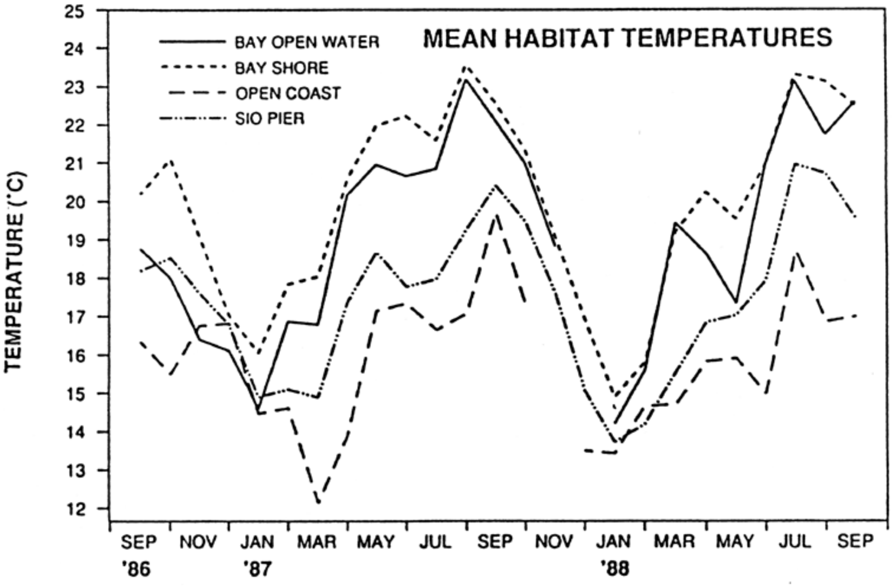

FIGURE 2. Monthly mean temperature (°C) of each habitat type.

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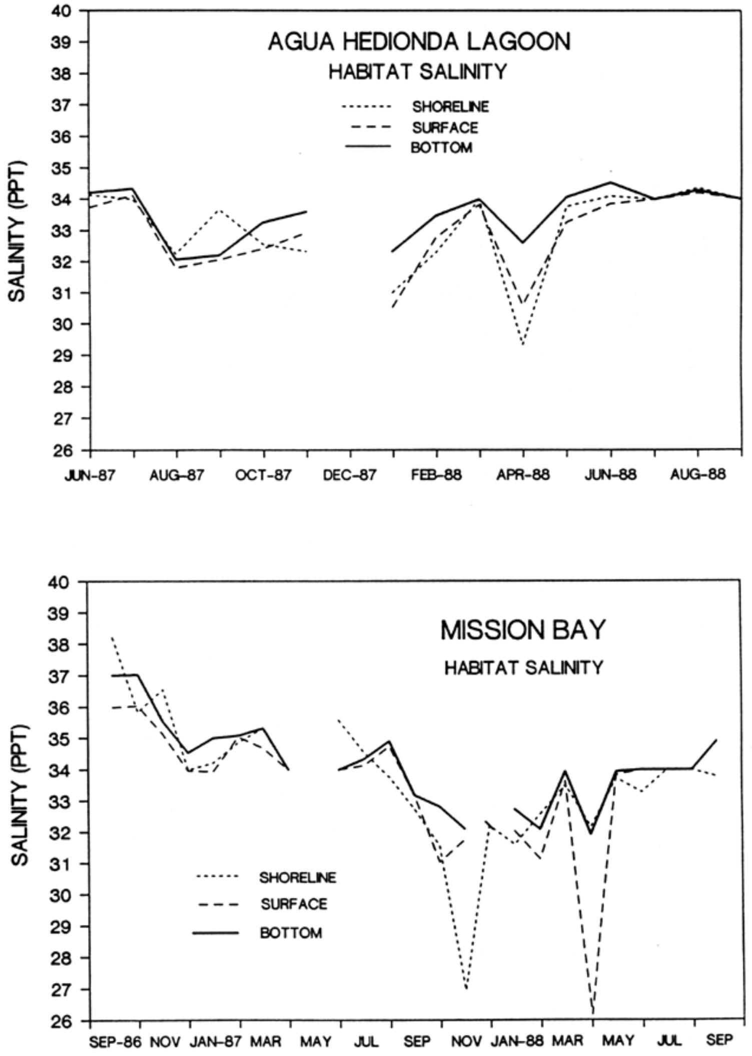

FIGURE 3. Salinity (ppt) in Agua Hedionda Lagoon and Mission Bay by habitat type.

FIGURE 3. Salinity (ppt) in Agua Hedionda Lagoon and Mission Bay by habitat type

Agua Hedionda Lagoon and Mission Bay differ in shape and in the extent of anthropogenic modification. The mouth of Agua Hedionda Lagoon is extended by short jetties into coastal water < 4 m deep and surf breaks across the opening. The outermost section of the lagoon is used by the Encina power plant for intake of cooling water and is dredged yearly to prevent filling by sand. The back part of the lagoon, with depths of less than 3 m, is not dredged. Mission Bay is a harbor with large jetties extending out to deeper coastal water (about 10 m) and the entrance and most of the bay is dredged to depth of at least 4 m. There are several other embayments in the study area, but they were closed by sand bars nearly all year and are much smaller than Agua Hedionda Lagoon.

Habitat types within the bays varied with the distance from the opening. The shallow coastal sediments are composed of sand with coarsest grain size found in shallow sediments exposed to waves and strong currents (Emery 1960). Measured grain sizes at the entrance to Mission Bay were 236 µm (Dexter 1983). Tidal currents deposit sands at the entrance to bays, but farther into bays, as circulation decreases, sediments of smaller grain sizes accumulate (Warme et al. 1976). Measurements taken in Mission Bay indicate that grain size remains fairly large (up to 160 µm) as far as 2 km into the bay in the channels with strong tidal currents (Dexter 1983). Runoff into bays deposits silts and clays (<60[u]m) which remain in areas with low circulation (Warme et al. 1976).

In the outer portions of bays where tidal circulation was strong, the bottom was usually dominated by eelgrass beds which represented a significant proportion of the bottom habitat in bays (nearly 25% in Agua Hedionda Lagoon; Bradshaw et al. 1976). The distribution of eelgrass is limited to areas in bays where the bottom substrate is stable and water is sufficiently clear for photosynthesis. Eelgrass beds were found in Mission Bay in blocks 2 through 5 and in Agua Hedionda Lagoon in blocks 2, 3, and the westernmost portion of block 1.

Farther into bays, the areas with poor circulation were dominated by invertebrate fauna including colonial bryozoans and sponges (Tetillidae). These areas included block 1 in Agua Hedionda Lagoon and blocks 1 and 2 in Mission Bay (Figure 1).

Gear Comparison

Interaction between gear type and block was usually not significant. Density calculated from the catch taken in the 1.6-m beam trawl was similar to that taken in the 1.0-m beam trawl when halibut were less than 80 mm, but for halibut > 80 mm they were significantly different (Table 3). The larger 1.6-m beam trawl captured more halibut > 80 mm than did the 1.0-m beam trawl.

Densities obtained by the 1.0-m beam trawl and 4.0-m beach seine were significantly different for the 40-, 60-, and 100-mm length classes (Table 3). The beach seine was a less effective sampler than the beam trawl; the 1.0-m beam trawl captured more halibut in all cases.

Comparison of the 1.6-m beam trawl and the 7.5-m otter trawl indicate that the beam trawl captured more small halibut ([<]20mm) per unit area than did the otter trawl, but the otter trawl captured more large halibut (> 200 mm) per unit area than did the 1.6-m beam trawl (Table 3).

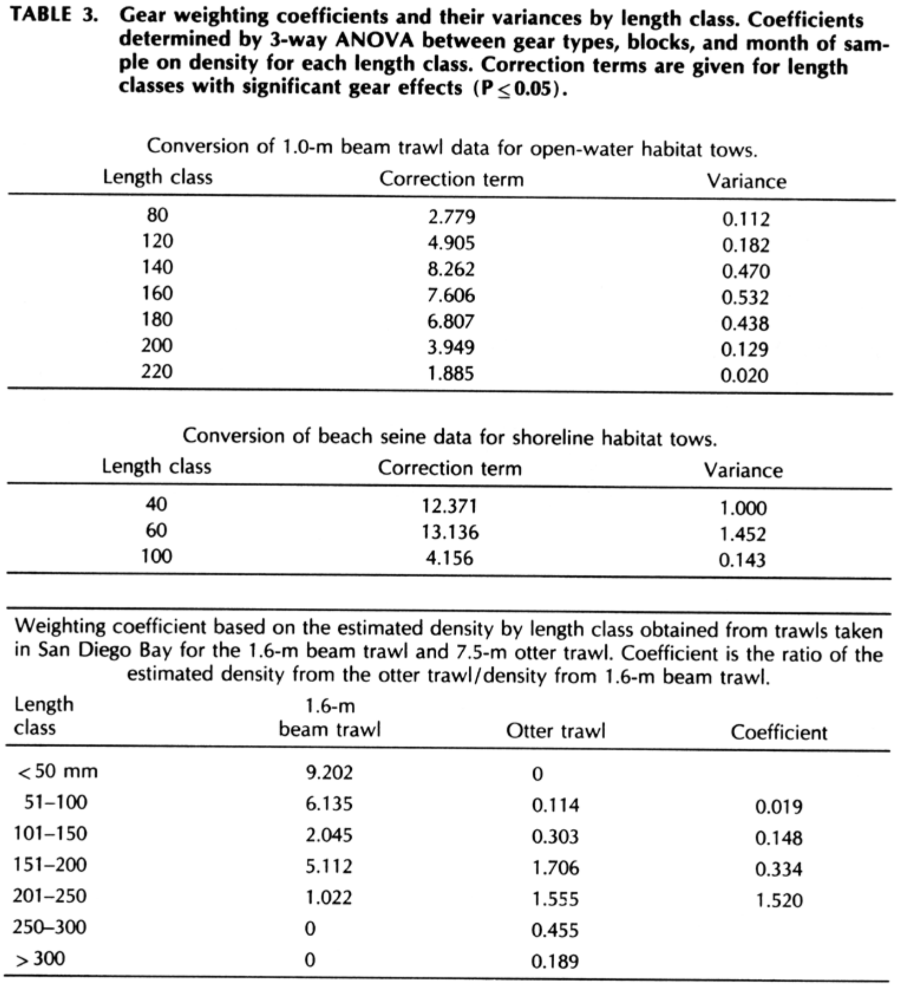

TABLE 3. Gear weighting coefficients and their variances by length class. Coefficients determined by 3-way ANOVA between gear types, blocks, and month of sample on density for each length class. Correction terms are given for length classes with significant gear effects ($P \leq 0.05$).

Conversion of 1.0-m beam trawl data for open-water habitat tows.

Length class	Correction term	Variance
80	2.779	0.112
120	4.905	0.182
140	8.262	0.470
160	7.606	0.532
180	6.807	0.438
200	3.949	0.129
220	1.885	0.020

Conversion of beach seine data for shoreline habitat tows.

Length class	Correction term	Variance
40	12.371	1.000
60	13.136	1.452
100	4.156	0.143

Weighting coefficient based on the estimated density by length class obtained from trawls taken in San Diego Bay for the 1.6-m beam trawl and 7.5-m otter trawl. Coefficient is the ratio of the estimated density from the otter trawl/density from 1.6-m beam trawl.

Length class	1.6-m beam trawl	Otter trawl	Coefficient
< 50 mm	9.202	0	
51–100	6.135	0.114	0.019
101–150	2.045	0.303	0.148
151–200	5.112	1.706	0.334
201–250	1.022	1.555	1.520
250–300	0	0.455	
> 300	0	0.189	

TABLE 3. ***Gear weighting coefficients and their variances by length class. Coefficients determined by 3-way ANOVA between gear types, blocks, and month of sample on density for each length class. Correction terms are given for length classes with significant gear effects (P[<]0.05).***

Temporal and Spatial Variation in Halibut Density

Catch Variability in Time and Space

Density of halibut is variable in both space and time. I tested for differences in variability in space and time using ANOVA on only three size classes—the smallest (20[<]mm), an intermediate length (141–160 mm), and a larger length class (201–220 mm)—assuming that the results obtained for these length classes applied to intermediate length classes. Significant differences in density by month and by block were found for all length classes with no significant difference found for the effect of year on the density of the smallest ([<]20mm) and largest (201–220 mm) length classes (Table 4). Although density was highly variable, it was necessary to combine data in time and space in order to establish important relationships.

TABLE 4. ANOVA of California halibut density on block, month, and year for three length classes: ≤ 20 mm, 141–160 mm, and 201–220 mm.

Source	Length class (mm)	Sum of squares	Mean square	F	df	P
Month	≤ 20	370978	33725	4.43	11, 3269	**
	141–160	12751	1159	2.89	11, 3269	**
	201–220	2911	265	2.03	11, 3269	*
Year	≤ 20	31907	15953	2.10	2, 3269	NS
	141–160	3140	1570	3.91	2, 3269	*
	201–220	300	150	1.15	2, 3269	NS
Block	≤ 20	373278	19646	2.58	19, 3269	**
	141–160	98749	5197	12.96	19, 3269	**
	201–220	17091	900	6.91	19, 3269	**
Error	≤ 20	24881588	7611			
	141–160	1310973	401			
	201–220	425523	130			

** $P < 0.001$

* $P < 0.05$

NS $P > 0.05$

TABLE 4. ***ANOVA of California halibut density on block, month, and year for three length classes: [<]20 mm, 141–160 mm, and 201–220 mm.***

Distribution of Metamorphosing and Newly Settled Halibut

Distribution and abundance of late larval and early juvenile stages of halibut is indicative of preference and suitability of habitat for settlement. Metamorphosing halibut with eyes migrating were between 7 and 11 mm SL; by the time halibut were 12 mm long, eye migration was complete and the fish had acquired juvenile pigmentation patterns ("settlement").

Transforming stages of halibut were captured mostly on the open coast; few were taken in bays (Figure 4). Transforming halibut captured on the coast had larval pigmentation patterns (Ahlstrom et al. 1984) and incomplete eye migration. Almost all of the halibut captured in bays had juvenile pigmentation patterns and complete eye migration. All halibut [<]20mm SL were considered "newly settled" in this study regardless of pigmentation or degree of eye migration.

Density of newly settled halibut differed in time and space over the 2 years of the study. In 1987, newly settled halibut were found primarily in the first and second quarters, while in 1988 most of the settlement occurred in the second and third quarters (Figure 5). Most of the halibut settled in bays in 1987, while in 1988 the greatest settlement occurred along the open coast (Figure 5).

The highest density of newly settled halibut encountered in the 2-year study was in the shallow (depth [<]1m) shoreline habitat in 1987 with the highest mean density for Agua Hedionda Lagoon in March (**x**=368.9/hectare, SD=556.9) and for Mission Bay in May (**x**=84.6, SD=278.2; Figures 6 and 7). The inner block of Agua Hedionda Lagoon had the highest density of newly settled halibut in 1987 (March **x**=919/hectare, SD=1373) and was significantly different from all other shoreline habitats (*F*=2.29, *P* < .0001). Water temperature in the shoreline habitat was warmer than the rest of the bay and the open coast in the time of year that newly settled halibut were found (Figure 2).

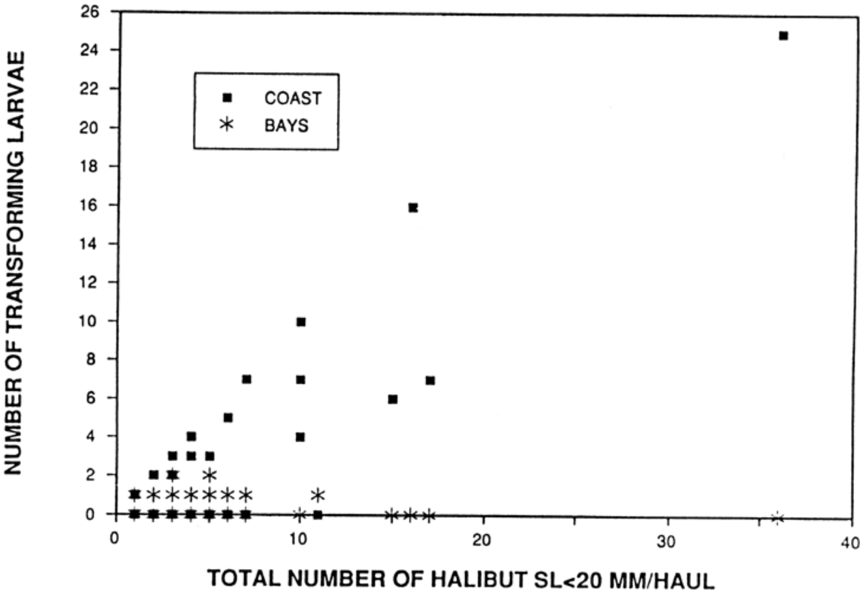

FIGURE 4. Number of transforming larvae of the total number of halibut in the 20-mm length class by haul for bay and open coast habitats.

FIGURE 4. Number of transforming larvae of the total number of halibut in the 20-mm length class by haul for bay and open coast habitats

In 1988, newly settled halibut were found along the open coast with highest densities occurring in the second and third quarters (Figure 5). During this time, the range in monthly mean density of halibut [<]20 mm was highest at Torrey Pines, between 5.9 and 171.3/hectare (SD=8.2 and 252.7, respectively), and lowest at San Onofre (**x**=0 to 16.0, SD=22.8).

Significant differences in the density of newly settled halibut existed between the coastal blocks and between the depth strata within these blocks (ANOVA for blocks *F*=6.19; for depth *F*=7.06; *P* < 0.001). The majority of the halibut settled in the shallowest strata, [<]8 m (Figure 8). The highest density occurred in the shallowest stratum (depth [<]8 m) at Torrey Pines (September **x**=305.0/hectare, SD=278.0); this block is far from any continuously open bay (Figure 1).

Distribution of Juvenile Halibut

Distribution of juveniles by length class can be used to infer movement patterns and ontogenetic changes in habitat preference. Juveniles of 61–120 mm were taken in bays, while halibut > 200 mm were taken mostly on the open coast (Figure 5). Overlap in relative frequency of length classes of halibut taken in bays and on the open coast indicates the timing of their movement out of bays and the length at which this occurs. Juveniles began to move out of bays to the open coast when they were 140 mm long and nearly all had migrated by the time they were 200 mm (Figure 5). Juveniles appeared to reach 200 mm in 9–12 months after they first settle to the bottom (Figure 5).

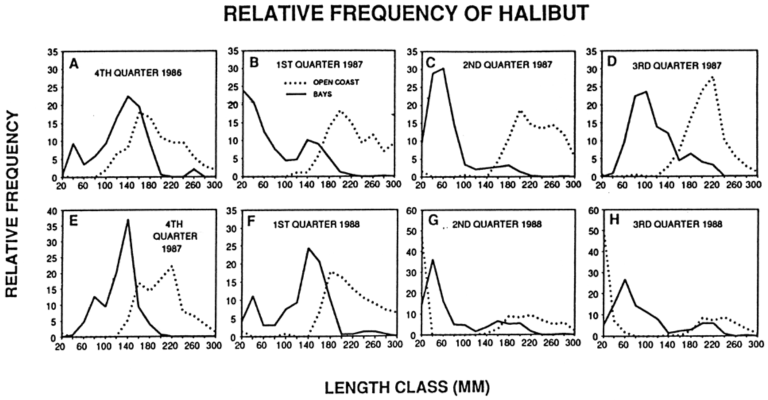

FIGURE 5. Relative frequency of halibut by habitat on the open coast and in bays by quarter. A. 4th quarter 1986; bay $N=138$, coast $N=200$. B. 1st quarter 1987; bay $N=468$, coast $N=87$. C. 2nd quarter 1987; bay $N=806$, coast $N=186$. D. 3rd quarter 1987; bay $N=224$, coast $N=180$. E. 4th quarter 1987; bay $N=127$, coast $N=77$. F. 1st quarter 1988; bay $N=160$, coast $N=123$. G. 2nd quarter 1988; bay $N=335$, coast $N=162$. H. 3rd quarter 1988; bay $N=306$, coast $N=319$.

FIGURE 5. Relative frequency of halibut by habitat on the open coast and in bays by quarter. A. 4th quarter 1986; bay N=138, coast N=200. B. 1st quarter 1987; bay N=468, coast N=87. C. 2nd quarter 1987; bay N=806, coast N=186. D. 3rd quarter 1987; bay N=224, coast N=180. E. 4th quarter 1987; bay N=127, coast N=77. F. 1st quarter 1988; bay N=160, coast N=123. G. 2nd quarter 1988; bay N=335, coast N=162. H. 3rd quarter 1988; bay N=306, coast N=319

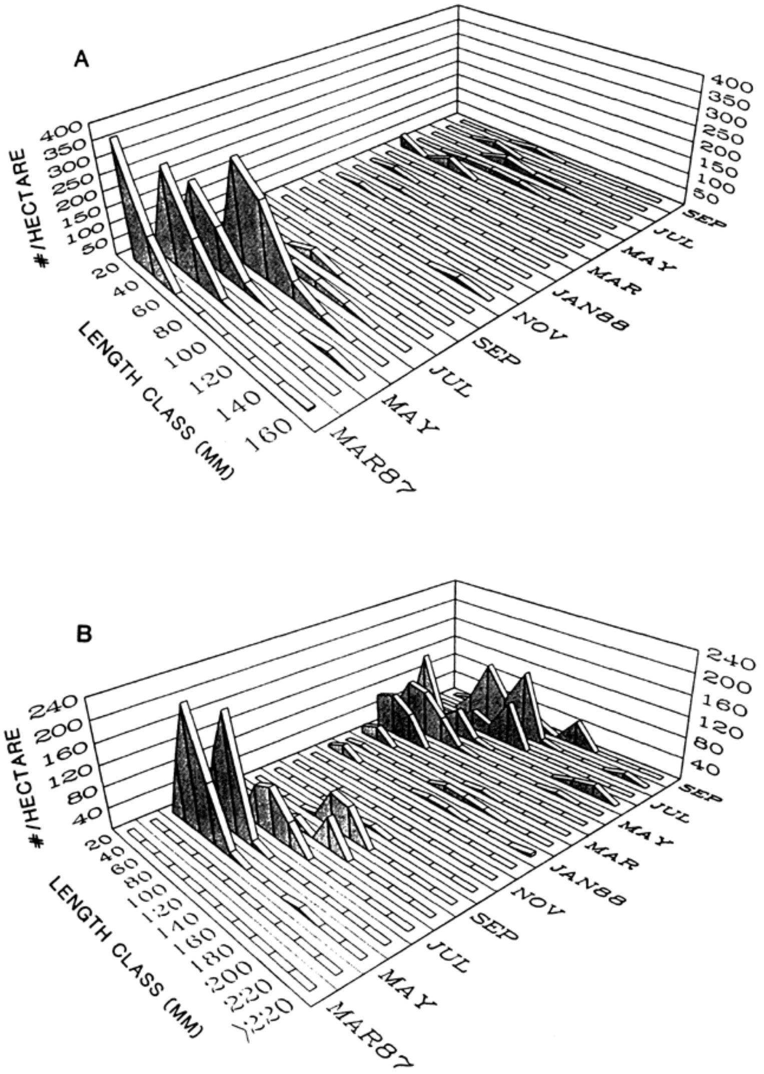

FIGURE 6. Density of halibut in Agua Hedionda Lagoon by habitat type: (a) shoreline, and (b) open water.

FIGURE 6. Density of halibut in Agua Hedionda Lagoon by habitat type: (a) shoreline, and (b) open water

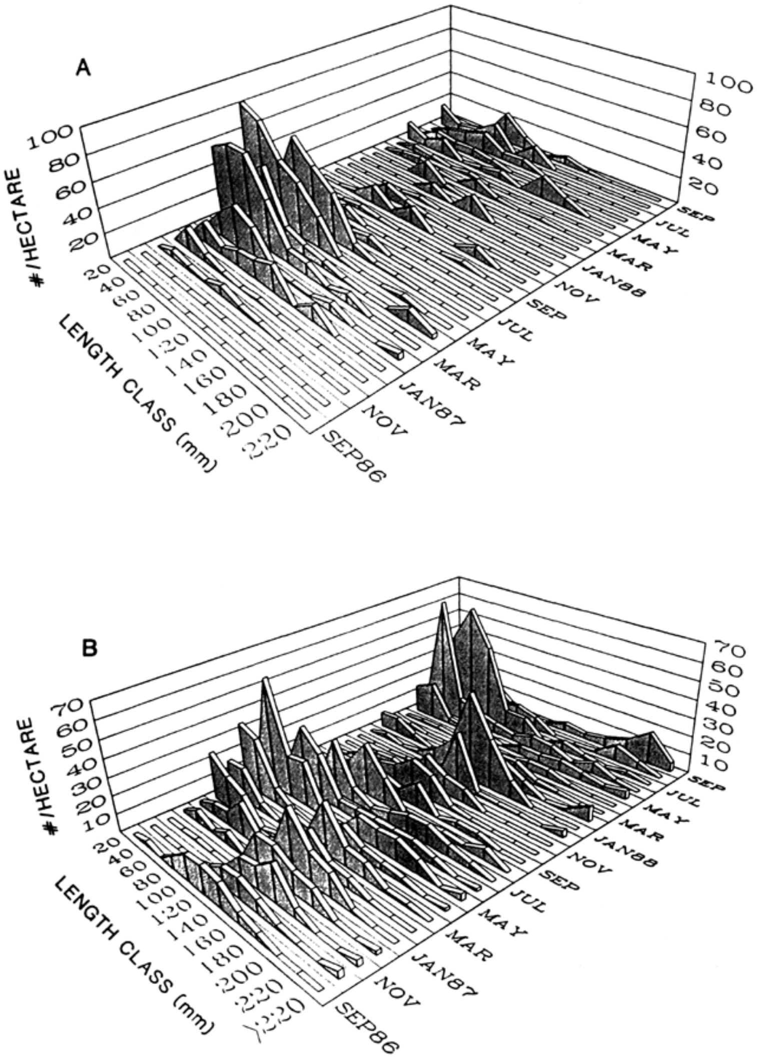

FIGURE 7. Density of halibut in Mission Bay by habitat type: (a) shoreline, and (b) open water.

FIGURE 7. Density of halibut in Mission Bay by habitat type: (a) shoreline, and (b) open water

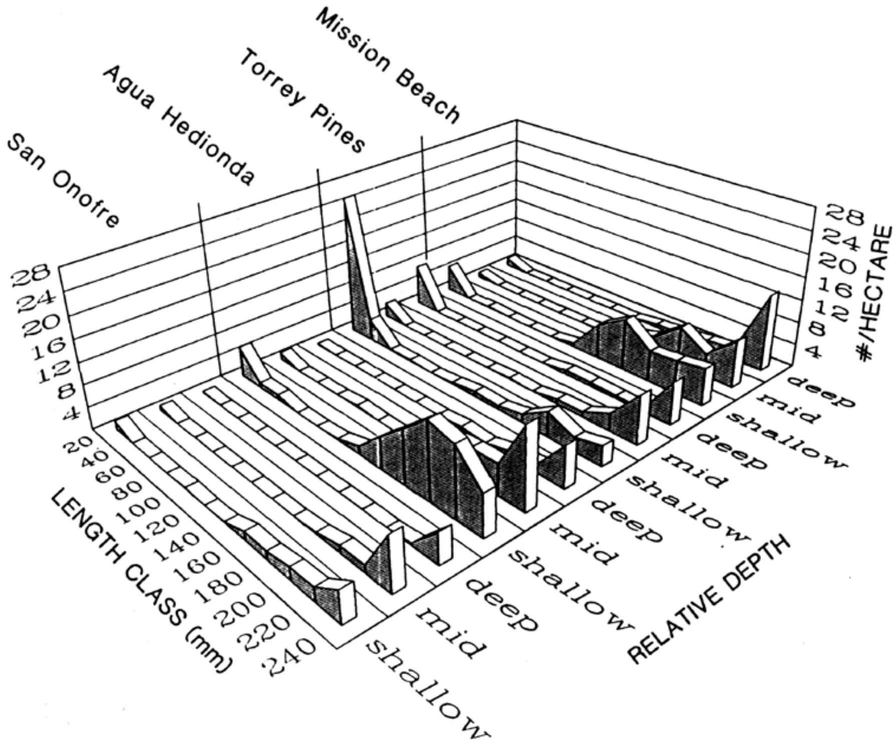

FIGURE 8. Mean density of halibut on the open coast by block and depth stratum. The three depth strata are “shallow” (5–8 m), “mid” (9–11 m), and “deep” (12–14 m). Densities are averaged over the entire sampling period.

FIGURE 8. Mean density of halibut on the open coast by block and depth stratum. The three depth strata are "shallow" (5–8 m), "mid" (9–11 m), and "deep" (12–14 m). Densities are averaged over the entire sampling period

Movement out of bays to the open coast was also indicated by the appearance on the coast of fish between 140–200 mm SL. This trend was most marked at the blocks adjacent to bays; small halibut (< 200 mm) were prominent off Mission Bay and Agua Hedionda Lagoon (Figure 8). Density of halibut (140–220 mm) in the two blocks near bays was significantly different from the two blocks that had no open bay nearby (ANOVA, P < 0.001; Figure 8). For example, the highest densities of all open coast juveniles in the 180-mm length class were at the blocks adjacent to Agua Hedionda Lagoon and Mission Bay ($\mathbf{x}_{AH}$=9.7/hectare, SD=18.0; $\mathbf{x}_{MB}$=9.3, SD=20.7), with lower densities at Torrey Pines and San Onofre ($\mathbf{x}_{TP}$=1.6, SD=6.5; $\mathbf{x}_{SO}$=1.6, SD=5.8; Figure 8).

Relationship Between Fish Size and Depth

Distribution of halibut was correlated with depth for the depths sampled. The relationship between standard length (mm) and depth of capture (m) was: SL = 14.87 x DEPTH + 48.19 (SE slope=0.29, r^2=0.40, *N*=3898; Figure 9).

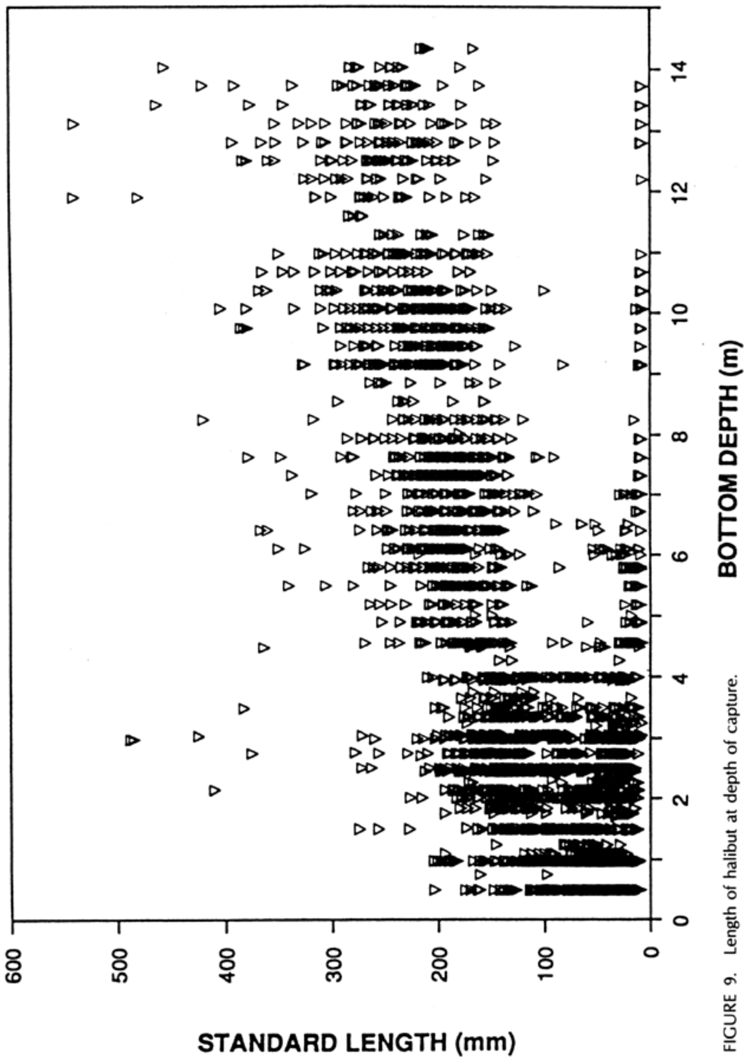

FIGURE 9. Length of halibut at depth of capture.

FIGURE 9. Length of halibut at depth of capture

Several authors have noted that halibut segregate by size on the open coast with larger halibut found in deeper water (Allen 1982; Plummer et al. 1983). Segregation by size was also found in this study with small length classes found primarily in bays (Figure 5). Although newly settled halibut occur in shallower water on the open coast, most halibut between 40 and 100 mm are in embayment habitats.

Density of Juveniles Within Bays

Density of juveniles within bays differed with size and with time of year. Mission Bay and Agua Hedionda Lagoon had the highest densities of small juveniles (21–60 mm SL) found throughout the survey. Density in bays was as great as 10 times that occurring on the coast (Figures 6, 7, and 10). Both bays had high densities of halibut in the shoreline habitat in spring 1987 (highest monthly density of the 60-mm length class in Agua Hedionda Lagoon **x**=322.7/hectare, SD=186.7; Mission Bay **x**=68.4, SD=61.2) with fewer juveniles in this size range in 1988 (Agua Hedionda Lagoon **x**=38.7, SD=39.0; Mission Bay **x**=13.1, SD=12.4; Figures 6 and 7).

of the open-water habitats, density of halibut in the 60-mm length class was highest in Agua Hedionda Lagoon ($\mathbf{x}_{1987}$= 235.2/hectare, SD=237.9; $\mathbf{x}_{1988}$=87.9, SD=79.9) and lower in Mission Bay ($\mathbf{x}_{1987}$=35.9, SD=58.2; $\mathbf{x}_{1988}$=64.0, SD=86.7). No halibut in this length class were found on the open coast in 1987, but in 1988 the density at the Torrey Pines block was **x**=1.9 (SD=6.4; Figure 10). While the shoreline habitat of bays appears to be important both as an initial settling area and as a nursery area for small juveniles, most juveniles greater than 100 mm did not remain in the shallow shoreline but occurred in the open-water habitat (Figures 6 and 7).

The greatest density of juveniles in the open-water habitat of Mission Bay was in blocks 2 and 3. For example, the highest density for the 141- to 160-mm length class from ANOVA (Table 4) was found in the open-water habitat of block 3 in Mission Bay, with a mean of 22.2/hectare (SE=3.6) and a maximum trawl density of 460.8/hectare. In these blocks the bottom was composed of sand and mud interspersed with eelgrass. In the summer and fall, invertebrates settled on the bottom in great abundance; often trawls would fill with either sponges (Tetillidae) or bryozoans (Zoobotryon sp.).

Larger juveniles also tended to occupy the open-water habitats in Agua Hedionda Lagoon (Figure 6). The greatest of juveniles in open water in Agua Hedionda Lagoon was in blocks 1 and 2; these blocks had habitat types similar to blocks 2 and 3 in Mission Bay.

Abundance of Juveniles

Abundance of halibut in different nursery habitats is an indication of the potential production of the habitat. Abundance of juveniles in Mission Bay and Agua Hedionda Lagoon was calculated for open-water and shoreline habitats. In 1987, the shoreline habitats had the highest densities of juveniles < 100 mm SL relative to all other habitats, but because the shoreline is a small area (about 1/7 of the total area of the bay) the standing stock of halibut is lower than in the open-water bay habitat (Figure 11).

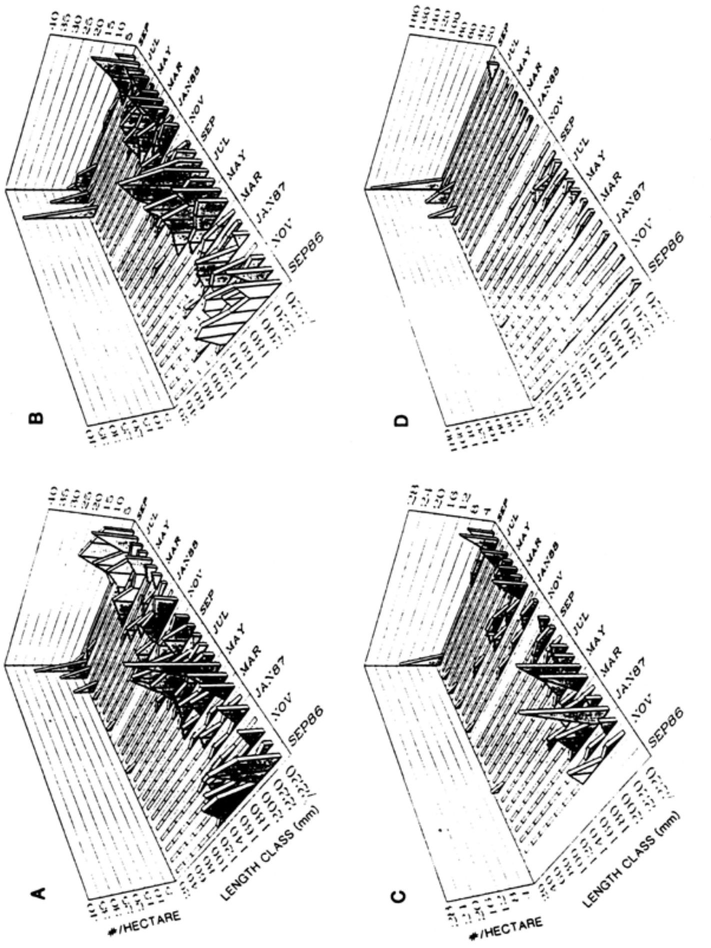

FIGURE 10. Density of halibut on the open coast by block. The blocks are (a) adjacent to Agua Hedionda Lagoon, (b) adjacent to Mission Bay, (c) San Onofre, and (d) Torrey Pines.

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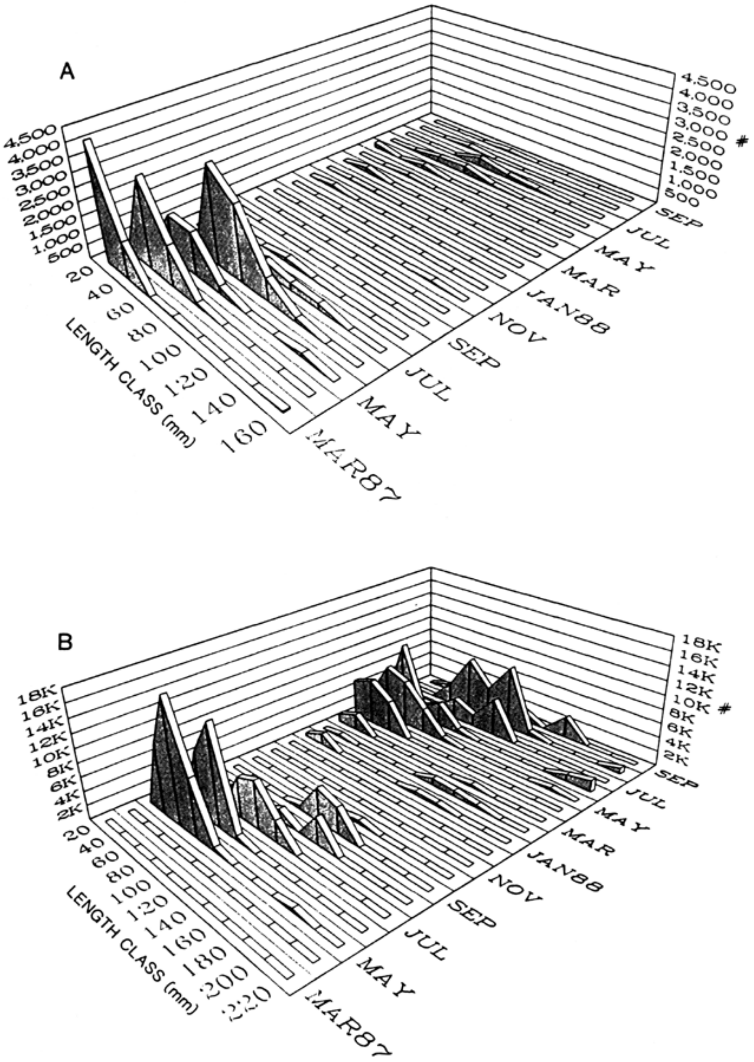

FIGURE 11. Abundance of halibut in Agua Hedionda Lagoon by habitat type: (a) shoreline, and (b) open water.

FIGURE 11. Abundance of halibut in Agua Hedionda Lagoon by habitat type: (a) shoreline, and (b) open water

Abundance of newly settled halibut by habitat and month differed between the 2 years of sampling. In 1987, halibut [<]20mm were most abundant in the open-water habitat of Mission Bay in April (*N*=23,610, SD=41,330) and less abundant in the shoreline habitat of Agua Hedionda Lagoon (*N*=4,170, SD=6,320; Figures 11 and 12). In contrast, newly settled halibut were least abundant in 1988 in both bays with the highest abundance in the Mission Bay open-water habitat in May (*N*=12,210, SD=42,500) and the lowest in Agua Hedionda Lagoon (*N*=190, SD=325; Figures 11 and 12). No settlement occurred on the open coast in 1987, but in 1988 there were 51,290 (SD=77,740) newly settled halibut in May and 92,260 (SD=137,690) in September (Figure 13).

The decline in number of halibut between the 20-mm and 60-mm length classes was greatest on the open coast with numbers dropping from several hundred thousand to nearly zero between May and September 1988 (Figure 13). Halibut settling on the open coast represented the largest standing stock of newly settled halibut ([<]20 mm) observed in this study. However, few halibut of 40–60 mm were taken later in the year after the large settlement, and none had been found in 1987 (Figure 13). Although these length classes were relatively rare on the open coast, in Mission Bay the highest numbers of juveniles occurred in the 40-mm length class with peak abundance in June 1988 of 48,800 juveniles (2 SE=28,390; Figure 12b). By August, the 60-mm length class was most abundant with 25,740 estimated juveniles (2 SE=15,440; Figure 12b).

If halibut are dependent upon bays as nursery areas, then the numbers of halibut leaving bays should be greater than or equal to the numbers appearing on the coast for the length classes that overlap between the bay and the coastal habitats (Figure 5). Indeed, the abundance of halibut in the 140- to 200-mm length classes in Mission Bay was greater than the abundance on the open coast block adjacent to Mission Bay. In 1986, estimated abundance of 140–200 mm halibut in Mission Bay was 79,020 (2 SE=58,810) and 61,750 on the adjacent coastline (2 SE=60,930); estimated abundances in 1987 and 1988 in Mission Bay were 220,370 and 123,320 (2 SE=95,880 and 68,380, respectively) with adjacent coastal estimates of 152,090 and 89,610 (2 SE=95,410 and 53,580 respectively). For each year, the estimated abundance of halibut leaving bays is greater than the numbers found on the coast, suggesting that bays could account for the population of halibut found on the open coast.

The standing stock of juveniles <50 mm SL in San Diego Bay was 13,760 (2 SE=10,880). In comparison, the standing stock of juveniles <50 mm in Mission Bay was 22,080 (2 SE=18,600) and in Agua Hedionda was 10,190 (2 SE=10,190). Thus the standing stock of juveniles in San Diego Bay was less than that in Mission Bay, yet the area of Mission Bay is only about # of the area of San Diego Bay. The abundance of juveniles was much lower than in any of the other habitats surveyed during the same time period (Figures 11, 12, and 13), although the area of San Diego Bay is large (3615 hectares).

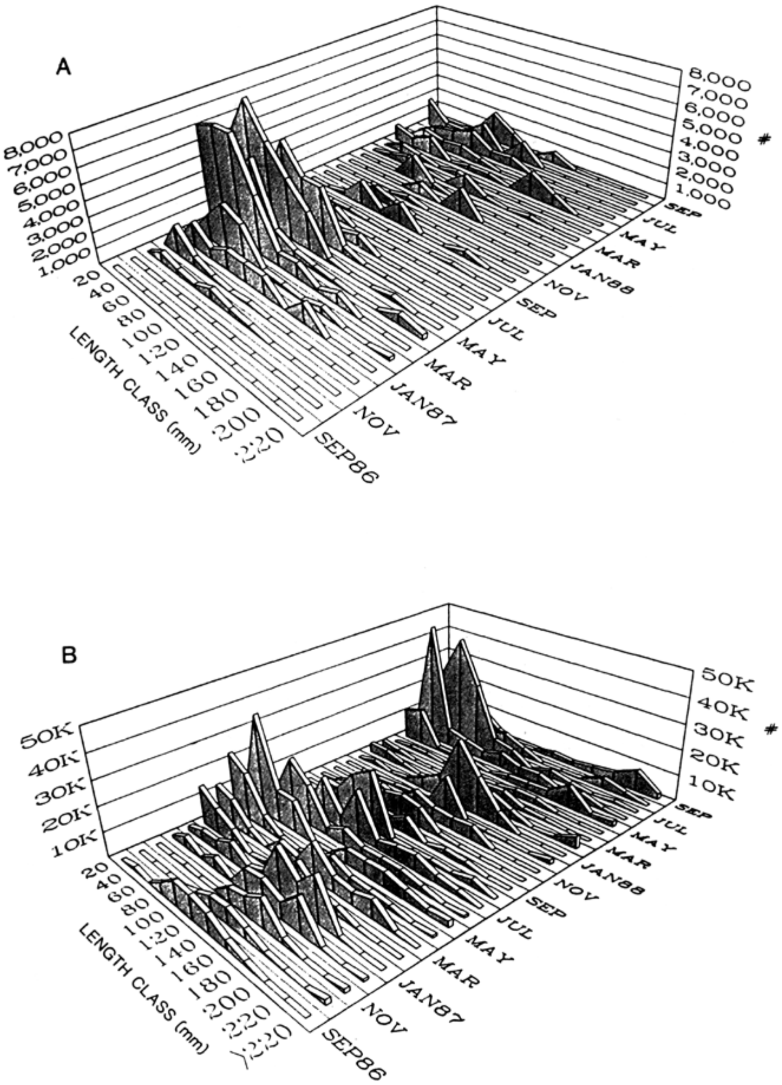

FIGURE 12. Abundance of halibut in Mission Bay by habitat type: (a) shoreline, and (b) open water.

FIGURE 12. Abundance of halibut in Mission Bay by habitat type: (a) shoreline, and (b) open water

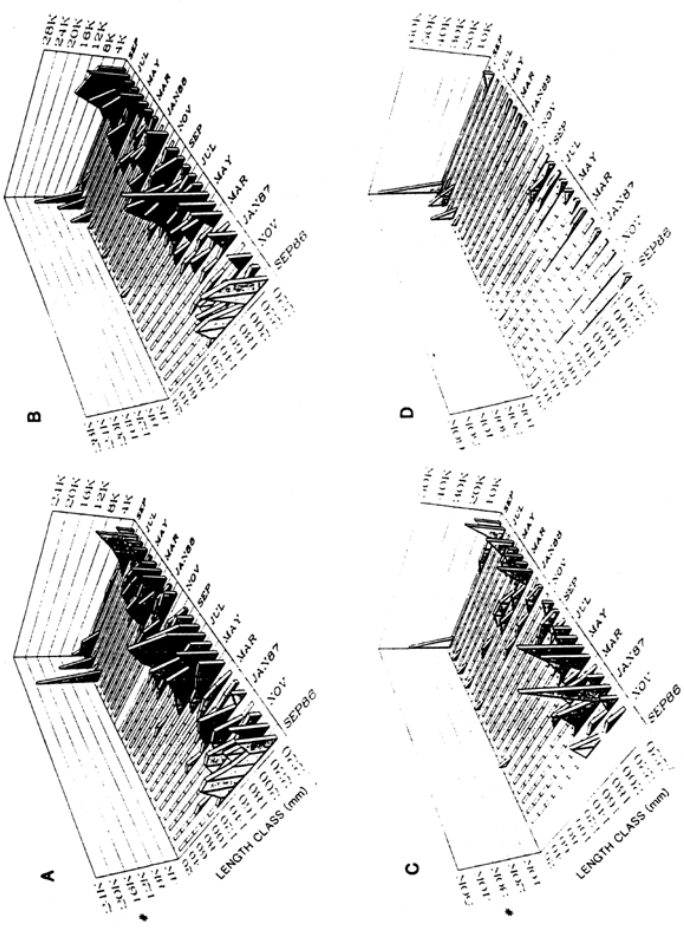

FIGURE 13. Abundance of halibut on the open coast by block. The blocks are (a) adjacent to Agua Hedionda Lagoon, (b) adjacent to Mission Bay, (c) San Onofre, and (d) Torrey Pines.

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DISCUSSION

Adaptive Value of Bays

The advantages of utilizing bays as nursery areas include providing a productive habitat that enhances juvenile growth and increasing survival by separating juveniles from predators that include adults. Adult halibut are mainly piscivorous (Plummer et al. 1983) feeding mostly on northern anchovy, Engraulis mordax, and incidentally on other coastal species including flatfishes (Ford 1965).

This study indicates that bays probably produce enough juvenile halibut to maintain the population on the open coast (Figures 11, 12, and 13). Scanty existing information suggests that halibut can move considerable distances. Tagging data indicate that there is little movement of juvenile halibut within bays before emigration (Haaker 1975), but larger halibut (up to 22 inches) have been recovered up to 140 mi from the release point (Frey 1971). It seems possible that movement of halibut from bays could support the population of larger halibut found on the coast.

The estimated additional area of bay habitat in southern California, excluding the bays studied and Los Angeles Harbor, is at least 800 hectares which is close to the combined areas of Mission Bay and Agua Hedionda Lagoon (Horn and Allen 1976). If the estimates for the abundance of halibut at Mission Bay and Agua Hedionda Lagoon are doubled, this should approximate the potential number of halibut produced annually by bays in the Southern California Bight region. Using this estimate, over 400,000 halibut came from bays in 1987, and nearly 250,000 in 1988. The estimate of annual recruitment of age-1 halibut for California is between 0.45 and 1.0 million fish (Reed and MacCall 1988); the estimates of recruits from this survey and from Reed and MacCall (1988) are reasonably close considering the recruitment estimate is for the entire California coast.

The Fate of Newly Settled Halibut in Coastal Areas

The fate of newly settled juveniles from the open coast in 1988 is uncertain. There are several possible outcomes: 1) they dispersed to deeper coastal habitats; 2) they settled on the coast and were lost because of high mortality; or 3) they first settled on the coast and later move into bays.

It is not likely that juveniles moved to deeper water habitats on the coast, because small juveniles (20–40 mm SL) were found only on the shallowest open coast strata (depth <8 m). If the settlement of halibut on the open coast was lost due to high mortality, then bays must be able to account for the population. If newly settled juveniles migrated from the coast to bays, there should be far greater numbers of intermediate-size juveniles in the 40- to 60-mm length classes then in the smaller size classes (20–40 mm) in the bays.

In bays, there were always fewer halibut in the 20-mm length class than in the 40-mm length class (Figures 11 and 12). The first peak of newly settled halibut (20-mm length class) occurred on the coast in May 1988, and a strong peak in abundance of 40-mm length class juveniles appeared in bays in June (Figures 12 and 13). The lack of <20-mm halilbut in bays and the great decline in abundance of halibut from the 20-mm to the 40-mm length class on the coast suggests that at least some of the halibut in the 40-mm and larger length classes in bays may have been derived from halibut that had settled originally on the coast and then moved into bays as larger (>20-mm) juveniles. English sole (Parophrys vetulus) also settle in bays and along the open coast with subsequent movement into bays (Krygier and Pearcy 1986; Boehlert and Mundy 1987).

An Evolutionary Perspective

Complete dependence on bays as nursery areas by juvenile halibut is not likely, as the existence and quantity of bay and shallow water habitats in the Southern California Bight over time has not been predictable. Pliocene otoliths referred to as P. californicus have been reported (Fitch and Reimer 1967), and Paralichthys antiquus was described from the Miocene (David 1943). Miocene and Pliocene sea levels were considerably higher than present day levels resulting in the formation of many large, shallow, warm embayments along the southern California coast (Vedder and Howell 1979). California halibut evolved in these conditions, assuming that halibut have been in the region since at least the Miocene and that the species has always been shallow dwelling.

On the other hand, Pleistocene glaciation events resulted in dramatic changes with colder water temperatures and sea levels 100 m lower than those of present day (Emery 1967; Vedder and Howell 1979). Lowered sea levels would decrease the area of shelf habitat and perhaps decrease shallow embayment habitats as well. This might have resulted in a decline in the halibut population. In the last 3000 years, the sea level has been near present levels (Emery 1967).

Southern California bay habitats have been considered to be relatively unpredictable with bays open to the ocean only in seasons with high rainfall and closed to the ocean by formation of sand bars across their entrances (Zedler and Nordby 1986). Currently many of the smaller bays in southern California are open to the ocean only when dredged open by removal of the sand blocking the mouth (Warme et al. 1976). The extent of shallow water and bay habitat is additionally decreased by destruction and pollution of these habitats by man.

I conclude that shallow water habitats are utilized as nursery areas by juvenile halibut, and that the amount of available nursery habitat may limit the size of the halibut population. Bay habitats can support a greater density of juvenile halibut than the shallow open coast and are probably the optimal habitats for juvenile growth and survival. The ability to utilize both open coast and bays as nursery areas is an important adaptive strategy in a region where bay habitats can be unpredictable.

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George, Dennis Gruber, Darlene Pickett, David Moser, Wayne Kicklighter, Mark Drawbridge, and many others were invaluable in the field. Richard Charter and Carol Kimbrell provided technical guidance with analysis and management of the database. Roy Allen, Henry Orr, and Ken Raymond assisted in drafting figures. I also thank MBC Applied Environmental Sciences for their support during the preparation of this paper for publication and for the use of the R/V WESTWIND.

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CALIFORNIA HALIBUT, PARALICHTHYS CALIFORNICUS, IN TODOS SANTOS BAY, BAJA CALIFORNIA, MEXICO

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ABSTRACT

A total of 163 California halibut, Paralichthys californicus, was caught from nine trawl stations in Todos Santos Bay, Baja California, Mexico, from August 1986 to July 1987, representing 2.2% of the abundance of all species caught and 16.0% of the total biomass. Average monthly catches per trawl ranged from 0.33 to 2.44 individuals. Significantly more halibut were caught in 8 m than in deeper waters (2.97 halibut per trawl at 8 m versus 0.65 halibut per trawl at 25 m). Total length increased with depth, especially at the central and southern regions. Halibut of ages 1 and 2 years composed 85% of the total catches; in Punta Banda Estuary, halibut of age 0 dominated. The overall sex ratio was 1.0:2.2 F:M; juveniles (28% of the halibut caught) were not macroscopically sexable. Age 3 females were significantly larger than males of the same age; no differences were found between the size at age for ages 1 and 2 males and females. On the average, halibut in Todos Santos Bay grew 0.79 cm per month. No significant difference was found between the length-weight relationship of males and females. Combining our information from Punta Banda Estuary and the icthyoplankton in the bay, the following life cycle can be developed. After spawning, larvae that are transported into the bay settle and move into the estuary where they spend several months of their first year of life. Juveniles quickly leave the estuary during spring and spend the next 2 years of their life in the semiprotected but deeper waters of the bay. After 2 years, halibut begin to move offshore, out of the bay to the deeper waters of the continental platform. Todos Santos Bay and Punta Banda Estuary, therefore, may play an important role in the life history of the California halibut off the northern coast of Baja California.

INTRODUCTION

The California halibut, Paralichthys californicus, Paralichthyidae, is a resource shared by both the United States and Mexico. It is the most valued

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species of the "marine fishes" group in the public fish market of Ensenada, Baja California, Mexico, and is also a major commercial (Barsky 1990) and sport (Helvey 1990) resource in the state of California. In California, commercial landings have been steadily decreasing due to ever-increasing gillnetting pressure and the ever-important sport demand (Barsky 1990). off the Pacific coast of Baja California, however, the commercial fishery is principally hook and line from small boats ("pangas"), and although no data are available, fishing pressure does not appear to be high; there is no sport fishery for this species other than that from privately owned vessels, about which once again there are no data. Escobar-Fernández (1989) reported the total flatfish landings for the state of Baja California during 1980–86 but stated that more than half was landed in the port of San Felipe from the bycatch of the shrimp fishery in the Gulf of California.

In the demersal fish assemblage of Todos Santos Bay, Baja California, the California halibut was found to be fifth in relative abundance and second in weight (Hammann and Rosales-Casián 1990). In Punta Banda Estuary within Todos Santos Bay, on the other hand, juveniles of this species dominated the captures throughout the year (Beltrán-Félix et al. 1986). California halibut larvae were common but not abundant in the ichthyoplankton of the bay (Grijalva-Chon 1985), but were not found in the estuary (Castro-Longoria and Grijalva-Chon 1988), supporting findings in California that spawning does not occur within such bodies of water (Horn and Allen 1981; Leithiser 1981; Zedler and Norby 1986), and that the larvae must migrate into the estuary after metamorphosing (Plummer et al. 1983; Allen 1988).

The life history of this species has been described from several different regions (Frey 1971; Haaker 1975; Plummer et al. 1983). Adults spawn offshore in coastal waters and the larvae settle in the nearshore zone and migrate into the semiprotected and protected waters of bays and estuaries (Allen 1988) where they grow until they return to their offshore habitat 2–3 years later (Haaker 1975). Plummer et al. (1983) suggested that young of the year do not occur in shallow exposed coastal waters; this was confirmed by Allen (1988), although in a short-term study. In California, however, these coastal embayments have been severely impacted in recent years, and Plummer et al. (1983) suggested that in addition to fishing pressure, the effects of man's activities upon the coastal nursery habitats of this species have also contributed to decreased population levels. In contrast, the coastal environment of the Pacific coast of Baja California has undergone relatively little development. It was not until November of 1983 that the first dredging in Punta Banda Estuary began (lbarra-Obanda and Escofet-Giansone 1987), and other than the port of Ensenada and municipal sewage of Ensenada, Todos Santos Bay is still quite clean. This paper reports the results of the first study of California halibut in the protected and semiprotected coastal water habitats of Pacific northern Mexico.

MATERIALS AND METHODS

Study Area

Todos Santos Bay is located at Ensenada, Baja California, about 100 km south of the United States-Mexican border between latitude 31°43' and 31°54' N, and longitude 116°26' and 116°49' W. It has a surface area of about 116 km^2, and about 80% of the bay is less than 50 m deep; the rest forms a deep submarine canyon at the southwest mouth. Todos Santos Bay can be considered a semiprotected habitat, although waves higher than 1 m are often found breaking on the southeast beach. Grijalva-Chon et al. (1985) described an annual cycle of temperature and turbidity characteristics of the bay.

The Punta Banda Estuary is within the bay at its southeast corner. It is L-shaped with a single semipermanent mouth at its upper end. A channel runs along the "L" with depth generally decreasing toward the head rarely exceeding 8 m. The surface area of the estuary ranges from 26 km^2 at high tide to 11 km^2 during low tide. The average width is approximately 345–1100 m, depending on the tidal state. No permanent streams flow into the estuary; water densities are equal to or higher than those of the open sea, and currents are entirely tide and wind driven. Acosta-Ruíz and Alvarez-Borrego (1974) and Celis-Ceseña and Alvarez-Borrego (1975) described the physical and chemical conditions of Punta Banda Estuary. Alvarez-Borrego et al. (1984) reported the temperature and salinity during the 1982–83 fish survey.

Field and Laboratory Procedures

Monthly samples of the demersal fish fauna in the bay were collected between August 1986 and July 1987 from 8-, 15-, and 25-m isobaths at each of three transects perpendicular to the coast (Figure 1). Catches in the bay were made with a 7.5-m headrope semiballoon otter trawl with 19-mm stretched-mesh net body and an 11-mm cod end liner. One tow at each station (total nine) was taken following the isobath for 5 min at 2 knots with a 11.4-m vessel between 0700 and 1500. Labelled samples were placed on ice to be later identified, measured (total length), weighed, and sexed in the laboratory. The sagittae were extracted, cleaned, and later read in glycerin with a stereomicroscope. Age was determined following Haaker (1975); ageing was not validated by other techniques, nor was it intercalibrated with other laboratories.

Data on California halibut in the Punta Banda Estuary, was taken from Beltrán-Félix (1984). Monthly tows were made from November 1982 to October 1983 with a 2.5-m headrope otter trawl with a 19-mm stretched-mesh net body and an 11-mm stretched-mesh cod end. Three replicate 5-min tows were taken in the tidal channel at the estuary's head and central regions from a 4-m vessel with outboard motor at a velocity of approximately 2 knots. All halibut were measured (total length) and weighed. Although the samples taken in the bay were collected 4 years later than those taken from the estuary, in this paper it will be assumed that spatial (bay-estuary) patterns overwhelm temporal variations (year-class phenomena) as influences of halibut numbers and size distributions.

Ichthyoplankton was initially collected from seven stations in the bay from October 1982 to September 1983 (February was not sampled due to bad weather) at 5- and 10-m depths by means of a 505[u] mesh net with a 60-cm diameter mouth; see Grijalva-Chon (1985) for more details. During the 1986–87 juvenile trawl survey, suprabenthic ichthyoplankton was also sampled from the same stations at the north and south transects between 0700 and 1500; data were taken from Almeda-Jáuregui (1989). Collections were made with a

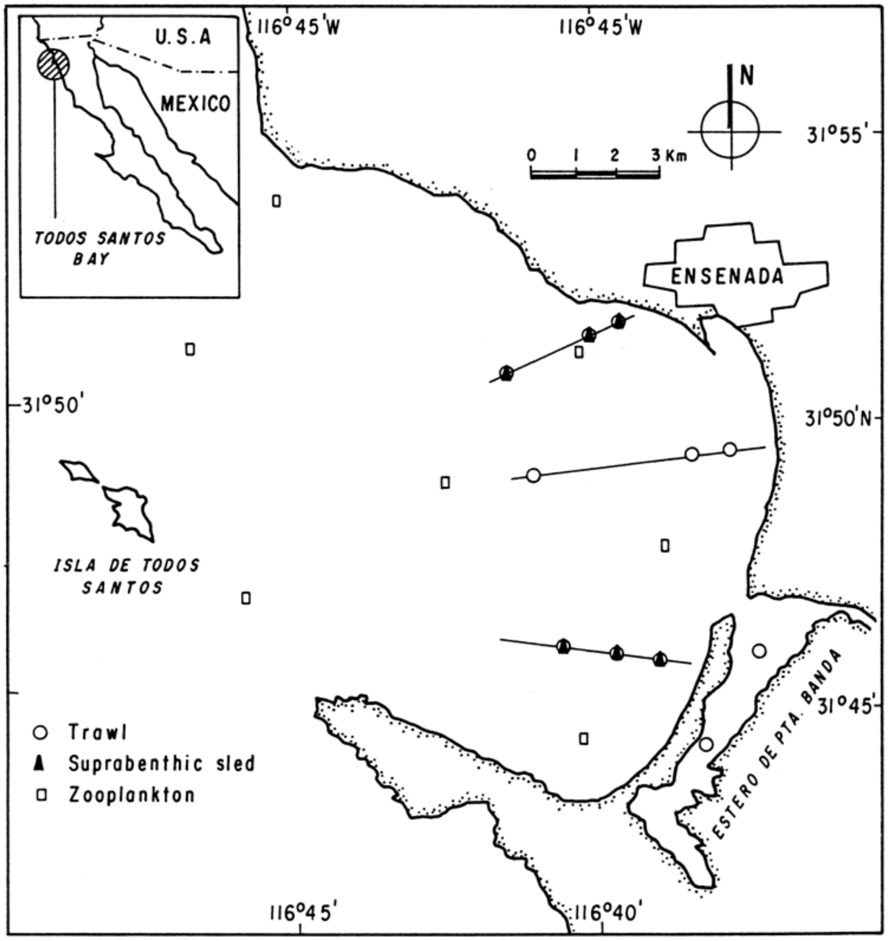

FIGURE 1. Study area and location of sampling sites for the trawl surveys in Punta Banda Estuary and Todos Santos Bay, and the two ichthyoplankton surveys in the bay.

FIGURE 1. Study area and location of sampling sites for the trawl surveys in Punta Banda Estuary and Todos Santos Bay, and the two ichthyoplankton surveys in the bay

suprabenthic sled that held a 505[u] mesh net with a 70x40-cm mouth 10 cm above the bottom (for more details see Almeda-Járegui 1989 and Alfonso-Hernández et al. 1987).

Data Analysis

Abundance data for halibut caught in the bay were standardized to a 5-min tow standard effort. In August, only four stations were sampled and effort was not consistent; these data were normalized to a 45-min monthly total effort by multiplying by 1.125, then standardized to the CPUE of number of fish per 5-min tow. Sample sizes were small, and abundance data were heavily skewed by zero catches and did not fit a normal distribution even after various transformations were attempted. The nonnormal distributions of each data set were, however, similar. To test for differences in abundance at different depths, transects, and months, the nonparametric Kruskal-Wallis (H) test for differences of location in ranked data (Sokal and Rohlf 1981) was used. Length and weight data were normalized with the log transformation, and one-way analysis of variance was applied (Sokal and Rohlf 1981).

The length-weight relationship was determined using nonlinear regression techniques (Saila et al. 1988) with the program "Fishparm," and, for comparative purposes, least-squares nonweighted linear regression of log-transformed length and weight data. Growth is expressed as a linear relation between age in years and total length in centimeters calculated with least- squares nonweighted linear regression.

Because catch data reported by Beltrán-Félix (1984) were the sum of the three replicates at each station, they were standardized to the 5-min tow standard effort by dividing by 3; thus monthly variances could not be calculated. These catch data were successfully normalized by the transformation log (number + 1), and one-way analysis of variance was used to test for significance of the differences between months (Sokal and Rohlf 1981). Monthly length-frequency data were adapted from Beltrán-Félix et al. (1986).

All abundances of halibut larvae were standardized to number of larvae per 100 m^3. These data did not fit a normal distribution, were skewed toward zero, and sample sizes were small. Differences between abundances between months and sampling stations were tested by the Kruskal-Wallis (H) analysis as previously described.

RESULTS

Captures

A total of 163 California halibut (42.2 kg) were caught in Todos Santos Bay. Average monthly catches varied from 0.33 to 2.7 per 5-min tow (Figure 2a) in September and November of 1986, respectively, and in biomass from about 66 in September to 796 g per 5-min tow in February (Figure 2a). The largest catches in weight were observed in February and April (Figure 2a). The number per 5-min tow significantly decreased with depth (H = 13.23, P = 0.001), but not between transects or months (H = 2.68, P = 0.26 and H = 13.71, P = 0.25, respectively; Figure 2b). Total weight per 5-min tow increased from north to south (H = 6.11, P = 0.047), but did not differ among months (H = 13.47, P = 0.26) or depths (H = 5.22, P = 0.073; Figure 2c).

In Punta Banda Estuary, catches ranged from zero to nearly 59 fish per 5-min tow in March 1983 at the central station; a marked increase was observed in March at both stations. (Figure 3). The difference between the monthly catch per 5-min tow was significant (ANOVA P < 0.01). The difference between the average year's catches at the center and head of the estuary was not, however, statistically significant (Student's t = 1.043, P = 0.31).

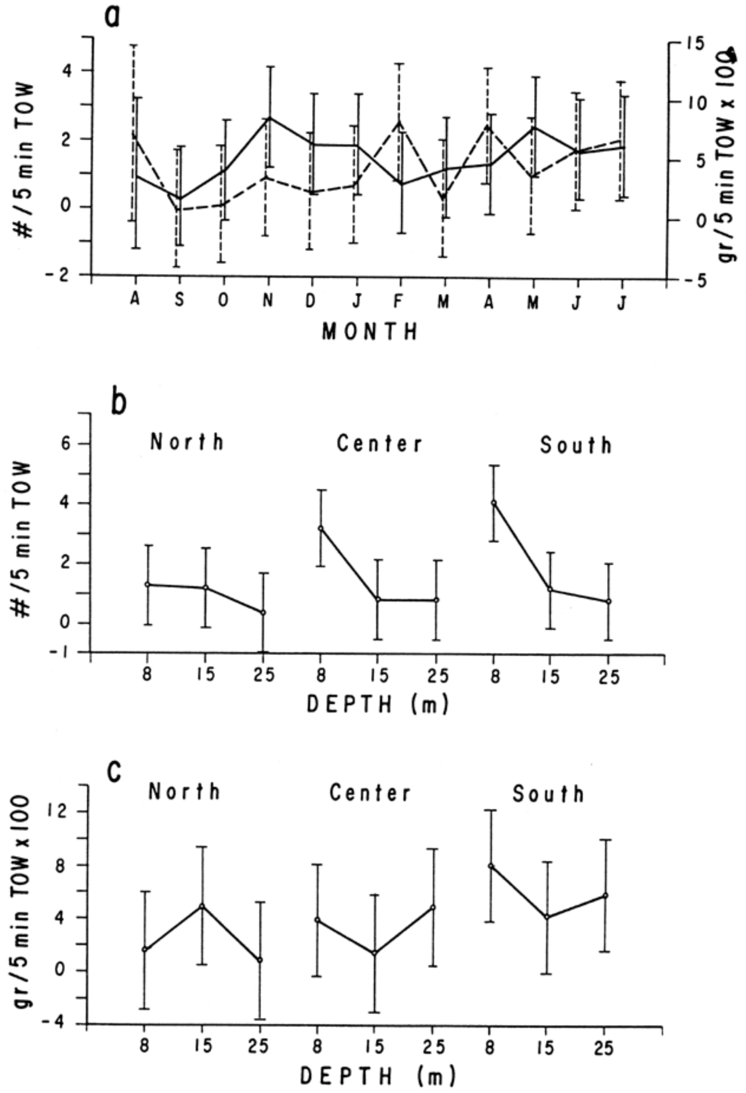

FIGURE 2. Mean CPUE (± 95% confidence interval) of California halibut in Todos Santos Bay during 1986-87: a. by month in number (solid line) and weight (dashed line); b. by depth and transect in number; c. by depth and transect in weight.

FIGURE 2. Mean CPUE (± 95% confidence interval) of California halibut in Todos Santos Bay during 1986–87: a. by month in number (solid line) and weight (dashed line); b. by depth and transect in number; c. by depth and transect in weight

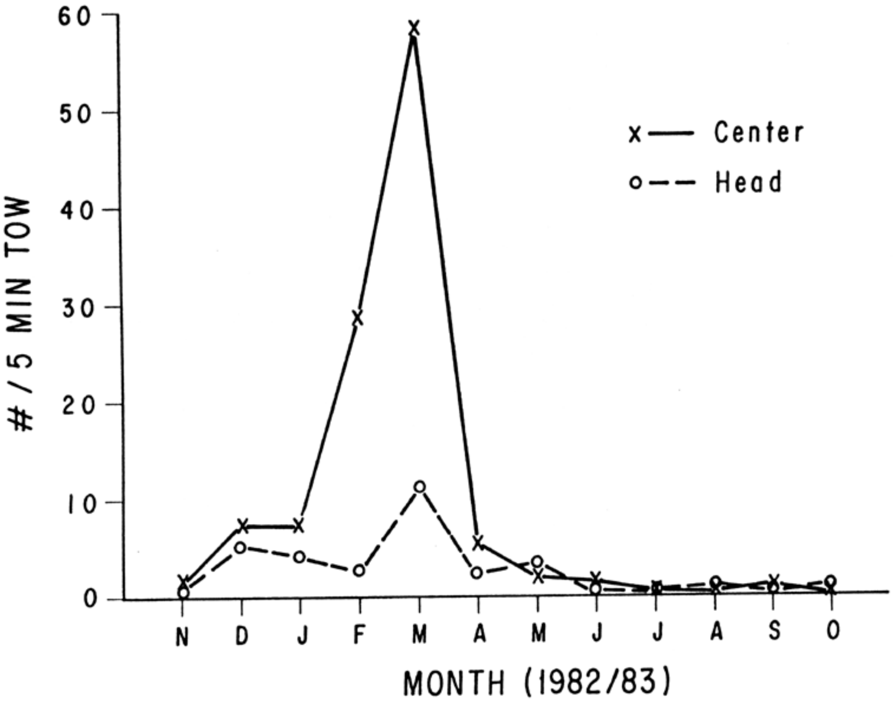

FIGURE 3. Monthly catches of California halibut in Punta Banda Estuary during 1982-83.

FIGURE 3. Monthly catches of California halibut in Punta Banda Estuary during 1982–83

Length

Significant monthly differences in the average total length of California halibut in Todos Santos Bay were observed (ANOVA, $P < .001$). The average total length decreased from August through December 1986, then increased from January through July 1987 (Figure 4a); during this period of increased average size, large monthly fluctuations were observed. Average total length also increased significantly with depth within the bay and from north to south (ANOVA $P < 0.001$ and $P = 0.032$, respectively; Figure 4b).

Percent length frequencies of California halibut in the bay during 1986–87 were compared with those from the estuary during 1982–83. Smaller halibut were caught in the estuary than in the bay; total length of estuary-caught halibut ranged from 10 to 44 cm (**x** = 15.2 ± 5.6 SD), with a mode at 13 cm, while those caught in the bay measured 13.2 to 70.4 cm (**x** = 25.6 + 9.12 SD), with a mode at 25 cm (Figure 5).

Age Structure and Sex Ratio

Age groups 1 and 2 represented 89.1% of the halibut caught in the bay; the largest specimen caught (70.4 cm) was a 7-year-old female (Figure 6). Overall, males predominated in the bay (1.0:2.2 F:M); 28.2% of the specimens collected

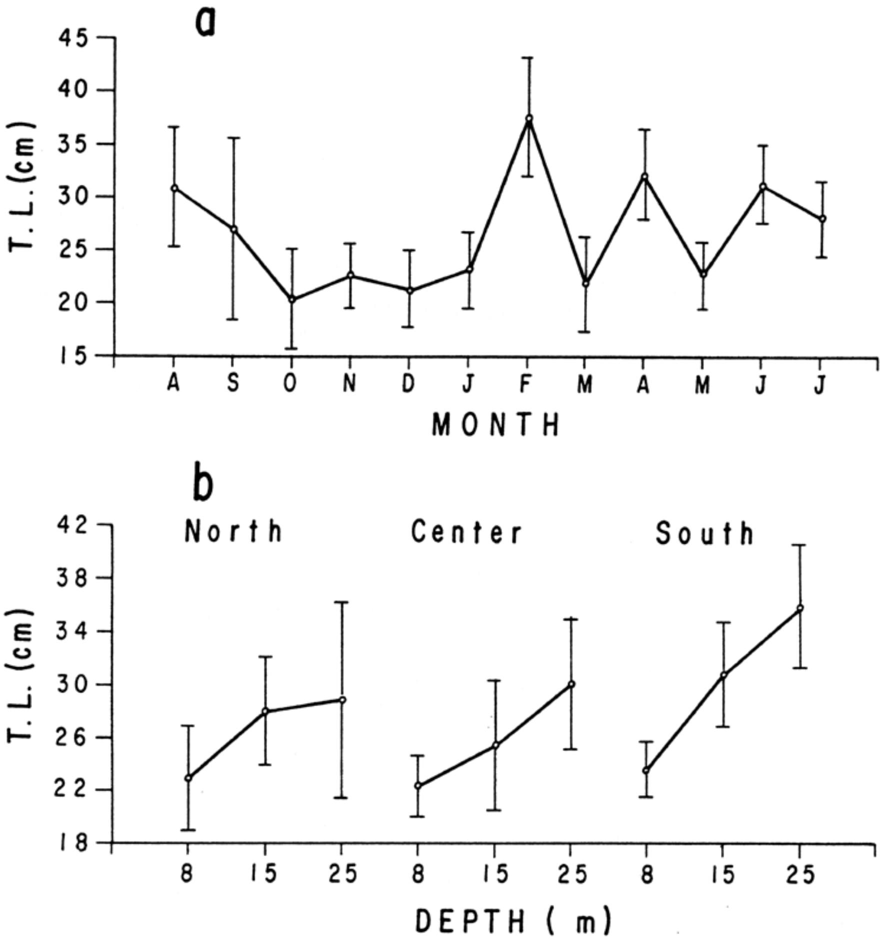

FIGURE 4. Mean total length (± 95% confidence interval) of California halibut caught in Todos Santos Bay during 1986-87: a. by month; b. by depth and transect.

FIGURE 4. Mean total length (± 95% confidence interval) of California halibut caught in Todos Santos Bay during 1986–87: a. by month; b. by depth and transect

were macroscopically unsexable. For those halibut of age groups 3 and older, females were more abundant (Figure 6). Females of age 3 were significantly larger than males of the same age (Student's t, t = 2.65, *P* = 0.02), but no significant differences were found between the size of ages 1 and 2 males and females (Student's t, t = -1.87, *P* = 0.07 and t = 1.43, *P* = 0.16, respectively).

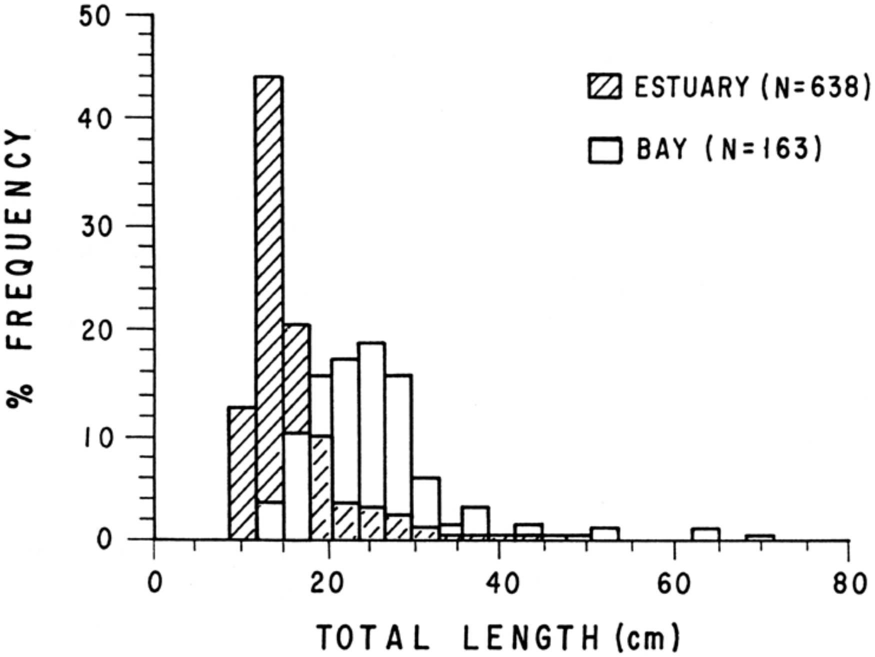

FIGURE 5. Length-frequency distribution of California halibut caught in Todos Santos Bay during 1986–87 (open bars, $N=163$), and in Punta Banda Estuary during 1982–83 (hashed bars, $N=638$).

FIGURE 5. Length-frequency distribution of California halibut caught in Todos Santos Bay during 1986–87 (open bars, N = 163), and in Punta Banda Estuary during 1982–83 (hashed bars, N = 638)

Growth

All data were combined to determine one general growth equation for juvenile halibut in Todos Santos Bay. Growth was best described by the unweighted linear equation $Y = 8.98 + 9.51\ X$ ($r = 0.92$), which represents a growth rate of 0.79 cm per month (Figure 7). The correlation was not improved by removing halibut older than age 3. Average total length for 1-, 2-, 3-, and 4-year-old fish were 18.5, 28.0, 37.5, and 47.0 cm, respectively; using the same relationship, those halibut caught in Punta Banda Estuary were mostly age group 0. On the average, halibut in Todos Santos Bay, reach the California state legal size in just under 5 years.

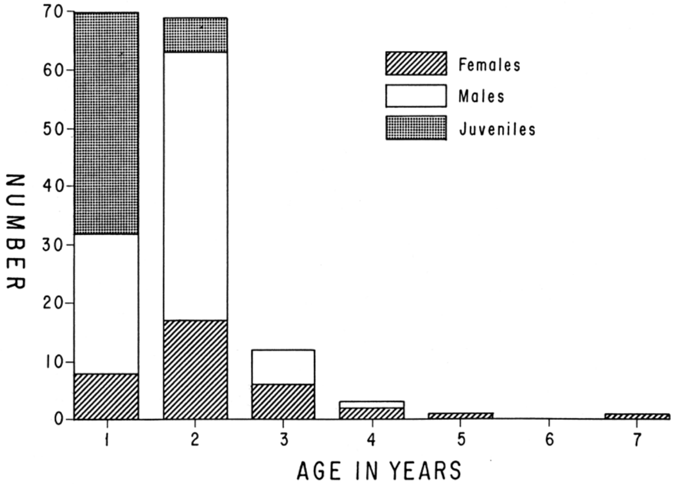

FIGURE 6. Age and sex composition of California halibut caught in Todos Santos Bay during 1986–87. Sex was not determined for juveniles.

FIGURE 6. Age and sex composition of California halibut caught in Todos Santos Bay during 1986–87. Sex was not determined for juveniles

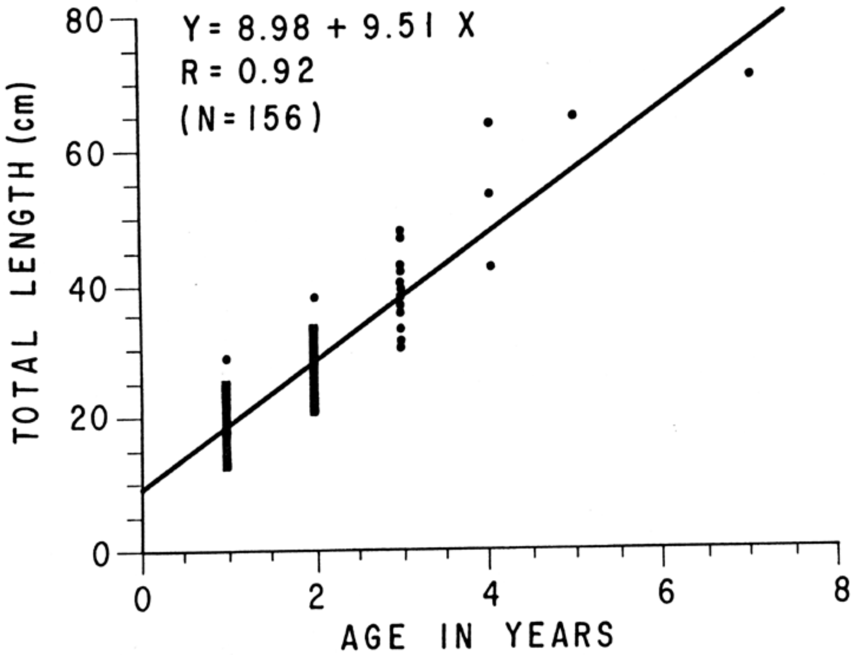

FIGURE 7. Linear regression of total length (cm) on age (years) for all specimens combined of California halibut juveniles caught in Todos Santos Bay during 1986–87.

FIGURE 7. Linear regression of total length (cm) on age (years) for all specimens combined of California halibut juveniles caught in Todos Santos Bay during 1986–87

Length-Weight Relationship

Fish caught in the bay were measured and weighed fresh (*N* = 163), and the curvilinear relationship between length and weight was determined by nonlinear analysis as $W = 3.70 \times 10^{-3} \times L^{3.28}$ (adjusted $r^2 = 0.99$). On the average, a halibut of legal size in Todos Santos Bay would weigh about 2 kg. For comparative purposes with other studies, the log-log length-weight relationship was also determined from least-squares regression to be $W = 9.09 \times 10^{-3}$ x L3.03 (Figure 8). No significant difference was found between the slopes of the length-weight relationships of males and females over a comparable size interval of 18.8–42.2 cm (ANCOVA *P* = 0.70). Females were slightly heavier at length than males, although not highly significantly (ANCOVA *P* = 0.051).

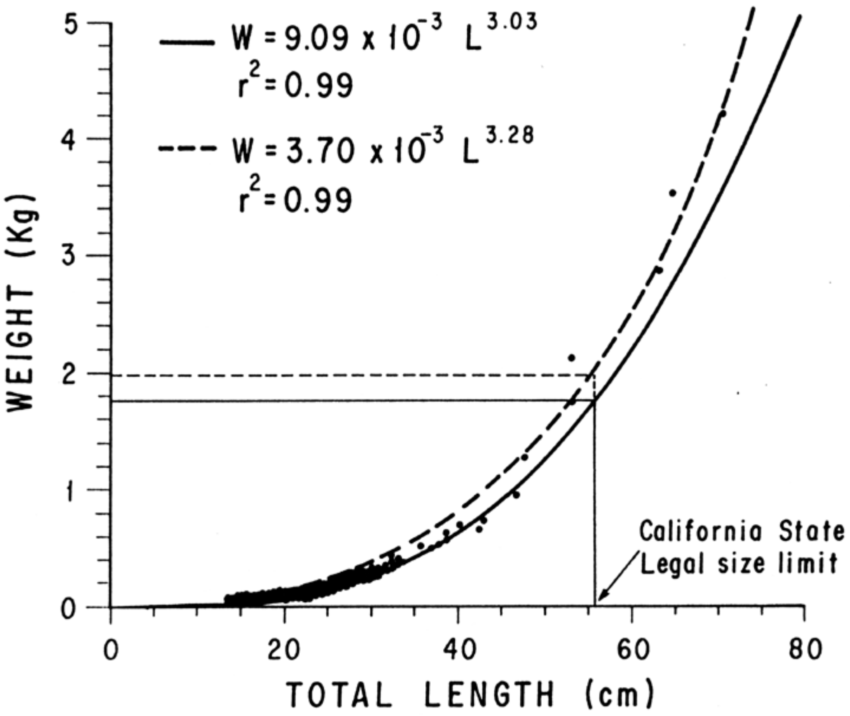

FIGURE 8. Length-weight relationship for California halibut juveniles caught in Todos Santos Bay during 1986–87 (*N* = 156). The predicted weight at the California state legal size is shown. The solid line was determined by linear regression on Log transformed data, and the dashed line by non-linear regression on untransformed data.

FIGURE 8. Length-weight relationship for California halibut juveniles caught in Todos Santos Bay during 1986–87 (N = 156). The predicted weight at the California state legal size is shown. The solid line was determined by linear regression on Log transformed data, and the dashed line by non-linear regression on untransformed data

Larval Abundance and Distribution

In the water column during 1982–83, monthly average abundances of halibut larvae ranged from zero to a maximum of 4.3 ± 9.0 larvae per 100 m^3 in March (Figure 9a); differences between monthly averages were statistically significant (H = 37.06, $P < 0.01$). No significant differences were found between depths (H = 1.52, $P = 0.22$) or stations (H = 5.61, $P = 0.47$).

Near the bottom of the bay during 1986–87, monthly average abundances of mostly post-flexion halibut larvae ranged between zero and a maximum of 19.3 ± 8.9 larvae per 100 m^3 in July (Figure 9b), more than double those found in the water column in previous years. Significant differences in average abundances were found between months (H = 42.59, $P < 0.001$), but not between depths (H = 0.75, $P = 0.69$) or transects (H = 0.55, $P = 0.46$).

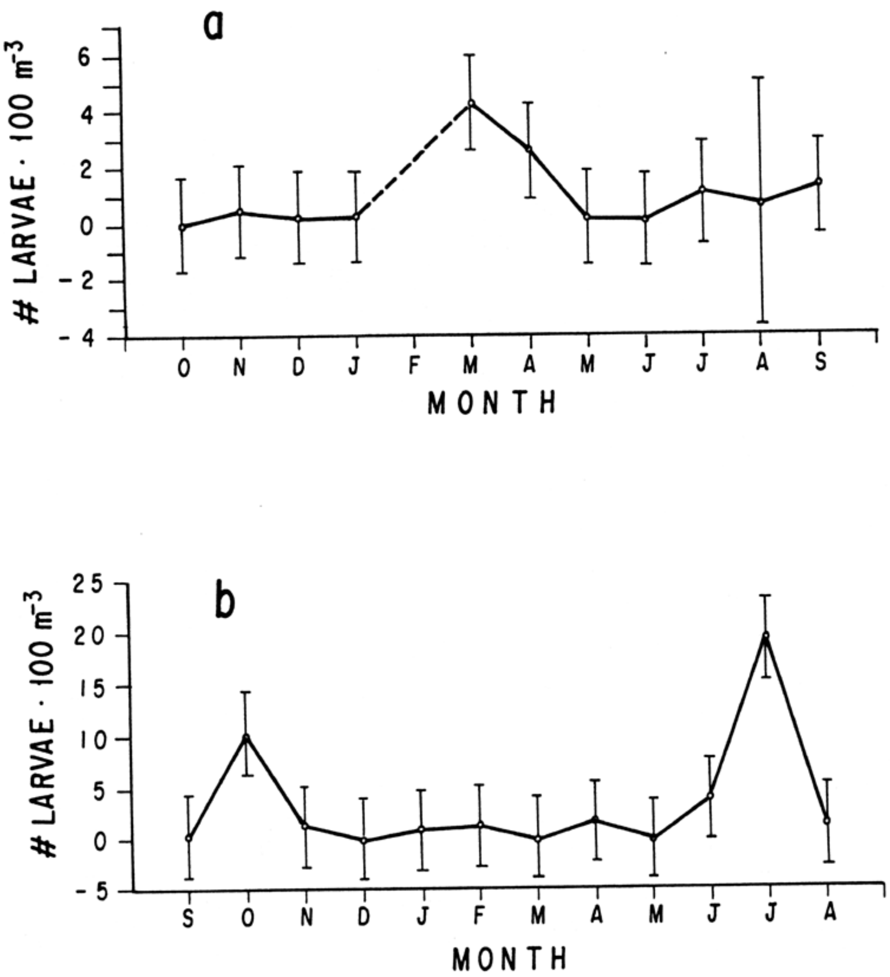

FIGURE 9. Mean (± 95% confidence interval) monthly abundance of California halibut larvae (number of larvae/100m ^{3}) in Todos Santos Bay: a. in the water column, during 1982–83; b. 10–50 cm above the bottom (suprabenthic zone), during 1986–87.

FIGURE 9. Mean (± 95% confidence interval) monthly abundance of California halibut larvae (number of larvae/ 100m ^{3}) in Todos Santos Bay: a. in the water column, during 1982–83; b. 10–50 cm above the bottom (suprabenthic zone), during 1986–87

DISCUSSION

The California halibut is an important species in the nearshore demersal community of Todos Santos Bay, being the fifth most abundant species in the bay, and the most abundant in Punta Banda Estuary located within the bay. Love et al. (1986), for the open-coast nearshore zone of the Southern California Bight, found this species to be the third to seventh most abundant species depending on depth and locality. Average catches per trawl, however, ranged from about 0.2 to 1.4 in the Southern California Bight and from 0.3 to 2.7 in Todos Santos Bay with similar sampling procedures. In Punta Banda Estuary, average catches ranged from zero to about 59 halibut per 5-min tow, with a much smaller net. This greater abundance of juvenile halibut in semiprotected and protected waters suggests the importance of these habitats as nursery areas.

Studying the settlement-recruitment patterns of young-of-the-year (YOY) halibut, Allen (1988) found the greatest abundances in fully protected waters, less in semiprotected areas, and no YOY halibut were found in the fully exposed coastal zone. Kramer (1990a, 1990b) found very little or no settlement by juvenile halibut in the open-coast environment during 1987, but during 1988 increased open-coast settlement was observed, thereby demonstrating the interannual variability of halibut settlement in open-coast versus coastal embayment environments.

In Todos Santos Bay, more juvenile halibut were caught at 8-m depth than at 15 and 25 m (Figure 2b). Love et al. (1986) did not find a clear difference in halibut abundance with depth. Juvenile halibut were also larger at deeper stations and in the southern regions of the bay. However, the lower abundance and smaller size of halibut caught in the northern region of the bay may be due to inferior trawl efficiency in the rocky-sandy substratum.

Although no significant differences were found between the monthly captures of halibut in the bay, a large increase was noted in February and March in the estuary (Figure 3). Because trawls were taken from the central channel in the estuary, the large increase in abundance could represent a movement of YOY halibut from nearby shallow sandy areas into the main central channel in preparation for their exit to the bay. The lack of a peak in the monthly catches in the bay (Figure 2a) is due to the absence of a channel to concentrate the organisms and increase their relative vulnerability to capture. Probably, as juveniles leave the estuary, they disperse as they enter the bay.

The decrease in average size of juvenile halibut caught in the bay during March may represent the movement of small halibut from the estuary into the bay (assuming data from different years can be compared); an overall increase in length was observed from October (Figure 4a). The proximity of the estuary to the southern region of the bay may also contribute to its greater abundances of juvenile halibut. During 1987, more halibut larvae were found in the suprabenthic zone near the mouth of the estuary than in the northern area. Castro-Longoria and Grijalva-Chon (1988) reported the absence of halibut larvae in Punta Banda Estuary.

Considering the findings of Kramer (1990a, 1990b) and Allen (1988) of less settlement on the exposed coast, it may be that larvae seek out the Punta Banda Estuary, where they spend part of their first year of life, and then move into the bay during spring. Alvarez-Sánchez et al. (1988) found that on the average, the input of water at the two entrances of the bay generates two currents parallel to the southern and northern coasts which converge adjacent to the mouth of Punta Banda Estuary. This circulation pattern may assist settling halibut larvae in entering the estuary.

Most of the juvenile halibut caught in Todos Santos Bay were 1 or 2 years old; judging from the growth curve calculated from fish caught in the bay (Figure 7), those caught in the estuary were mostly young of the year. As has been reported in other studies for other regions (e.g. Haaker 1975), the growth coefficient of juvenile halibut in Todos Santos Bay was near 3.00, and older females were found to be larger at age than males. In Anaheim Bay, however, little or no difference was found between the length-weight relationships of males and females (Haaker 1975). Because an underestimation of the slope in the length-weight relationship was found when derived by linear regression, nonlinear estimation is recommended.

Males in Todos Santos Bay dominated the first two year classes; the largest and oldest specimens caught in the bay were all females. In Anaheim Bay (Haaker 1975), and in the nearshore area off San Onofre (Plummer et al. 1983), males were also found to dominate juvenile to subadult fish. Females were found to dominate the sex ratio in the commercial captures of California (Sunada et al. 1990) due to increased selectivity for the female's larger size and faster growth rate. In Punta Banda Estuary, however, females dominated over males and a sex ratio of 1:1.68 M:F was reported (Navarro-Mendoza 1985). We suggest that the dominance of females in the estuary is due to their slower maturity rates (Frey 1971; Haaker 1975), and that males migrate to the bay earlier than the females, leaving them behind in the estuary. This would also explain the dominance of males in the bay.

In conclusion, the following life cycle for the California halibut in the vicinity of Todos Santos Bay can be described. Spawning occurs offshore and larvae are transported into the bay, settle, and move into Punta Banda Estuary where YOY spend the first several months of life. First male, then female, juvenile halibut leave the estuary during spring to spend the next 2 years in the semiprotected but deeper water of Todos Santos Bay. After 2 years, halibut begin to move out of the bay into the deeper waters of the continental platform. The Todos Santos Bay-Punta Banda Estuary system, therefore, may play an important role in the life history of the California halibut off the northern coast of Baja California. Due to the clear importance of protected and semiprotected habitats in the life history of this species, the necessity of careful coastal management may be paramount for the future success of this species in the Californias.

ACKNOWLEDGMENTS

The great efforts of the many people who cheerfully labored in the field and laboratory over the years, especially J.A. Rosales-Casián, J. Sidón-Pérez, M. Diaz-Lucero, M.A. Medina-Rodríquez, and R. Vásquez-Yoemans are very gratefully acknowledged. M. Grijalva-Chon and R. Castro-Longoria are thanked for their extensive work collecting and analyzing the 1982–83 ichthyoplankton, and C.O. Almeda-Jáuregui for his work with the suprabenthic ichthyoplankton. The studies reported here were funded by the Mexican Secretaría de Programación y Presupuesto. R. Rosenblatt, J.R. Hunter, and an anonymous reviewer are thanked for their very helpful comments and suggestions on the manuscript. We thank C. Haugen for his careful editorial revision.

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RESEARCH NOTE

OPEN COAST SETTLEMENT AND DISTRIBUTION OF YOUNG-OF-THE-YEAR CALIFORNIA HALIBUT (PARALICHTHYS CALIFORNICUS) ALONG THE SOUTHERN CALIFORNIA COAST BETWEEN POINT CONCEPTION AND SAN MATEO POINT, JUNE–OCTOBER, 1988[1]

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An understanding of the settlement process of young-of-the-year (YOY) California halibut, Paralichthys californicus, is essential for the effective management of adult stocks. Based on previous studies (e.g. Haaker 1975) and unpublished data from various sources, Plummer et al. (1983) proposed that YOY halibut occur primarily in embayments along the California coast and not in shallow coastal waters. This proposal has been corroborated by recent studies in certain areas of the southern California coastline (Kramer and Hunter 1987; Allen 1988). Allen (1988) found that, in the Long Beach area of southern California, the greatest densities of YOY halibut occur in protected habitats (bays and estuaries). Semi-protected environments (e.g. harbors and, possibly, leeward sides of points and islands) contained YOY halibut but at densities of one-half to one-quarter of those in protected habitats. In addition, settlement at semi-protected sites generally occurred later in the year than in embayments. Prior to 1987 our studies had captured only one YOY halibut in exposed, open-coast stations in both the Alamitos and San Onofre-Oceanside areas in over 75 trawls (0.44 individuals/hectare). The single, 35-mm standard length (SL) specimen was captured at San Onofre in the 3- to 6-m depth range (Allen 1988). Kramer and Hunter (1987, 1988) also found YOY halibut along the open coast but in extremely low densities (0.6/hectare in 1987 and 11–28/hectare in 1988).

Newly settled halibut ranged from 8 to 12 mm SL and were probably about 30 d old (Allen and Jensen, unpublished data). For this study, we set the

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[1] Contribution No. 59 to the Ocean Studies Institute.

maximum size of YOY at 80 mm SL based on Allen (1988). However, recent data indicates that growth rates of halibut in their natural environments may be much faster than originally thought. The size of a halibut at 1 year of age may be greater than 80 mm SL.

A trawl survey of YOY white seabass, Atractoscion nobilis, along the open coast from Point Conception south to San Mateo Point funded through the Ocean Resource Enhancement and Hatchery Program (OREHP) afforded a great opportunity to also examine recruitment and distribution of YOY California halibut along the open coast.

Sixteen stations (Figure 1) were sampled along the coast of the Southern California Bight between Point Conception and San Mateo Point in each of the 5 months of June–October 1988 on the following dates: 13–17, 23–24 June; 8, 11–15 July; 14–18, 25–26 August; 3–7, 20–21 September; and 3–4, 13–17 October. At each station, four replicate 5-min tows were taken with a 1.6-m beam trawl (2-mm mesh) at each of two depth strata, 5 m and 10 m, from two 5.6-m skiffs launched from the R/V YELLOWFIN. The YELLOWFIN, owned and operated by the Ocean Studies Institute of the California State University, served as our base of operation. Calibration tows using a meter wheel indicated that a 5-min tow covered an average of about 183 m of bottom making the mean area of coverage about 293 m^2. Density estimates in this report are based on this estimate of trawl area coverage. The sampling strategy of this survey yielded 128 tow samples in each month and 640 tows overall.

At each station, temperature, salinity, dissolved oxygen, and pH were monitored at the surface and bottom of both depth strata. Depth, bottom profiles, and potential snags were monitored using depth sounders mounted on each skiff. Loran fixes were taken at the beginning and end of each replicate tow. For each tow, the weight of drift algae and debris was determined by use of a hanging metric scale.

The majority of catch data was entered into project databases on board ship with a laptop computer. Halibut data was subsequently tabulated and analyzed on desktop computers.

A total of 164 YOY ([<]80mm SL) and 54 newly settled ([<]12mm SL) halibut were captured from June to October 1988. The majority (74%) of newly settled were taken in July. Seventy-nine percent of the YOY halibut were captured at the 5-m depth stratum.

Density estimates for all YOY halibut ranged from 4.0 individuals/hectare in October to 14.9/hectare in September (Table 1). Overall density of YOY halibut over the entire study was 8.7/hectare. Densities of newly settled halibut were lower ranging from 0/hectare in October to 10.6/hectare in July. Population estimates along the 300 km of habitable coastline over the 5 months varied from 35,959 YOY (0 newly settled) in October to 100,700 YOY (95,892 newly settled) in July. Integration over the 5 months yielded an overall population estimate for the open coast of only about 78,660 YOY and 25,891 newly settled halibut. This estimate seems low for a nearshore, egg-broadcasting species of fish.

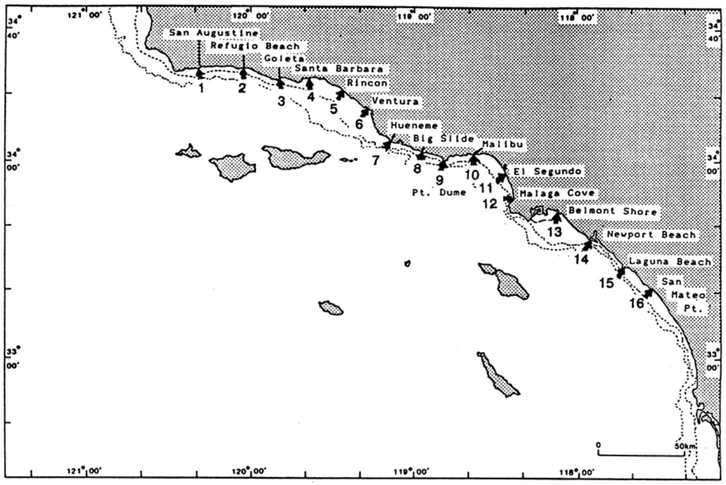

FIGURE 1. Location of the 16 beam trawl stations sampled each month from June to October 1988 from near Point Conception south to San Mateo Point, California.

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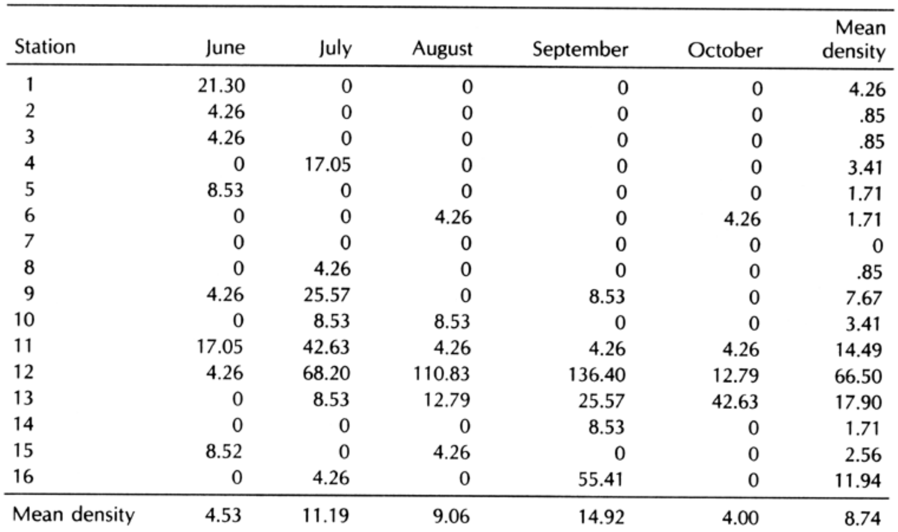
TABLE 1. **Estimated densities (number/hectare) of young-of-the- year California halibut at 16 stations from near Point Conception to San Mateo Point, June–October 1988.**



Station	June	July	August	September	October	Mean density
1	21.30	0	0	0	0	4.26
2	4.26	0	0	0	0	.85
3	4.26	0	0	0	0	.85
4	0	17.05	0	0	0	3.41
5	8.53	0	0	0	0	1.71
6	0	0	4.26	0	4.26	1.71
7	0	0	0	0	0	0
8	0	4.26	0	0	0	.85
9	4.26	25.57	0	8.53	0	7.67
10	0	8.53	8.53	0	0	3.41
11	17.05	42.63	4.26	4.26	4.26	14.49
12	4.26	68.20	110.83	136.40	12.79	66.50
13	0	8.53	12.79	25.57	42.63	17.90
14	0	0	0	8.53	0	1.71
15	8.52	0	4.26	0	0	2.56
16	0	4.26	0	55.41	0	11.94
Mean density	4.53	11.19	9.06	14.92	4.00	8.74

TABLE 1. ***Estimated densities (number/hectare) of young-of-the- year California halibut at 16 stations from near Point Conception to San Mateo Point, June–October 1988.***

Most (71%) of the YOY halibut were captured at only three of the 16 stations: EI Segundo (station 11; *N* = 17), Malaga Cove (station 12; *N* = 78), and Belmont Shore (station 13; *N* = 21; Table 1; Figure 2). Malaga Cove alone accounted for almost 48% of all YOY and 37% of the newly settled halibut.

In June, only five newly settled fish were collected (Figure 2). All were taken in southern stations 11, 12, and 15 where the warmest temperatures were encountered. By July, relatively heavy settlement was observed as far north as Point Dume (station 9) with the greatest concentrations of fish occurring off EI Segundo (station 11) and Malaga Cove (station 12). These two stations had the highest mean temperatures over the study period (Figure 3). About 74% of all newly settled fish were captured in July (Figure 2). By August, the numbers of newly settled halibut captured had fallen off sharply. Settlement of halibut appeared to be over by September. YOY halibut densities were greatest from July through September, particularly at Malaga Cove (Figure 2).

The most striking change in any of the physical-chemical parameters monitored during the 5 months of the survey occurred with temperature (Figure 3). Both surface and bottom temperatures were relatively low in June at all stations with the highest temperatures found in the southernmost stations. The temperatures increased dramatically in July at all stations except station 1. Surface and bottom temperatures increased about 4–5°C per station between June and July. During August through October, temperatures dropped off slightly at most stations by about 1–2°C. The heaviest and most widespread settlement of YOY halibut occurred in July at the time of this striking rise in coastal temperature within the study area. Temperature, particularly bottom temperature, was significantly and positively correlated with the abundance

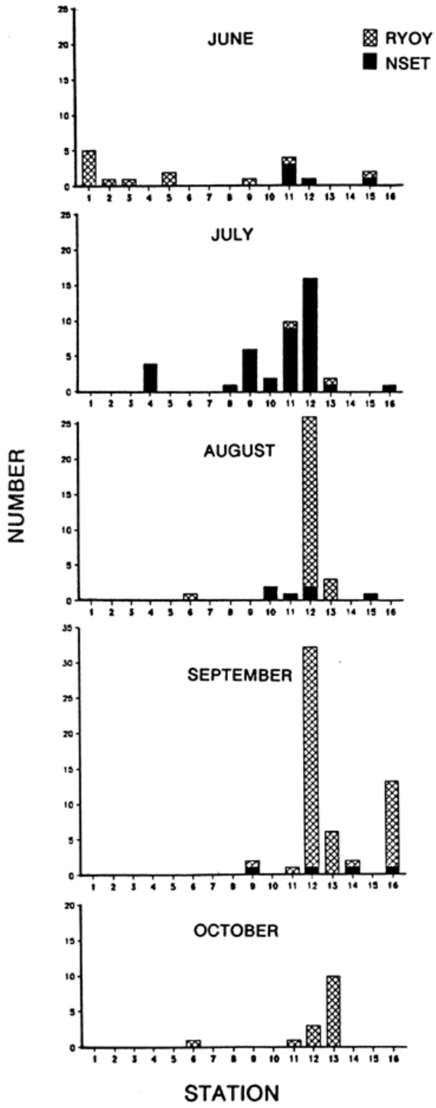


FIGURE 2. Distribution of newly settled (≤ 12 mm SL) and of remaining (13–80 mm SL) YOY California halibut among the 16 stations along the southern California coast, June–October 1988.

FIGURE 2. Distribution of newly settled ([<]12mm SL) and of remaining (13–80 mm SL) YOY California halibut among the 16 stations along the southern California coast, June–October 1988

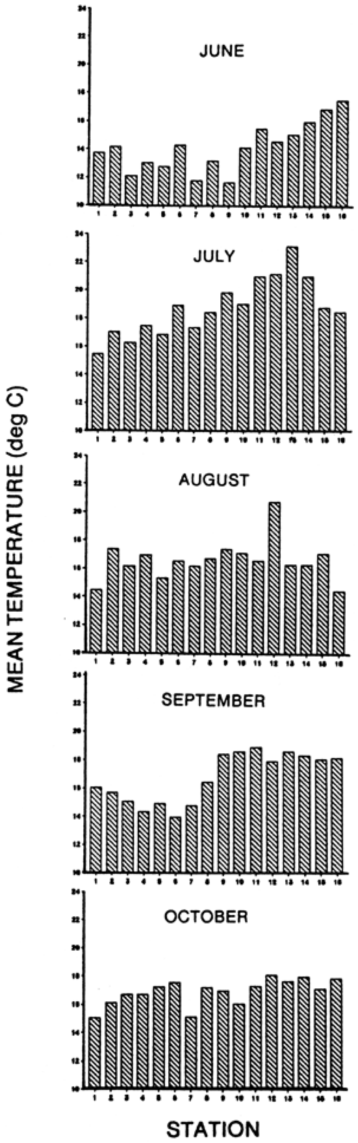


FIGURE 3. Mean bottom temperatures (°C) of all 16 stations by month, June–October 1988.

FIGURE 3. Mean bottom temperatures (°C) of all 16 stations by month, June–October 1988

(log[x + 1]) of both newly settled YOY (r = 0.365; df = 78; $P < 0.0001$) and all YOY (r = 0.337; df = 78; $P < 0.0001$). These correlation models explained 13% ($R^2 = 0.13$) of the variance of newly settled and 11% ($R^2 = 0.11$) of the variance in all YOY halibut. There is little doubt that a relationship existed between temperature, particularly bottom temperature, and settlement and subsequent distribution of YOY halibut. The identification of other influential environmental factors awaits future multivariate analyses.

Satellite infrared imagery photographs for this time period indicated that a large, warm-water mass moved north along the southern California coastline in early July 1988. This phenomenon probably accounted for the sudden rise in temperature, and may also have accounted for the increased settlement if this water mass contained a large supply of larval halibut from more southerly waters.

Halibut inhabiting the southern California coastline are probably north of their main center of abundance in most years. The seemingly low densities of YOY halibut may reflect sporadic, unpredictable settlement success over the course of a breeding year. Successful settlement, at times, may rely heavily on the northward transport of eggs and larvae from the central populations of halibut off Baja California.

The vast majority of YOY halibut ranged from 8 mm to 20 mm SL. The low proportion of larger YOY in the catches indicates that our sampling method may be biased toward smaller, slower fish. Halibut > 20 mm SL seem capable of evading our nets with greater regularity than smaller fish.

Low densities of YOY halibut on the open coast are not surprising since halibut occur in greatest abundance in bays and estuaries in the Southern California Bight (cf. Allen 1988). The mean density of YOY halibut in Alamitos Bay over the 3-year period of 1983–85 was high at 321/hectare (Table 2). The overall density along the coast in 1988 was less than 3% of the density estimate from Alamitos Bay. Overall density of YOY at Malaga Cove was approximately 66/hectare, much higher than the open coast as a whole. Halibut density at Malaga Cove was about 21% of the mean density found in the shallow waters of Alamitos Bay.

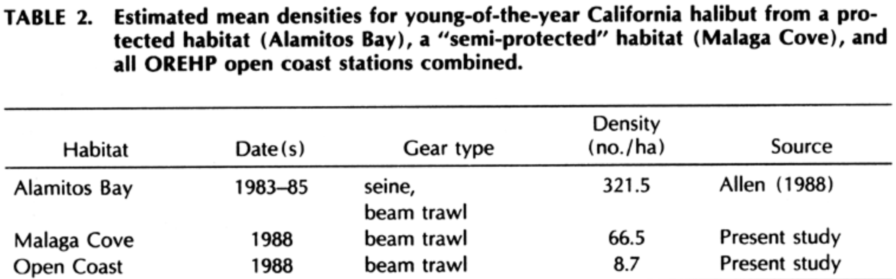


TABLE 2. Estimated mean densities for young-of-the-year California halibut from a protected habitat (Alamitos Bay), a "semi-protected" habitat (Malaga Cove), and all OREHP open coast stations combined.

Habitat	Date(s)	Gear type	Density (no./ha)	Source
Alamitos Bay	1983–85	seine, beam trawl	321.5	Allen (1988)
Malaga Cove	1988	beam trawl	66.5	Present study
Open Coast	1988	beam trawl	8.7	Present study

TABLE 2. ***Estimated mean densities for young-of-the-year California halibut from a protected habitat (Alamitos Bay), a "semi-protected" habitat (Malaga Cove), and all OREHP open coast stations combined.***

Even though open coast YOY halibut densities are low, these areas may represent important nursery habitat for halibut based simply on the large size of this habitat in southern California. Low densities can convert to a large population size if the habitat area is large enough. For example, a low density of newly settled young of 2.88/hectare becomes 25,891 when the total area of habitable mainland coast, estimated at 9000 hectares, is considered. Bays and estuaries contain the highest densities of YOY halibut but are very small and few in number in southern California (about 10% of coastline; Kramer 1990). If halibut populations are completely dependent on bays and estuaries as nursery grounds, their populations may be in trouble since about 90% of the bays and estuaries in southern California have been severely altered or destroyed by human activities. Kramer (1990) concluded that the ability of juvenile halibut to utilize both open coast and bays as nursery areas represents an important adaptive strategy in this region where bay habitats are rare and unpredictable.

We gratefully acknowledge the help given by the numerous field assistants on this rather demanding research program. They include: Jan Cordes, Dominique Evans, Michael Franklin, Carlos Herrera, Steve McGee, Robert Scott, Jodie Smith, Phyllis Travers, Alison Wolgast, Lisa Wooninck, and James Wolf. Without their consientious assistance the sampling could not have been accomplished. We also thank the crew of the R/V YELLOWFIN, Jim Cvitanovich, Dan Warren, and Dennis Dunn for their expertise and advice. The data on California halibut was collected as part of a larger trawl study funded by the Ocean Resource Enhancement and Hatchery Program administrated by the California Department of Fish and Game. We thank the department and, especially, Steve Crooke for the opportunity to work on recruitment of nearshore marine fishes in southern California.

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JUVENILE CALIFORNIA HALIBUT, PARALICHTHYS CALIFORNICUS, GROWTH IN RELATION TO THERMAL EFFLUENT

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ABSTRACT

Three size classes of young California halibut, Paralichthys californicus, were held for 8.5 months to compare growth under two laboratory treatments: ambient temperature seawater alone and ambient mixed with power plant thermal effluent. Total-length growth rates in both treatments were similar to published values for estuarine inhabitants, but less than the rates predicted from an age and growth study based on offshore commercial and sport fishery catches. Estuarine halibut populations, however, demonstrated allometric weight:length relations that differed from isometric relations of published data on offshore halibut populations. Conditions associated with thermal effluents from California coastal power plants did not inhibit growth. Like other predatory fishes, California halibut may congregate near warm discharge areas for metabolic advantages.

INTRODUCTION

In California approximately 10.6 billion gallons of seawater are pumped daily through coastal-sited electric generating stations to condense steam. Discharging waste heat as a thermal effluent has raised serious concern about damaging or altering the nearshore environment (Cairns 1971). This concern has resulted in strict regulatory measures and considerable research on the effects of discharging thermal effluent.

In this work I contrast growth and survival of juvenile California halibut, Paralichthys californicus, exposed to power plant discharge and ambient seawater temperatures. The results may help clarify the effect of man-induced alterations of natural habitat during a sensitive life stage of the California halibut.

METHODS AND MATERIALS

During October and November 1976, California halibut were captured at Agua Hedionda Lagoon, Carlsbad, California (northern San Diego County) in 5-to 10-min trawls using a 2-m semiballoon otter trawl with a cod end of 20-mm stretch mesh. Long-term growth studies were conducted between 11 December 1976 and 27 August 1977, a 259-d period, at the San Diego Gas & Electric Company's Encina Power Plant Biology Laboratory in Carlsbad, California (Van Olst et al. 1976).

Juvenile halibut (100–350 mm TL) were distributed randomly to two open system fiberglass aquaria ([245 x 110 x 76cm, = 1900 l]) supplied with flowing, filtered seawater. Preventive measures to control disease and parasitism included prophylactic treatments with Nitrofurazone at 150–300 mg/L (Golden State Medical Supply Company) and/or seawater diluted formalin (0.1–0.2 ml/L), which were flushed after 1 h. Live and frozen northern anchovy, Engraulis mordax, and live adult brine shrimp, Artemia salina, were fed ad libitum to large (> 120 mm TL) and small (< 120 mm TL) halibut, respectively.

After the fish began to feed, one experimental group of 35 individuals was acclimated from approximately 15 to 22°C at a rate not exceeding 1°C/d. Seawater temperature was controlled by a pneumatic, Teflon-coated mix valve and epoxy-coated pressure-proportioning thermostat (Innis 1980). Source waters from the ambient lagoon and power plant effluent were blended to maintain approximately constant temperature. The proportion of effluent and ambient water varied constantly, depending upon the thermal conditions of the source waters. Thus, temperature averaged 22.0 ± 1.5°C (mean ± standard deviation) which corresponds to typical conditions in the Encina Power Plant thermal plume a short distance from the point of discharge. In a similar treatment, 34 fish were supplied seawater at ambient temperature which averaged 19.4 ± 1.8°C and varied with season between 15 and 24°C (see Figure 1).

Every 30 to 40 d, halibut were anesthetized (MS 222, 1:15,000, 67 mg/L for 5 to 10 min depending on size and weight), measured to the nearest millimeter total length, and weighed (blotted wet weight) to the nearest 0.1 g. Growth data were recorded as each fish's size, weight:length ratio (condition factor), position of the eyes (either sinistral or dextral), and morphological anomalies such as the extent of blind side ambicoloration. No tags were used, because Haaker (1971) found that tagged P. californicus grew at only one-half the rate of untagged halibut.

To account for differences among fish at the experiment's outset, halibut growth data were divided into three size categories, small (0–159 mm), medium (160–249 mm), and large ([>]250 mm), based on the growth regression equation determined by Haaker (1971, 1975). These groupings correspond closely to ages of 0–12 months (Age 0+), 12–24 months (Age 1+), and 24+ months (Age 2+), respectively, for California halibut reported by Haaker. Halibut weight:length ratio was calculated by Fulton's condition factor equation: $\mathbf{CF = W / TL^3 \ X \ 10^5}$ where **CF** = Condition factor, **W** = Body weight (grams), and **TL** = Total length (millimeters).

The cubed length, indicative of isometric growth, was used in condition factor calculations because the slope of the growth curve for juvenile California halibut was calculated to be 3.088 (Haaker 1971).

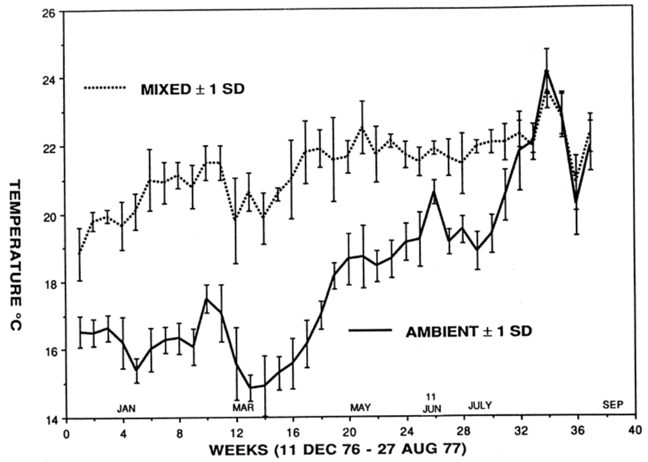

FIGURE 1. Laboratory temperature conditions presented as weekly means ± 1 standard deviation.

FIGURE 1. Laboratory temperature conditions presented as weekly means ± 1 standard deviation

Growth data (**TL, W, CF**) were analyzed for differences among treatments and size groups using two-way ANOVAs (Dixon 1975) in which the sums of squares were calculated using a generalized linear model procedure for unbalanced designs (Snedecor and Cochran 1967; Searle 1971; Barr et al. 1976). For significant ($P < 0.05$) ANOVAs, Duncan's multiple range test was used for *a posteriori* comparison of means (Zar 1974). Survival analysis followed life table methods described by Deevey (1947) and Cox (1967).

RESULTS AND DISCUSSION

Growth differed significantly among size classes, but not between treatments for all size classes (see Figure 2; Table 1). Small and medium halibut grew at rates between 103 and 109 mm and 80 and 150 g/year based on least squares regression. Large halibut increased in size at rates between 16 and 46 mm and 40 and 128 g/year. Small halibut held at ambient temperature shrunk in size (lost 6.6 mm and 18 g/year) and died before the experiment ended.

Combined halibut size classes grew slightly faster than rates determined by Haaker (1971, 1975; Figure 3). At these rates, under either treatment, it would take about 5.4 years (65 months) for the average California halibut to reach legal size (558.8 mm, 22 inches) for capture by fishermen. Haaker's estimate of growth rate for P. californicus inhabiting Anaheim Bay, California was equivalent to 90.2 mm/year—66 months to reach legal size. Compared to published growth rates, these are faster than those reported by Clark (1930, 1931), similar to Kramer's (1990) estimate of 120 mm/year, and slower than determined by Frey (1971) and Schott (Hulbrock 1974) for males and females (Figure 3). The variety of growth rate estimates in these studies may be related to habitat differences.

Ontogenetic growth rate variation, described as growth stanzas (Ricker 1975), is indicated by changes in weight:length ratios or as sudden changes in growth rate. Haaker (1971) and Kramer (1990) reported that halibut inhabit estuaries as young but emigrate to the nearshore open coast at a size of 150 to 200 mm. Emigration from an estuary to the open coast could be responsible for the differences in growth rates presented by Hulbrock (1974). Growth estimates of estuarine inhabitants are based on the younger California halibut populations and do not incorporate age-growth relations of older individuals.

Fish growth is described by the equation: $\mathbf{W = a \times TL^{b}}$ where **a** = constant, and **b** = the coefficient of increase in length relative to weight. When **b** equals 3.00, fish are growing at an isometric rate indicating that body proportions are unchanging (Ricker 1975). Isometric growth for California halibut was determined by both Haaker (1971, 1975; **b** = 3.088) and Hulbrock (1974; **b** = 3.048). However, laboratory growth in this study yielded coefficient **b** values that were allometric; 3.29 in ambient alone and 3.40 for the mixed treatment. This indicates that weight increased faster than in the isometric

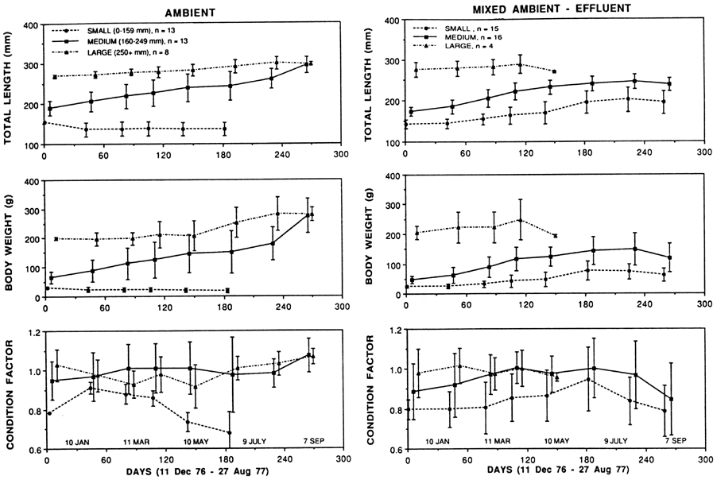

FIGURE 2. California halibut growth, mean ± standard deviation, for total length (TL), wet body weight (W), and condition factor (W/TL ^{3} × 10 ^{5}) under ambient and mixed ambient-effluent temperatures.

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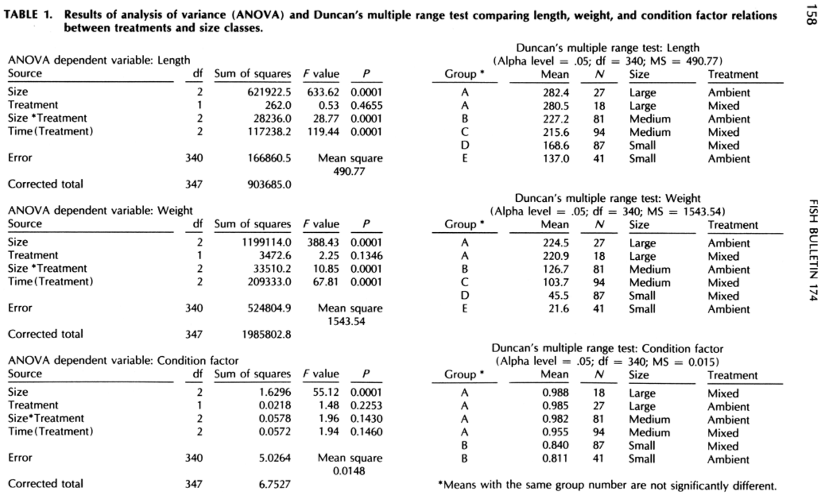

TABLE 1. Results of analysis of variance (ANOVA) and Duncan's multiple range test comparing length, weight, and condition factor relations between treatments and size classes.

ANOVA dependent variable: Length

Source	df	Sum of squares	*F* value	*P*
Size	2	621922.5	633.62	0.0001
Treatment	1	262.0	0.53	0.4655
Size *Treatment	2	28236.0	28.77	0.0001
Time (Treatment)	2	117238.2	119.44	0.0001
Error	340	166860.5	Mean square 490.77	
Corrected total	347	903685.0		

Duncan's multiple range test: Length
(Alpha level = .05; df = 340; MS = 490.77)

Group *	Mean	*N*	Size	Treatment
A	282.4	27	Large	Ambient
A	280.5	18	Large	Mixed
B	227.2	81	Medium	Ambient
C	215.6	94	Medium	Mixed
D	168.6	87	Small	Mixed
E	137.0	41	Small	Ambient

ANOVA dependent variable: Weight

Source	df	Sum of squares	*F* value	*P*
Size	2	1199114.0	388.43	0.0001
Treatment	1	3472.6	2.25	0.1346
Size *Treatment	2	33510.2	10.85	0.0001
Time (Treatment)	2	209333.0	67.81	0.0001
Error	340	524804.9	Mean square 1543.54	
Corrected total	347	1985802.8		

Duncan's multiple range test: Weight
(Alpha level = .05; df = 340; MS = 1543.54)

Group *	Mean	*N*	Size	Treatment
A	224.5	27	Large	Ambient
A	220.9	18	Large	Mixed
B	126.7	81	Medium	Ambient
C	103.7	94	Medium	Mixed
D	45.5	87	Small	Mixed
E	21.6	41	Small	Ambient

ANOVA dependent variable: Condition factor

Source	df	Sum of squares	*F* value	*P*
Size	2	1.6296	55.12	0.0001
Treatment	1	0.0218	1.48	0.2253
Size*Treatment	2	0.0578	1.96	0.1430
Time (Treatment)	2	0.0572	1.94	0.1460
Error	340	5.0264	Mean square 0.0148	
Corrected total	347	6.7527		

Duncan's multiple range test: Condition factor
(Alpha level = .05; df = 340; MS = 0.015)

Group *	Mean	*N*	Size	Treatment
A	0.988	18	Large	Mixed
A	0.985	27	Large	Ambient
A	0.982	81	Medium	Ambient
A	0.955	94	Medium	Mixed
B	0.840	87	Small	Mixed
B	0.811	41	Small	Ambient

*Means with the same group number are not significantly different.

TABLE 1. ***Results of analysis of variance (ANOVA) and Duncan's multiple range test comparing length, weight, and condition factor relations between treatments and size classes.***

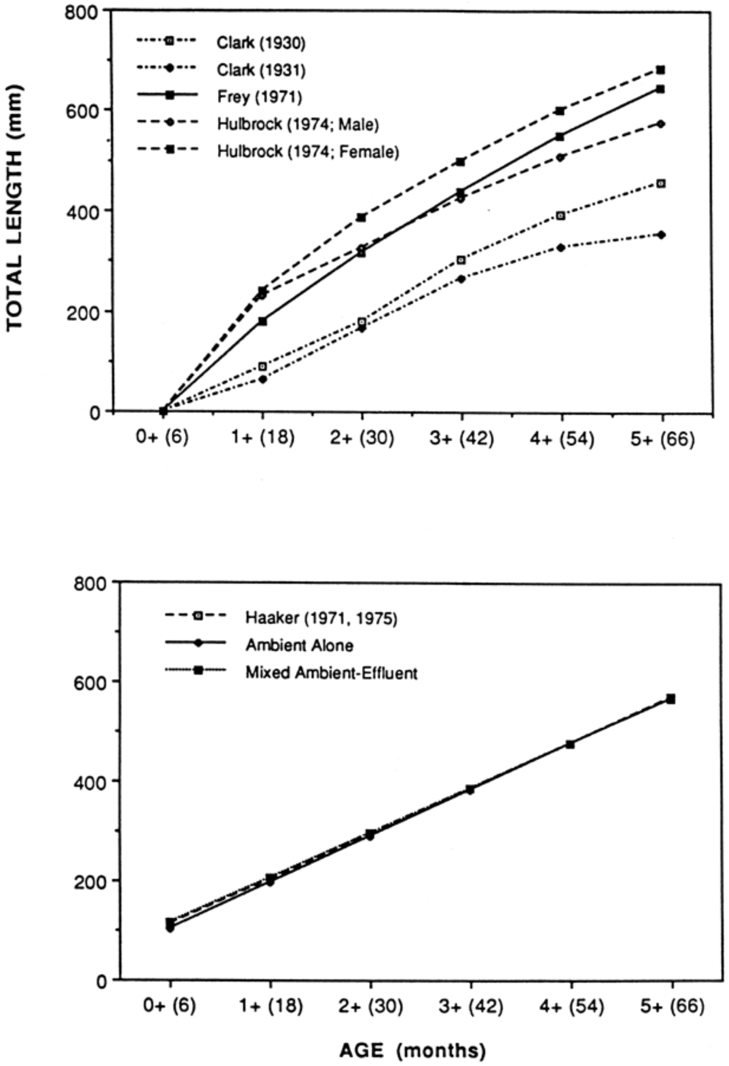

FIGURE 3. Comparison of projected California halibut linear growth (TL) in laboratory treatments of mixed ambient-effluent and ambient alone, with published growth information from field sampling studies.

FIGURE 3. Comparison of projected California halibut linear growth (TL) in laboratory treatments of mixed ambient-effluent and ambient alone, with published growth information from field sampling studies

weight:length relation calculated by Haaker (1975; Figure 3). However, Haaker's coefficient was developed from standard length (SL) measurements; when an adjustment is made to total length, his weight:length coefficient indicates an allometric growth rate (**b** = 3.311; shown in Figure 4).

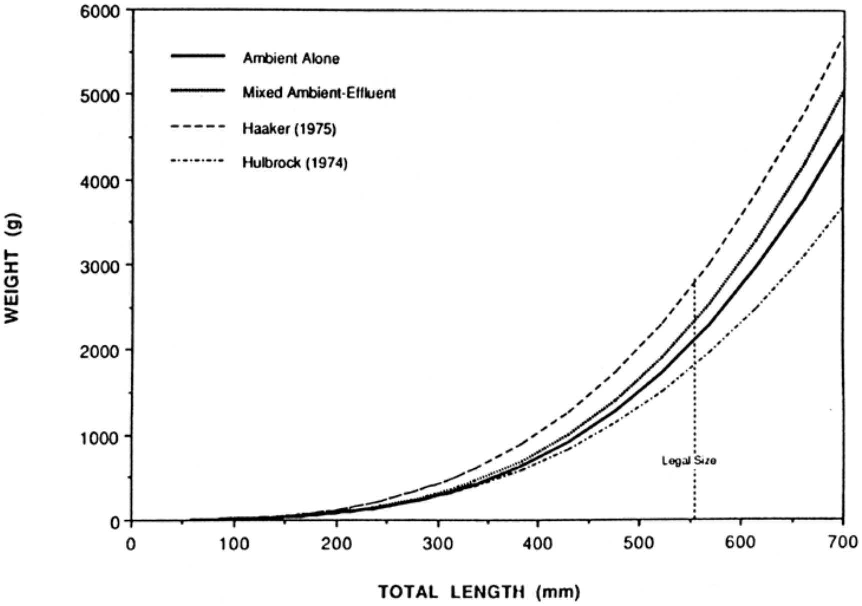

FIGURE 4. Projected length:weight relations of *Paralichthys californicus* grown in ambient temperature seawater and in mixed ambient-thermal effluent compared with published W:L ratios. Note Haaker (1975) W:L relation adjusted for total length.

FIGURE 4. Projected length:weight relations of Paralichthys californicus grown in ambient temperature seawater and in mixed ambient-thermal effluent compared with published W:L ratios. Note Haaker (1975) W:L relation adjusted for total length

Comparison of the growth data between treatments and fish sizes by ANOVA indicated that the size-treatment interactions are significant for length, weight, and condition factor (Table 1). The significant difference based on size, of course, is attributable to the experimental design, for which individuals were originally assigned to categories of small, medium, and large. Thus, the significant interactions indicate a probable size-dependent treatment effect on growth. This is confirmed by the multiple range test between means for size-treatment combinations. Analysis by Duncan's multiple range test (Zar 1974) indicated no differences between treatment (length and weight) for large animals. However, the effects of treatment on younger individuals (small and medium) were significantly different from one another, although inconsistent between treatments.

Smith and Daiber (1977) determined the growth equation for summer flounder, Paralichthys dentatus, from Delaware Bay is: $\mathbf{W = 0.404 (10^{-5}) TL^{3.151}}$, which like the P. californicus tested, grew allometrically. Both species utilize estuaries for nursery grounds. Juvenile rates of growth would be expected to differ from those of older individuals because of a change in habitat associated with age. Therefore, the growth pattern of only juvenile California halibut may appear different from estimations for an entire population, which tend to confound different growth stanzas. Feeding at ad libitum levels in the laboratory may also increase the change in weight per unit length above levels characteristic of fish in the field.

Condition factor (CF), a function of the weight:length relation, approximates 1.000 for healthy California halibut. As halibut grow at allometric rates, weight tends to increase faster than length and so their condition factors increase. Comparison of CF values by multiple range test (Table 1) based on size and treatment showed that the mean values of halibut in the small group were significantly different from the other size classes and treatment combinations (see also Figure 2). This general case was evident in Schott's work, as CF values range between 1.02 for year 1 and 1.10 for year 18 females (Hulbrock 1974).

Temperature also appeared to influence survival under treatment conditions (Figure 1). Although mortalities early in the experiment resulted from animals escaping from the experimental tanks, a direct relation between increasing temperatures and mortality was observed in both treatments later in the experiment when temperatures approached and exceeded 20°C (see Figure 5). After 11 June 1977, mortality increased rapidly, as all of the small individuals in ambient seawater and the large halibut in the mixed treatment died shortly thereafter. All other size groups survived past this point until even warmer ambient conditions (> 23.0°C) led to a rapid increase in mortalities (> 60%) and the growth experiment was stopped.

Growth rates also slowed after the June to July (weeks 26 to 34, days 180 to 240) influx of warm water (Figures 2 and 5). Overall, the mixed ambient-effluent group, which was subjected to warmer temperatures earlier in the experiment, tolerated thermal stress somewhat better than the ambient group. Increased thermal tolerance by fishes acclimated to warmer temperatures has been well documented (Fry 1967; Brett 1970; Cherry et al. 1975).

CONCLUSIONS

As cryptic predators, juvenile California halibut are naturally sedentary. In estuaries young animals, as well as adults living offshore, assume a sit and wait behavioral mode before responding to abiotic changes in their environment. The estuarine environment is highly dynamic and moderate changes in temperature occur in a diel cycle (Emery and Stevenson 1957). Gradually increasing warmer temperatures, as generally found in a thermal discharge zone (Koh and List 1974), will eventually evoke an avoidance response by P. californicus at [=]24 to 28°C; decreasing temperatures may or may not elicit avoidance movements, as indicated by halibut responses in an artificial thermal gradient (Innis 1980). In general, however, this species tolerates a wide range of temperature and prefers warm (15–23°C) temperatures, so long as there is sufficient time for acclimation. Temperature conditions in thermal plumes from coastal generating stations, therefore, would not adversely affect P. californicus.

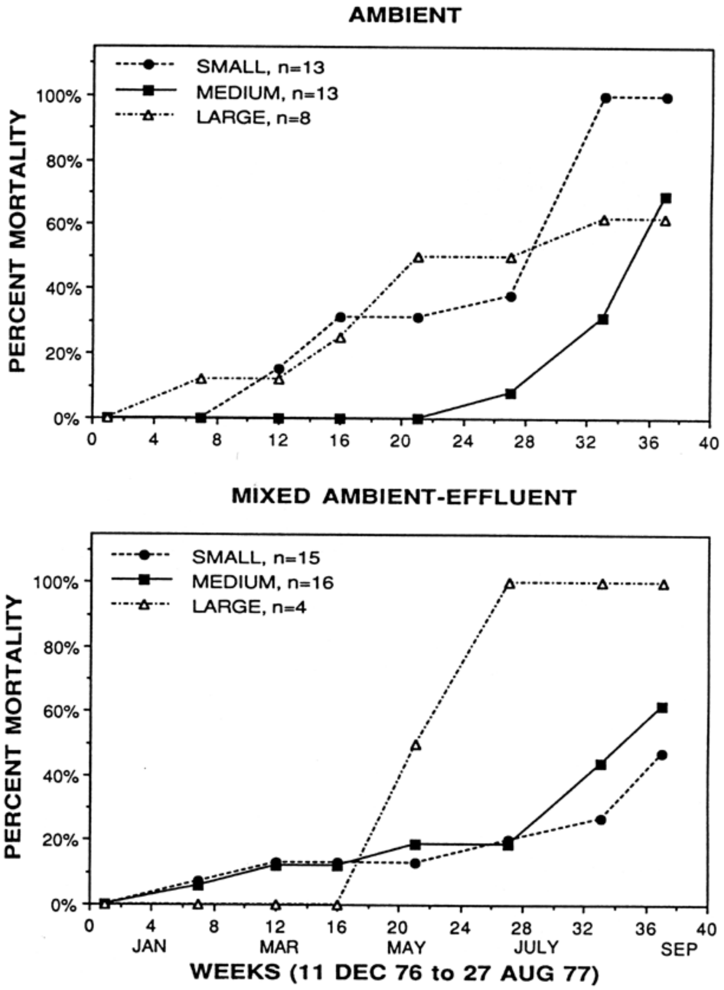

FIGURE 5. Mortality of three size classes of California halibut during an 8.5-month growth experiment comparing lagoon ambient seawater and mixed ambient-power plant effluent conditions.

FIGURE 5. Mortality of three size classes of California halibut during an 8.5-month growth experiment comparing lagoon ambient seawater and mixed ambient-power plant effluent conditions

Based upon laboratory tests, California halibut would not avoid a 1°C [8]T. This would be the typical exposure at the leading edge of a thermal plume from some southern California open coast discharges (e.g. those of the Encina Power Plant, San Diego County or the San Onofre Nuclear Generating Station Unit 1, Orange County). However, discharges into enclosed bays may elicit avoidance behavior because the [8]T increases the already higher temperatures in these areas (e.g. south San Diego Bay; Ford and Chambers 1973). On the other hand, thermal discharges from coastal generating stations with direct oceanic discharges into cool water may actually attract P. californicus.

Although the laboratory experiments showed little growth advantage for fish in heated effluent averaging about 3°C above ambient, other studies have generally suggested clear cut benefits. Poikilotherms in an elevated-temperature discharge increase their metabolic activity and, hence, their potential for accelerated growth rate. In addition, the energetic benefit (Webb 1978; Krubb et al. 1980; Graham 1983), indicates that predators at higher trophic levels, such as the top carnivore P. californicus, may store their increased scope for metabolic activity to good advantage while in or near discharge plumes. When positioned in an elevated thermal field, the temperature of fish musculature rises. After an exposure interval, large fish have mechanisms of conserving stored body heat while foraging in cooler waters away from the discharge plume (Krubb et al 1980). Accordingly, discharge-orienting predators would have a "metabolic edge" over prey species. At higher metabolic rates, these predators could swim at faster bursts of speed. Swim speeds could increase by 7% for every 1°C increase in body temperature (Webb 1978). Therefore, predators emerging from a discharge area could obtain prey more easily from nearby cooler waters. This mechanism would be advantageous to California halibut as their prey pursuit generally begins from a standing start. In addition, many species of prey fish in the southern California nearshore environment appear to be attracted to the warmer temperatures near discharges, which would increase feeding opportunities of piscivores that orient to the thermal plume (Stephens 1978).

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SIZE AND AGE AT FIRST MATURITY OF THE CALIFORNIA HALIBUT, PARALICHTHYS CALIFORNICUS, IN THE SOUTHERN CALIFORNIA BIGHT

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ABSTRACT

In 1984, 1988, and 1989, California halibut, Paralichthys californicus, were sampled by otter trawl along the Southern California Bight. Males between 14 and 53 cm (total length) and females between 15 and 62 cm were examined. Males matured at smaller sizes and younger ages than females. A few males matured at 19 cm, 50% were mature at 23 cm, and all were reproductive at 32 cm. Many males matured at age 1 and all were mature at age 3. A few females matured at 36 cm, 50% were mature at 47 cm, and all were mature at 59 cm. This corresponded to an initial age of 2 years, 50% maturity at 4 years, and 100% at age 7.

INTRODUCTION

For at least 75 years, the California halibut, Paralichthys californicus, has been a popular commercial and sport species in California. As summarized by Allen (1988), catches have shown a general decline over this time, with progressively decreasing peaks in the 1930s, 1940s, 1960s, and early 1980s. Over the years, various sport and commercial landing limitations have been instituted, including bag and minimum size limits. Current restrictions are 56 cm (22 inches) total length and five fish per day for the sport catch, and 56 cm and unlimited poundage for the commercial fisheries.

Remarkably, little work on P. californicus maturity has been published to back up these size limits. Higgins (1919) first addressed the question of size and age at first maturity in a study of about 800 individuals collected from December 1918 to summer 1919. In this paper Higgins states: "The smallest ripe or milting

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male taken to date is 9 inches [22.9 cm] long. . . . The smallest spawning female is 17 inches [43.2 cm]. . . . These figures can scarcely more than indicate that the majority of halibut are four or five years old before they become sexually mature. . . ."

Clark (1930) acknowledges using some form of this data to conclude that, "The smallest mature fish are about 9 inches in size and the spawning fish roughly embody part of the three-year fish and all of the four-, five-, and six-year classes as well as the more advanced ages." Clark (1931), again crediting Higgins, stated matters somewhat differently: "The California halibut first reaches maturity at about 9 inches in length. These small fish are probably males as they mature at an earlier age than do females. . . . The nine inch group appear to include the larger fish of the two-year class."

No further mention of P. californicus maturity was made until Frey (1971), evidently relying partially on Higgins' work, reported: "Males may mature as early as the second year, when they are about 9 inches long. Females start to mature 1 or 2 years later when they are at least 17 inches long. Probably it is at the end of the fifth or sixth year before all females reach maturity." Lastly, Haaker (1975) stated: "Males mature at about 200 mm (7.87 inches) while females mature at about 375 mm (14.76 inches).

The lack of clarity on this issue, and the increasing demand for more stringent regulations of this fishery, led us to address the question of size and age at first maturity of the California halibut.

METHODS

We sampled P. californicus from March to July 1984, April to July 1988, and March to June 1989. As we have noted in previous papers on rockfish, Sebastes spp., (Love et al. 1990) and white croaker, Genyonemus lineatus, (Love et al. 1985), it is often difficult to discern immature from mature fish during the nonreproductive season (for California halibut, September to December). Thus, we focused our study on fish taken well within the reproductive period as ascertained in a previous study (Love, unpublished data). Fish were sampled with a 7.6-m semiballoon otter trawl along four areas of the Southern California Bight (Figure 1) at depths of 6–20 m. Most fish were frozen for later study. Fish were measured (total length) and their sagittal otoliths and gonads removed. Initially, gonads were examined macroscopically by us and histologically by Stephen Goldberg, Department of Biology, Whittier College. A comparison of Dr. Goldberg's results and ours showed 100% agreement. Thus, we examined the rest of the gonads macroscopically. Otoliths were dried, soaked in clove oil for about 2 weeks, and read under a dissecting microscope. Three hundred thirteen males (14–53 cm) and 295 females (15–62 cm) were examined.

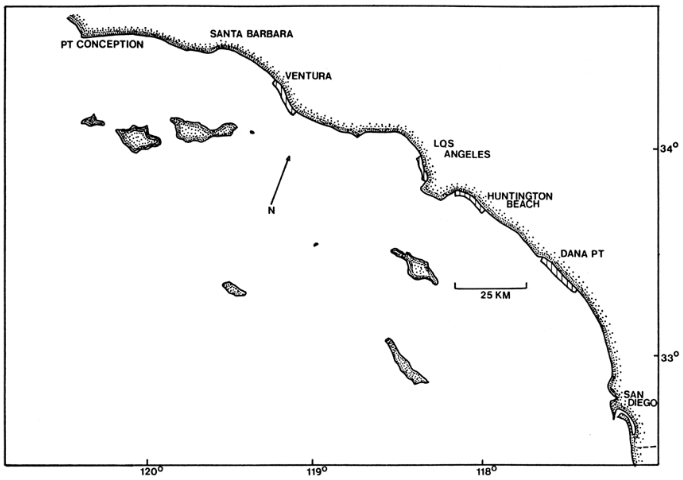


FIGURE 1. California halibut, *Paralichthys californicus*, sampling sites within the Southern California Bight. Crosshatched areas represent sampling locations.

FIGURE 1. California halibut, Paralichthys californicus, sampling sites within the Southern California Bight. Crosshatched areas represent sampling locations

The relationships between length and maturity and age and maturity was established using a transformation of

$$P_x = \frac{1}{1+e^{ax+b}}$$

(Gunderson et al. 1980) to yield

$$\ln\left(\frac{1}{P_x}-1\right) = ax+b$$

where P_x = the proportion mature at length x. We then plotted x against

$$\ln\left(\frac{1}{P_x}-1\right)$$

TABLE

using stepwise linear regression (SPSS, version 2.1) to obtain values for a and b (Figure 2). Fifty percent maturity was arrived at using calculated values for a and b and $P_x = 0.50$ to solve for x (Figure 3).

RESULTS

Males matured within a relatively narrow length range (Figure 3). While a few matured at lengths as small as 19 cm, 50% were mature at 22.7 cm, and all fish were fully mature at 32 cm (Figure 3). In comparison, females matured over a much wider range of lengths. While a few were mature at 36 cm, 50 % of females were mature at 47.1 cm, and all were mature at 59 cm (Figure 3).

Similar patterns were noted for age at maturity. Most males matured at age 1, and all were mature by age 3 (Figure 3). Fifty percent of males mature at 1.3 years (Table 1). A few females spawned during age 2, 50% were mature at 4.3 years, and all were mature by age 7 (Table 1, Figure 3).

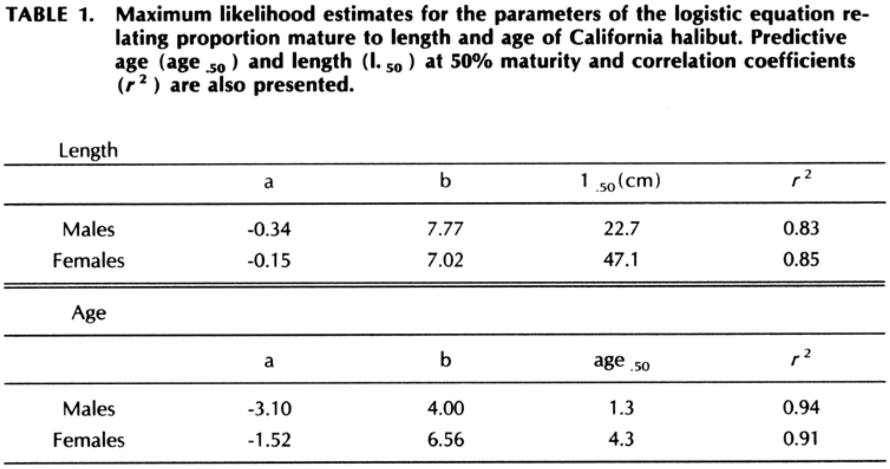


TABLE 1. Maximum likelihood estimates for the parameters of the logistic equation relating proportion mature to length and age of California halibut. Predictive age (age $_{.50}$) and length (l. $_{50}$) at 50% maturity and correlation coefficients (r^2) are also presented.

Length	a	b	$1_{.50}$(cm)	r^2
Males	-0.34	7.77	22.7	0.83
Females	-0.15	7.02	47.1	0.85

Age	a	b	age $_{.50}$	r^2
Males	-3.10	4.00	1.3	0.94
Females	-1.52	6.56	4.3	0.91

TABLE 1. ***Maximum likelihood estimates for the parameters of the logistic equation relating proportion mature to length and age of California halibut. Predictive age (age $_{.50}$) and length (I.$_{50}$) at 50% maturity and correlation coefficients (r^2) are also presented.***

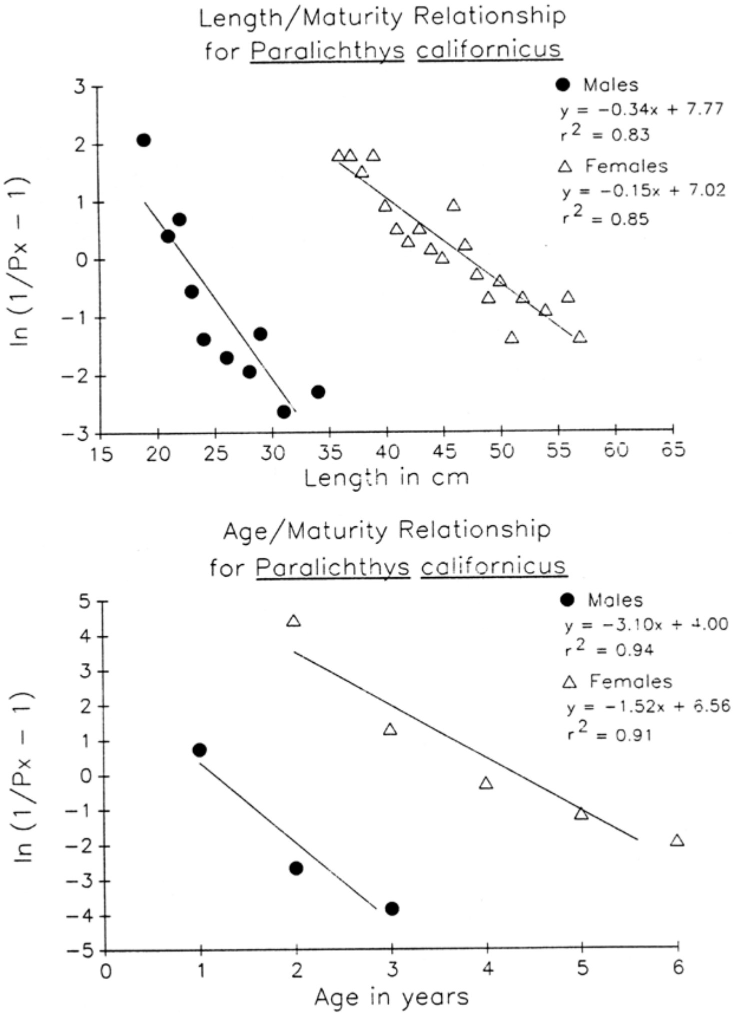
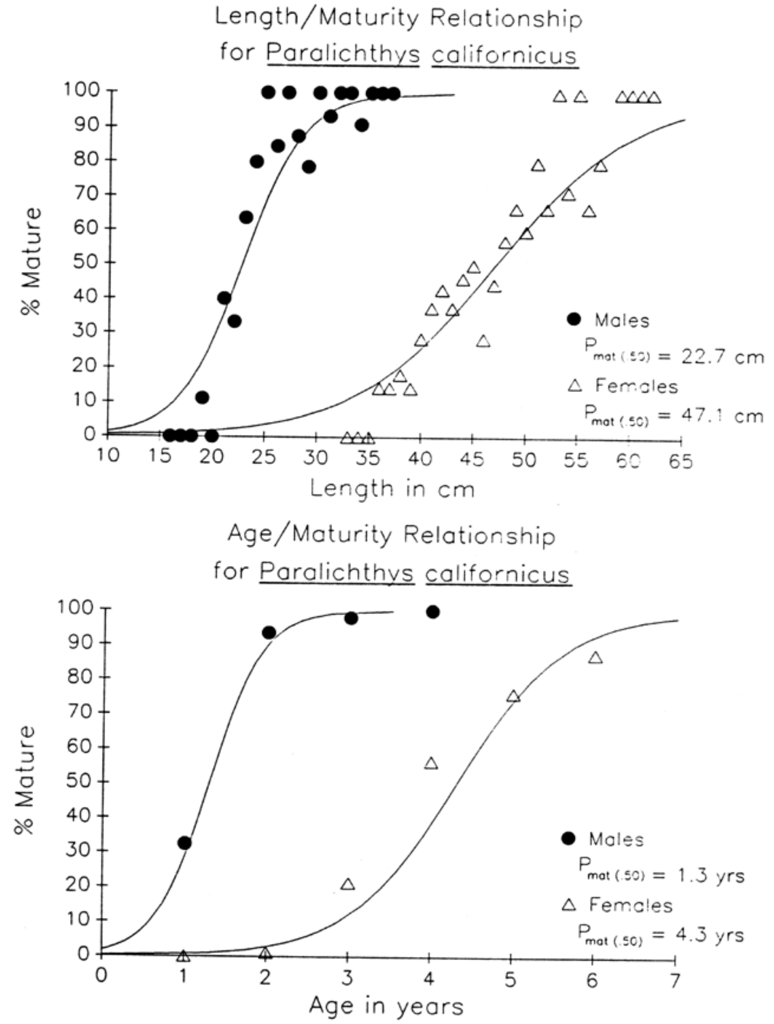


FIGURE 2. The relationship between length or age and maturity 1 expressed as a function of $P_x = \frac{1}{1+e^{ax+b}}$. Natural log transformed values of the percent fish mature at size or age x ($=P_x$) were regressed against size or age to yield values for a and b.

FIGURE 2. The relationship between length or age and maturity 1 expressed as a function of [$P_x = 1/1+e^{ax+b}$]. Natural log transformed values of the percent fish mature at size or age x (=P_x) were regressed against size or age to yield values for a and b



Length/Maturity Relationship for *Paralichthys californicus*

Age/Maturity Relationship for *Paralichthys californicus*

FIGURE 3. The relationships between observed and predicted length/maturity and age/maturity relationships of California halibut, *Paralichthys californicus*, sampled from the Southern California Bight. (Illustrated lines calculated from values based on regression equations presented in Figure 2.)

FIGURE 3. The relationships between observed and predicted length/maturity and age/maturity relationships of California halibut, Paralichthys californicus, sampled from the Southern California Bight. (Illustrated lines calculated from values based on regression equations presented in Figure 2.)

DISCUSSION

Though the data presented by Higgins (1919), Clark (1930, 1931), Frey (1971), and Haaker (1975) were similar to our results, there were some noteworthy differences. Our male length at 50% maturity (22.7 cm) was very close to the minimum length found by Higgins, although we found some fish that matured at smaller lengths (down to 19 cm). Similarly, while the smallest spawning female of Higgins and subsequent authors was 43.6 cm, between 15 and 50% of females 36–43 cm were mature in our study. Higgins' minimum figure was close to our 50% maturity length of 47.1 cm.

Frey's statements on age at maturity were most like our own findings. The highest percentage of our males matured at age 1 (Frey's "second year") and most females at ages 3 and 4, also corresponding to Frey's report. A few females matured earlier than noted by Frey and a few were still immature at age 6 (Frey's "seventh year"), an age when Frey believed all halibut to be mature. Haaker's lengths at maturity for males (20.0 cm) and females (37.5 cm) are very close to our minimum size at first maturity.

As previously mentioned, the current minimum sport and commercial length for P. californicus is 56 cm. This corresponds to 100% maturity for males (32 cm) and almost that for females (59 cm). Based of this size limit and 50% maturities of 22.7 and 47.1 cm, males will have 4–5 years to reproduce and females 1 or 2 years before reaching legal size.

We compared P. californicus length and age at maturity with published records from Atlantic and Caribbean species of Paralichthys (Table 2). Males mature at a smaller size than females in three species (P. californicus, P. dentatus, and P. lethostigma) , but apparently not in a fourth (P. albigutta) . There does not appear to be any relationship between maximum size and size at first maturity. For instance, P. albigutta and P. dentatus mature at about the same length, even though P. dentatus grow to about three times the size. With the exception of P. californicus, all the Paralichthys listed mature at about age 2. California halibut males begin to mature slightly earlier and females considerably later.

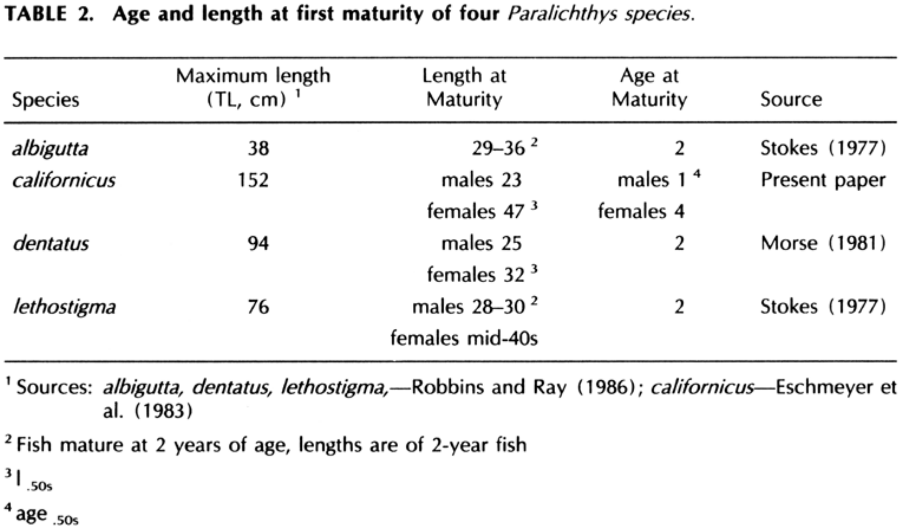


TABLE 2. Age and length at first maturity of four *Paralichthys species.*

Species	Maximum length (TL, cm) [1]	Length at Maturity	Age at Maturity	Source
albigutta	38	29–36 [2]	2	Stokes (1977)
californicus	152	males 23	males 1 [4]	Present paper
		females 47 [3]	females 4	
dentatus	94	males 25	2	Morse (1981)
		females 32 [3]		
lethostigma	76	males 28–30 [2]	2	Stokes (1977)
		females mid-40s		

[1] Sources: *albigutta, dentatus, lethostigma,*—Robbins and Ray (1986); *californicus*—Eschmeyer et al. (1983)

[2] Fish mature at 2 years of age, lengths are of 2-year fish

[3] $l_{.50s}$

[4] age $_{.50s}$

TABLE 2. ***Age and length at first maturity of four Paralichthys species.***

ACKNOWLEDGMENTS

This research was funded by the California Department of Fish and Game under Dingell-Johnson Project F-32-R (Southern California Marine Sportfish Research Program) supported by Federal Aid to Fish Restoration funds. We thank J. Stephens for the use of the RV VANTUNA in securing most of the specimens for this study and S. Goldberg for histological workups. The crew of the VANTUNA (M. Kibby, M. Maher, J. Gavran) were always helpful. Assisting on board the vessel were G. Jordan, V. Mason, H. Parker, P. Garrahan, S. Smith, B. Westphal, M. Singer, and L. Targgart.

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INDUCED SPAWNING OF THE CALIFORNIA HALIBUT, PARALICHTHYS CALIFORNICUS, (PISCES: PARALICHTHYIDAE) UNDER ARTIFICIAL AND NATURAL CONDITIONS

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ABSTRACT

Research concerning reproductive parameters of the California halibut, Paralichthys californicus, maintained in captivity was undertaken as the first step towards investigating the early life history stages of the species. Brood stocks were placed under natural (outdoor) and artificially simulated (indoor) environmental conditions. Fish in natural situations produced 27 spawns from February through May 1986; 5 spawns from March through April 1987; and 64 spawns from late March through September 1988. Since tanks held multiple females, the number of fish participating per spawning incident was unknown and spawning frequency can only be estimated. Diel estimates of fertilization time were made from comparisons with egg development studies conducted earlier. Spawning during 1986 initially occurred during the late afternoon but became primarily nocturnal as the reproductive season progressed. In contrast, spawning in 1988 typically occurred in late afternoon throughout the season with no apparent diel

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periodicity (in 1987, spawning was too infrequent for meaningful analysis). Halibut residing under simulated environmental conditions never successfully spawned until 1988 following their introduction into a larger tank. Approximately 55 spawns were recorded beginning in mid-January and continuing to October, although a large percentage of these eggs were nonviable. Halibut injected with lutenizing hormone, LHRH, produced eggs which were manually stripped and fertilized, but egg viability was variable and fertilization success significantly below noninjected individuals. At this time, the precise influence exerted by environmental factors (temperature and photoperiod) on spawning of California halibut is only partially known because synergistic interactions among variable laboratory conditions, nutrition, and social behavior are poorly understood. However, both in the laboratory and in the field, halibut usually begin spawning in the winter or early spring following the lowest annual temperatures and shortest photoperiod. Behavioral observations of halibut suggest that inadequate tank size adversely impacts spawning behavior.

INTRODUCTION

The California halibut, Paralichthys californicus, is highly prized by both commercial and sports fishermen along the southern California coast. Historically, halibut populations were quite abundant, supporting a sizable commercial industry (Clark 1931; Holmberg 1949). However, current total commercial catches remain severely depressed compared to landings reported during the early 1900s. Although fishing pressure (Clark 1930; Martin 1983) and habitat depletion are the most probable causes (Kramer 1990), insufficient knowledge of life history and population dynamics precludes reliably assessing these declines and implementing effective management programs.

Studies were initiated in 1984 to investigate the early life history stages of California halibut. Research goals included: 1) establishing several captive brood stocks and inducing year-round spawning; 2) formulating optimal rearing protocols for larvae; and 3) assessing the feasibility of augmenting the natural population with hatchery reared individuals. Prior to recommending production-scale hatchery operations, these three components must be evaluated and quantified. In addition, this research would generate valuable life history information, supplementing current knowledge. Results concerning the first goal are reported here.

Efficient aquaculture operations require sustained egg production at manageable levels, yet most temperate marine species exhibit relatively short, but intense, spawning seasons limiting both the scope and duration of experimental work. Productivity would be greatly enhanced if spawning periods were artificially protracted and spawning activity induced when desired. Field investigations indicate California halibut spawn year-round in the Southern California Bight, but show an intensive winter–spring spawning pattern (Lavenberg et al. 1986).

In studies investigating induced spawning of temperate marine fishes, photoperiod and temperature are most often cited as the dominant exogenous cues (De Vlaming 1972; Sundararaj and Vasal 1976; Johns and Howell 1980;

Crim 1982; Bye 1984; Reay 1984). Manipulating photoperiod and temperature, in conjunction with hormonal injections, typically induces successful ovulation (Smigelski 1975a; Arnold et al. 1977; Hettler and Powell 1981; Minton et al. 1983). However, hormone effectiveness is quite dependent on dosage (Haydock 1971), time between injections if multiple dosages are required (Lam 1982), initial stage of oocyte development (Colura 1974; Hoff et al. 1978), and environmental conditions (Bye 1984). Hormone-induced spawning techniques often produce significant proportions of nonviable eggs through improper maturation, egg overripeness, or imposed stress from handling (Stevens 1966; Arnold et al. 1976; Roberts et al. 1978). Therefore, spawning inducement was attempted by relying upon environmental conditioning and employing hormones only if ovulation appeared unlikely. Knowledge from this work could then be applied towards designing a program of year-round spawning by alternating appropriately conditioned brood stocks.

METHODS

Brood Stock Acquisition and Care

California halibut were collected with rod and reel, otter trawls, and donations. Each individual received 96-h Prefuran antibiotic treatments followed by 4-h formaldehyde (39% HCOH at 0.13 ml/L) baths that eliminated ectoparasites. After 1 week isolation, each fish was weighed, measured, sexed, marked with plastic floy tags, and segregated into experimental spawning tanks under either artificial or natural environmental conditions. Sexing was accomplished by inserting a catheter (constructed from flexible 2-mm diameter tubing attached to a hypodermic syringe fitted with a 12-gauge needle) into the gonad and removing and examining the gametes. This method proved unreliable for immature individuals (<33 cm SL). Monogenetic trematode infestations, presumably facilitated by the confined holding conditions and relatively high fish densities, initially killed approximately 25% of the laboratory fish. Bioassay experiments utilizing varying concentration of formaldehyde and Dylox revealed the former to be superior in controlling these parasites (Table 1). Bimonthly formaldehyde treatments administered at 0.13 ppm for 4 h within each holding tank, successfully eradicated the trematodes with no observable detrimental effects to the brood stock.

Feeding

Adequate feeding plays an important role in gonad maturation (Hoff et al. 1972; Middaugh and Lempesis 1976; Reay 1984). Halibut were fed approximately 2% of their total body weight three times each week in 1985, 1986, and 1987. Food types included frozen white croaker, Genyonemus lineatus; Pacific mackerel, Scomber japonicus; northern anchovy, Engraulis mordax; and queenfish, Seriphus politus, all considered natural prey. Periodic growth measurements conducted on each individual allowed subjective evaluations of brood stock health. Feeding procedures were modified in 1988 to evaluate seasonal feeding patterns and any possible relationship with spawning activities. Fish were fed to excess with frozen fish obtained from local retailers (surf smelt,

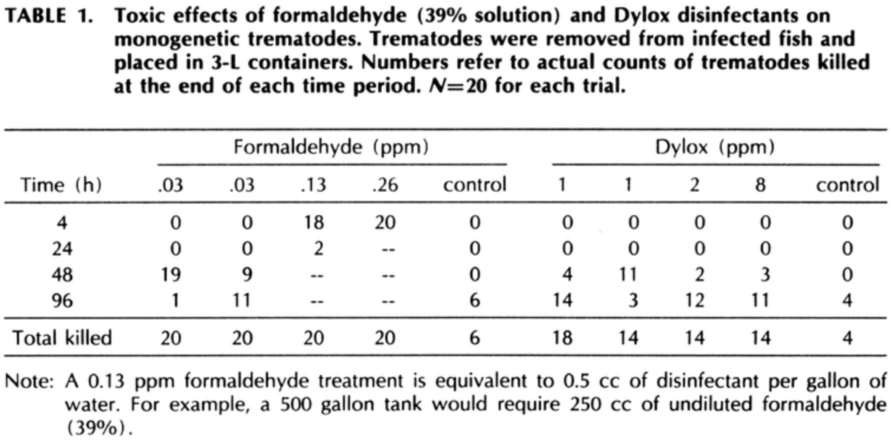

TABLE 1. Toxic effects of formaldehyde (39% solution) and Dylox disinfectants on monogenetic trematodes. Trematodes were removed from infected fish and placed in 3-L containers. Numbers refer to actual counts of trematodes killed at the end of each time period. N=20 for each trial.

	Formaldehyde (ppm)					Dylox (ppm)				
Time (h)	.03	.03	.13	.26	control	1	1	2	8	control
4	0	0	18	20	0	0	0	0	0	0
24	0	0	2	--	0	0	0	0	0	0
48	19	9	--	--	0	4	11	2	3	0
96	1	11	--	--	6	14	3	12	11	4
Total killed	20	20	20	20	6	18	14	14	14	4

Note: A 0.13 ppm formaldehyde treatment is equivalent to 0.5 cc of disinfectant per gallon of water. For example, a 500 gallon tank would require 250 cc of undiluted formaldehyde (39%).

TABLE 1. ***Toxic effects of formaldehyde (39% solution) and Dylox disinfectants on monogenetic trematodes. Trematodes were removed from infected fish and placed in 3-L containers. Numbers refer to actual counts of trematodes killed at the end of each time period. N=20 for each trial.***

Hypomesus pretiosus; herring, species unknown; and Pacific mackerel) and the amount of food consumed recorded.

Hormone Injections

Initially, powdered carp pituitary was administered at various dosages to induce spawning. This hormone was injected intramuscularly with 2-cc syringes fitted with 25-gauge needles; an isotonic sodium chloride solution was used as the carrier. Careful retraction and pressure placed over the needle entry point minimized fluid loss. Based on our earlier experimental work with field specimens, hormone effectiveness was not increased through successive injections or primer dosages. Females were considered eligible for hormone injection if eggs were distinctly spherical, attained average diameters of 0.4 mm, and yolks through vitellogensis appeared yellowish-orange.

Since attempts to hormonally induce captive halibut spawning with carp pituitary were unsuccessful, another hormone, lutenizing hormone-releasing hormone analog (LHRH-a), was investigated. LHRH-a was administered intramuscularly at predetermined dosages, using the same methodology described above. In the first trial, conducted October 1987, one 5 kg female was injected at 1700 h with LHRH-a at a dosage of 50 [u]g/kg of body weight. Ovarian development was evident approximately 40 h after injection and monitored (through catheter insertion) at 40, 48, and 64 h; eggs were manually stripped at 64 h.

On 25 January 1988, a second trial was conducted using the same fish (no weight change) and LHRH-a dosage. Manual stripping of the eggs was attempted at 24, 42, 48, 66, and 72 h following injection. When stripping was successful, eggs were fertilized with sperm from at least two males. To determine dosage effectiveness and avoid hormone-induced fish mortalities, another female (8 kg) was injected on 22 March with LHRH-a at a lower dose of 30 [u]g/kg and eggs extracted at 48 and 64 h after hormone injection. The fourth and last trial occurred on 23 June using a 4.8 kg female and 50 [u]g/kg hormone dosage. Eggs were stripped at 41 and 64 h.

Experimental Conditions

Brood fish were conditioned under two environmental regimes. California halibut subjected to artificially recreated photoperiod and temperatures were partitioned into two indoor groups, and a third group, considered the control, was placed outside and maintained under natural variations of temperature and light.

Natural Conditions (Group I)

January 1985–October 1988. Fish were released into a 20,000 L cylindrical, redwood tank (depth 2.5 m, diameter 4.9 m) covered with a black vinyl canopy (Figure 1A). Gravel (2–5 cm) lining the bottom provided suitable habitat to accommodate burying activity but was not deep enough to completely cover the fish. Sunlight penetrated through two side viewing ports and a circular rooftop access hole. Ambient water flow was 20 gpm, producing exchange rates of 98% per day (calculated from Kraul et al. 1985). Water was also circulated through a pressurized sand and 25-[u]m cartridge filter system that removed large particulate matter and served as an auxiliary biofilter. Water quality parameters (pH, dissolved oxygen, and ammonia) were routinely monitored.

Brood stock composition and numbers varied from 1985 to 1988 but remained relatively constant (Table 2). Eggs were collected in a double-walled circular fiberglass tank (50-cm diameter) placed over the surface drain (Figure 2). Floating eggs entered and spilled through a horizontal row of 2.5-cm holes situated along the outer wall's upper rim. The inner standpipe maintained water levels below these outer holes, stopping eggs from flowing outward. A Nitex 333-[u]m mesh filter screen surrounding the standpipe retained and concentrated the buoyant ova, facilitating their removal via siphoning. If removed within 10 h, total egg loss through mechanical damage was estimated to be below 2%. Spawning time was estimated by comparing spawned eggs to an egg developmental series compiled from previous laboratory work (Gadomski and Caddell 1991) with hormonally spawned fish.

Artificial Conditions (Group II)

February 1985–June 1986. Ten California halibut were transferred from acclimation tanks into two 3000 L vinyl pools (depth 1 m, diameter 2.5 m) provided with sand substrate (2–4 cm) in February 1985 (Table 2). Seawater was recirculated through a treatment system consisting of a pressurized sand filter, oyster shell biofilter, 25-[u]m cartridge filter, air compression water chiller, and twin UV sterilizers (Figure 1B). Recirculating flow rates were approximately 30 gpm. Photoperiod manipulations simulating sunrise, daylight, and sunset, were accomplished using a timer-controlled array of incandescent and fluorescent lights suspended 1.5 m over each pool. Previous studies linked reduced light levels with successful spawning of marine species (Olla et al. 1972; Kuronuma and Fukusho 1984). Verheijen and De Groot (1967) concluded that high light intensities inhibited normal daytime activity of plaice, Pleuronectes platessa. Therefore, darkened plastic sleeves were installed over the fluorescent bulbs to reduce light intensities.

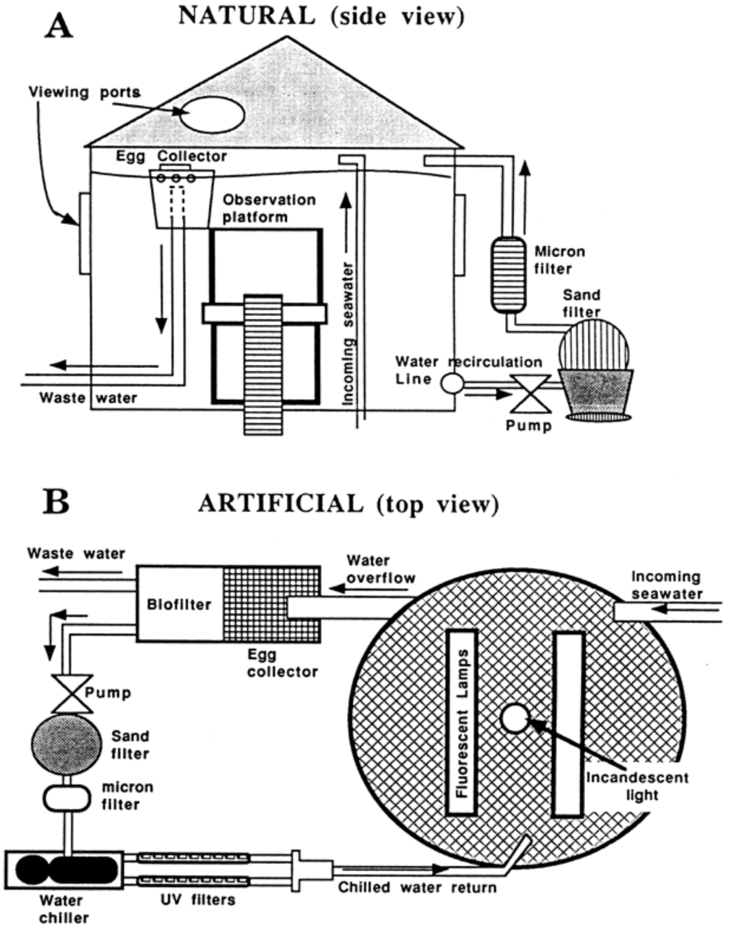

FIGURE 1. Experimental holding conditions for captive halibut brood stocks. The artificial system depicted represents the system installed in the summer of 1986 when the two smaller breeding tanks were replaced with one larger tank.

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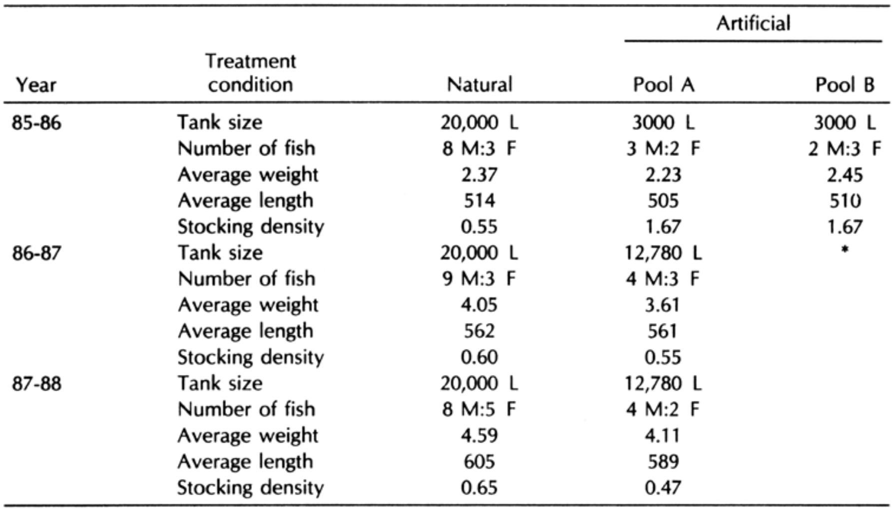
TABLE 2. Chronology of holding conditions for California halibut brood stocks. Note artificial brood fish were combined in 1986 (*). Weight is in kg, length is in mm and stocking density is number of fish per 1000 L.



Year	Treatment condition	Natural	Artificial	
			Pool A	Pool B
85-86	Tank size	20,000 L	3000 L	3000 L
	Number of fish	8 M:3 F	3 M:2 F	2 M:3 F
	Average weight	2.37	2.23	2.45
	Average length	514	505	510
	Stocking density	0.55	1.67	1.67
86-87	Tank size	20,000 L	12,780 L	*
	Number of fish	9 M:3 F	4 M:3 F	
	Average weight	4.05	3.61	
	Average length	562	561	
	Stocking density	0.60	0.55	
87-88	Tank size	20,000 L	12,780 L	
	Number of fish	8 M:5 F	4 M:2 F	
	Average weight	4.59	4.11	
	Average length	605	589	
	Stocking density	0.65	0.47	

TABLE 2. ***Chronology of holding conditions for California halibut brood stocks. Note artificial brood fish were combined in 1986 (*). Weight is in kg, length is in mm and stocking density is number of fish per 1000 L.***

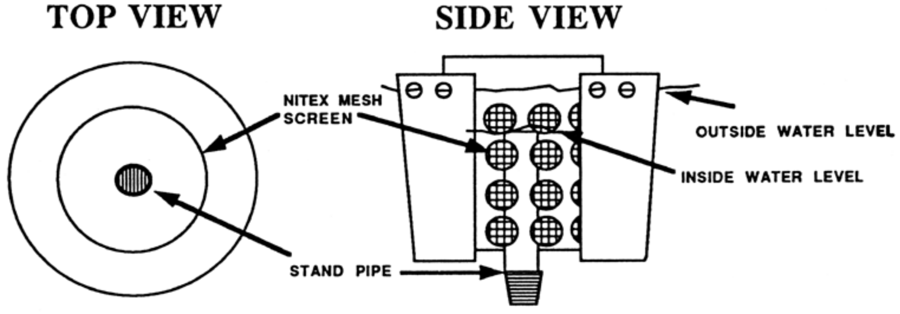


FIGURE 2. Schematic of egg collecting basket. Cut away view reveals inner standpipe and lower water level. Water exits through Nitex mesh screen into the standpipe but eggs are retained. See figure 1A for actual placement in brood stock holding tank system.

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Larval California halibut abundance data collected from ichthyoplankton surveys (Lavenberg et al. 1986), nearshore environmental parameters (Petersen et al. 1986) and Gonadal- Somatic Index analysis of adult halibut (M.S. Love, University of California, Santa Barbara, pers. comm.), indicated halibut spawning usually commenced after the shortest annual daylength and coldest water temperatures. Simulated environmental regimes were thus patterned after water temperature and photoperiod conditions typical for this time period (Figure 3D). Oocyte development was monitored by ovarian sampling conducted every 3 months.

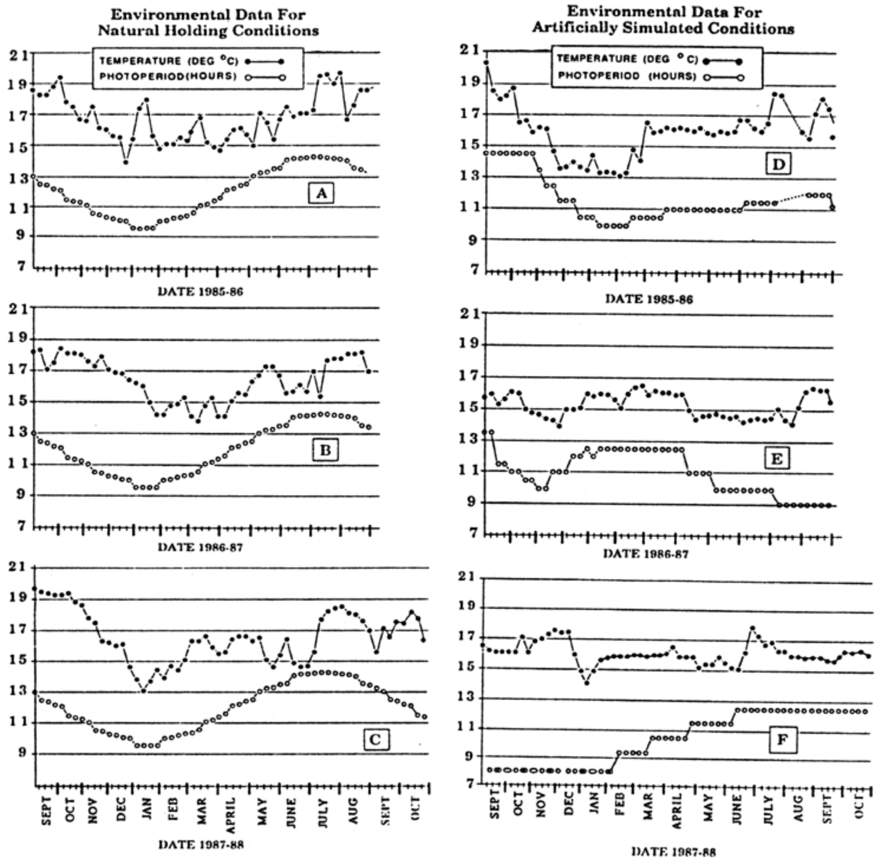

FIGURE 3. Photoperiod and temperature regimes recorded for experimental holding conditions during 1985-88. Photoperiod of the natural group was not directly measured but derived from local tide table publications.

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July 1986. General observations indicated the smaller tank size suppressed halibut reproductive behavior (see discussion). To test this hypothesis, the two vinyl pools were replaced with one 12,780 L vinyl pool (depth 1.2 m, diameter 3.7 m) and the two brood stocks combined (Table 2). All other environmental control systems were used with minor modifications (Figure 1B).

September 1986. Because fish had been in captivity for over 1 year, an attempt was made to compress the spawning cycle from 1 year to 6 months. The environmental conditioning cycle began in September on a brood stock consisting of three females and four males. Water temperatures were reduced to approximately 13.5° by early December and maintained between 14.0°C and 16.5°C thereafter (Figure 3E). Daylength was reduced to 10 h light in November and gradually increased to 12.5 h light by January.

January 1988. Based on spawning patterns displayed by Group I (natural) brood stock fish from 1986 to 1987, seasonal temperature cycles appeared less important in stimulating gametogenesis than maintaining water temperatures within a specified range and manipulating photoperiod. Temperatures, therefore, were maintained between 15.0 and 16.5°C from January through October 1988 except during several weeks between June and July when cooling requirements exceeded the capacity of the chilling system. Photoperiod began at 8.0 h light in January and was sequentially increased each month by 1.5 h to a maximum of 12.5 h light (Figure 3F).

March 1988. The original monochromatic fluorescent lights were replaced with "full spectrum" fluorescent tubes that more accurately simulate natural sunlight by providing greater amounts of wavelengths in the blue and ultraviolet range.

RESULTS

Feeding

Measured weight increases exhibited under laboratory conditions during the study averaged 8.9% and approximated reported field growth length-weight relationships (Figure 4; Frey 1971; Haaker 1975) indicating a reasonable condition factor for all brood stock groups. Food consumption rates in 1988 varied throughout the year but appeared more variable with fish under artificial conditions than naturally maintained brood fish.

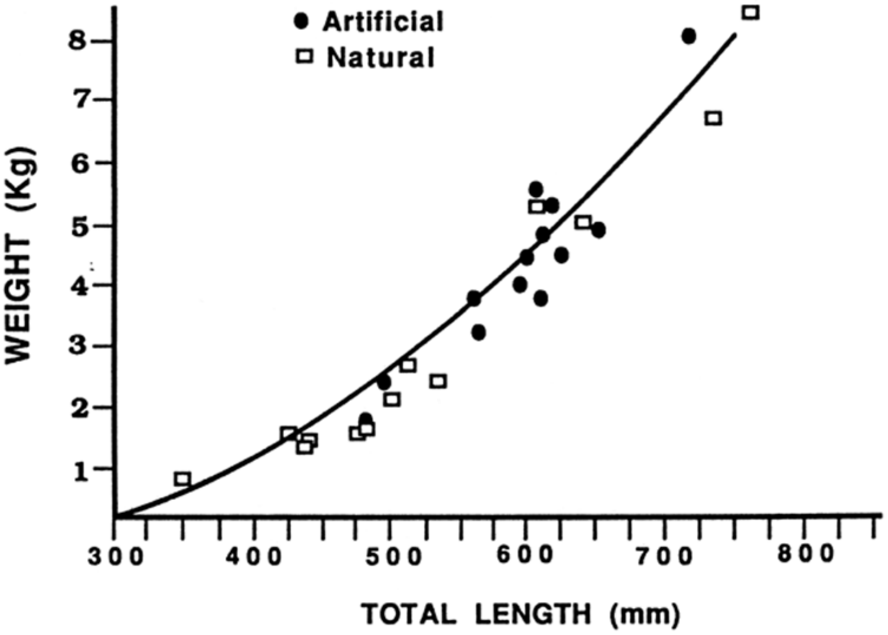

FIGURE 4. Length-weight relationships of experimental groups and regression line derived from field specimens (Haaker 1975).

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Spawning

Group I—Natural

1985–86. in 1985 ambient water temperatures progressively declined from an October peak of 19.8°C to a December low of 14.0°C (Figure 3A). Starting in January 1986, water temperatures increased slowly but remained relatively constant from February through May (15.0–16.5°C); large temperature changes were the result of oceanographic conditions at the offshore intake pipe, while daily fluctuations of approximately 0.5°C often resulted from solar heating of the tank. Disruption of the ambient water source from 28 December to 4 January caused on abrupt temperature spike that appeared inconsequential to reproductive behavior. Photoperiod gradually declined from just over 13 h light in September to a low of about 9.5 h light by January. Day length continually increased after the third week of January. Spawning occurred during photoperiods above 11 h light and water temperatures of 15.0–16.5°C; spawning ceased when photoperiod reached 13.5 h light.

California halibut spawned 27 times between February and mid- May 1986 (Figure 5A). Spawning activity was initially sporadic but rapidly intensified after the fifth spawn occurring at 1–2 d intervals for six successive spawns in April (Figure 6A). Spawning activity slowed noticeably in early May as spawns occurred every 4–7 d and ceased by 20 May. Initially, most spawning took place 6–11 h after sunrise (1400–1700) but became predominately nocturnal in April and May (11.5–15.5 h after sunrise [1800–2200]). Total egg production exceeded 10 million eggs. Fertilization success normally surpassed 90%, although eggs from two spawns never developed and appeared unfertilized. We attribute this phenomenon to unsynchronized gamete release between the sexes.

Although the spawning act of captive halibut was never observed, laboratory observations of other pleuronectiform species indicate that several males attend one larger female with limited courtship behavior (Breder and Rosen 1966; Arnold et al. 1977). On days when California halibut spawned, participating females remained uncovered constantly vibrating their dorsal fins. Egg hydration noticeably distended the abdominal region and arched the ventral body surface off the tank bottom; normal body morphology returned following oviposition. Only three females were present in the brood stock at this time and one was reproductively immature. Therefore, each of the two females spawned at least 13 times confirming California halibut as multiple spawners. In all probability, each female spawned more frequently because observations of body morphology changes suggested females spawned concurrently rather than alternating between spawns. On the average, each female emitted approximately 420,000 eggs per spawn and produced almost 5.5 million eggs for the entire season (Table 3). Spawning frequency was estimated at 7 d.

1986–1987. In 1987, spawning of halibut residing under natural conditions began on 1 March and continued until early April. Spawning activity was significantly diminished compared to spawning of the previous year, and only five spawns occurred producing approximately 1.5 million eggs. Water temperatures were slightly below those of 1986 (13.5–15.5°C versus 14.5–16.5°C) during this time and may have delayed spawning (Figure 3B). However, gonad biopsies conducted on two females after spawning ceased, revealed the ovaries

TABLE 3. Spawning results for California halibut calculated from captive brood stocks. Values presented are standardized per female. Spawning frequency equals the average number of days between spawning episodes over the spawning season for that year.

Environmental condition	Year	No. spawns	Average no. eggs per spawn	Total eggs spawned	Spawning frequency
Natural	1985-86	12	455,000	5,460,000	7.0 d
Natural	1986-87	5	313,000	1,565,000	7.2 d
Natural	1987-88	13	589,000	7,657,000	14.0 d
Artificial	1987-88	55	325,000	17,875,000	4.7 d

TABLE 3. ***Spawning results for California halibut calculated from captive brood stocks. Values presented are standardized per female. Spawning frequency equals the average number of days between spawning episodes over the spawning season for that year.***

had severe bacterial infections effectively blocking the oviduct. Extracted eggs appeared hydrated but were atretic. The infection was successfully treated with antibiotics and ovarian development partially resumed. Water temperatures were above 16.5°C during most of May and decreased slightly below 16.0°C during the last week of May. We believed this condition might induce spawning since halibut spawned most often in temperatures below 16.5°C during the previous year. Females were anesthetized and ovaries examined for spawning condition on 29 June. Egg diameters in the largest female averaged 0.43 mm with some as large as 0.62 mm (exceeding the minimum 0.4 mm size required for hormone injection); thus hormones (carp pituitary) were administered resulting in egg hydration. Again, inflammation of the oviduct blocked oviposition even when manual stripping was attempted and no further spawning occurred. Spawning output noticeably diminished compared to the previous year as eggs produced per spawn and for the entire season were 313,000 and 1.5 million, respectively (Table 3). The spawning frequency of 7.2 d, however, was similar to that observed from the previous year.

1987–88. Winter water temperatures in 1988 were similar to other years with cold temperatures (13.0–15.0°C) prevailing through March (Figure 3C). Spring water temperatures, however, were different from the prior 2 years in that cold water persisted into early summer. Ambient water temperatures during May uncharacteristically cooled below 15°C until late June when temperatures rapidly increased to 18°C (Figure 3C). Consistent spawning began in mid-May (one small spawn occurred in late March) and continued through September (Figure 5C). This pattern differed from the previous 2 years when spawning occurred primarily during March and April and ended in May. Further, spawning activity in 1988 continued in water temperatures well above 18°C compared to the prior two years when spawning ceased at water temperatures above 16.5°C.

Sixty-four spawns were recorded producing over 38 million eggs which greatly surpassed reproductive output from any prior year. Spawning occurred every other day for six to seven consecutive spawns with limited resting periods (Figure 6B). Based upon a female population of five, each female spawned at least 13 times producing approximately 589,000 eggs per spawning event.

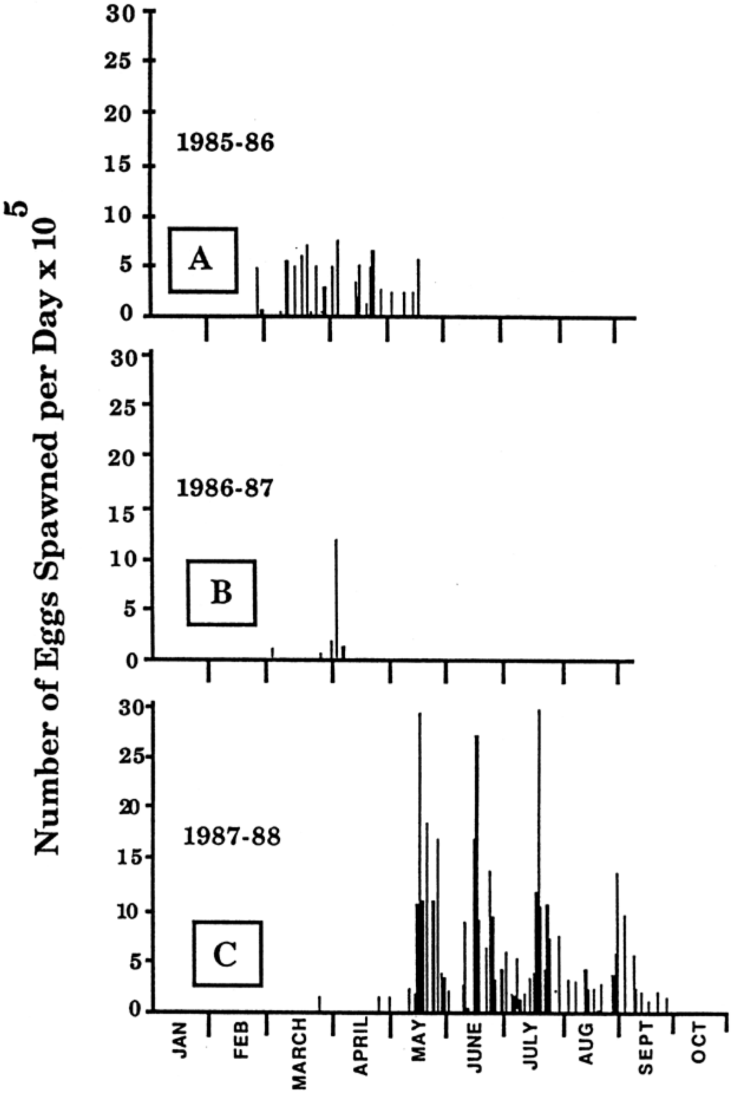

FIGURE 5. Recorded spawning events for halibut brood stocks held under natural conditions. No spawns occurred during falls of 1985-87.

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Seasonal egg production equaled about 7.6 million eggs but the calculated spawning frequency dropped to 14 d (Table 3).

Group II-Artificial

1985–86. California halibut subjected to artificial conditions exhibited well developed gonads following increased water temperatures and photoperiod in February. Since analogous environmental regimes were inducing the natural brood stock to spawn, an 11 h daylength and 16.0°C temperature were maintained during March and April (Figure 3D) to improve the likelihood of spawning. When no spawning occurred under these conditions, hormone injections (carp pituitary) were administered in mid-May because presumably oocytes were sufficiently mature, based on previous work. Two spawns followed the hormone injections, but eggs were malformed and nonviable.

1986–87. The environmental conditioning cycle began in September 1986 on the brood stock combined in July. Halibut exhibited limited ovarian development by late March 1987 with few eggs progressing beyond primary oogenesis. Because spawning was anticipated in late February, each female received hormone injections (carp pituitary) to induce spawning; no response occurred so this inducement trial was terminated. During April, temperatures and photoperiod were reduced simulating winter conditions with the expectation that ovarian maturation might be stimulated (Figure 3E). This was partially successful as egg diameters increased somewhat by late May, but mean oocyte diameters remained far below the minimum size of 0.4 mm necessary for successful hormone injection. Temperatures were raised to 16°C in August to simulate spring water conditions, however, gonadal examinations conducted in mid-August and October revealed no further oocyte development.

1987–88. Group II spawned naturally for the first time 18–20 January 1988 producing over 500,000 unfertilized eggs (Figure 7). After a several month hiatus, spawning activity recommenced during April and occurred through early October. Spawning activity increased in intensity through July falling off after August. There were only two females in the tank during this spawning period, one of which was noticeably emaciated; gonadal biopsies revealed no evidence of ovarian development. Thus all spawning activity resulted from just one female that had resided under artificial conditions since 1985. Spawning intervals of 1–3 d were sustained over several months (Figure 6) averaging approximately 325,000 eggs every 5 d with total egg production exceeding 17 million for the season (Table 3).

This spawning effort was not entirely successful as spawned eggs exhibited significant reductions in fertilization success and viability rates compared to spawns from Group I residing under natural conditions. Almost 90% of all spawns examined exhibited abnormal or non-fertilized eggs, often accounting for over 50% of all eggs produced. During August and September seven spawns were closely examined to document egg morphology and quantify the proportion of viable eggs. In one spawn, no eggs were viable; in five spawns, less than 2% of the eggs appeared normal; only one spawn had normally developing ova in excess of 50%. Most eggs appeared malformed and were negatively buoyant, but we could not always clearly distinguish unfertilized eggs

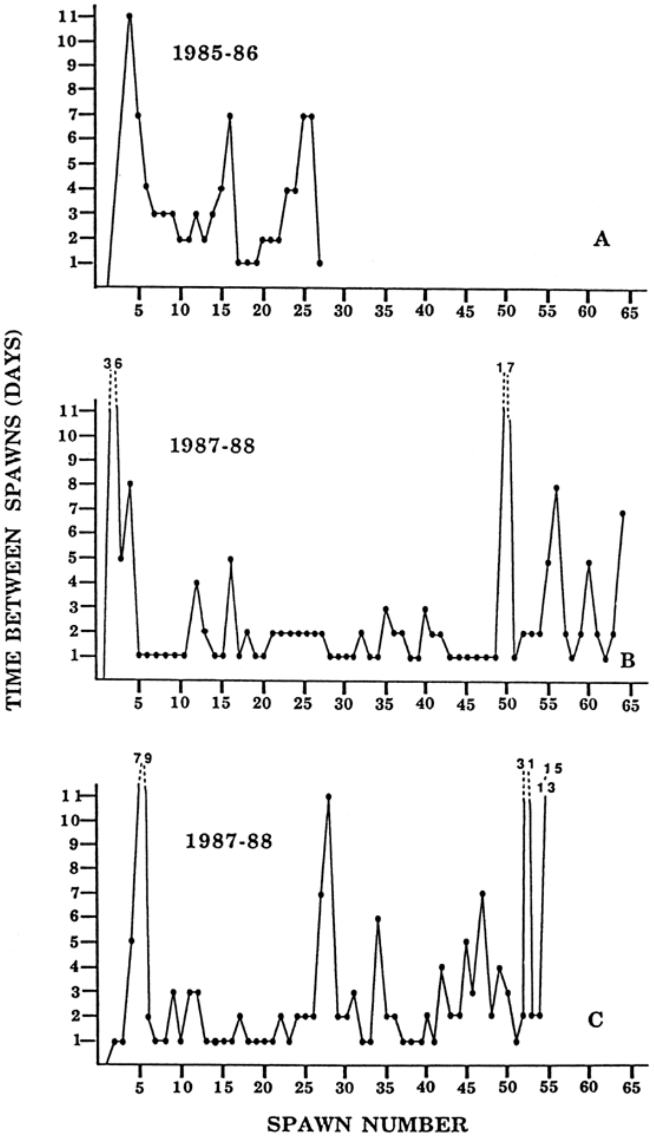

FIGURE 6. Elapsed time between consecutive spawns. A) and B) Group I brood stocks; C) Group II brood stocks.

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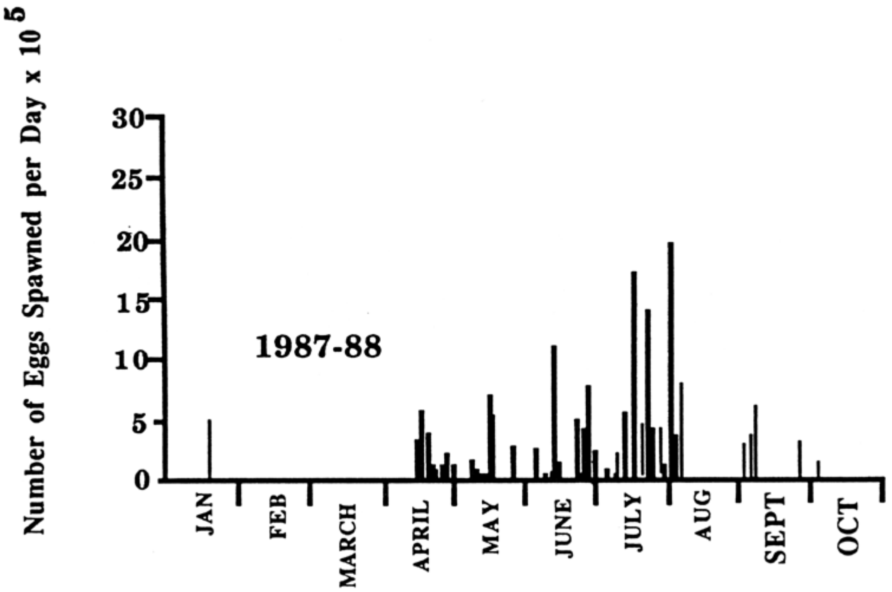

FIGURE 7. Recorded spawning events for halibut brood stocks held under artificial environmental conditions. No spawns occurred until January of 1988.

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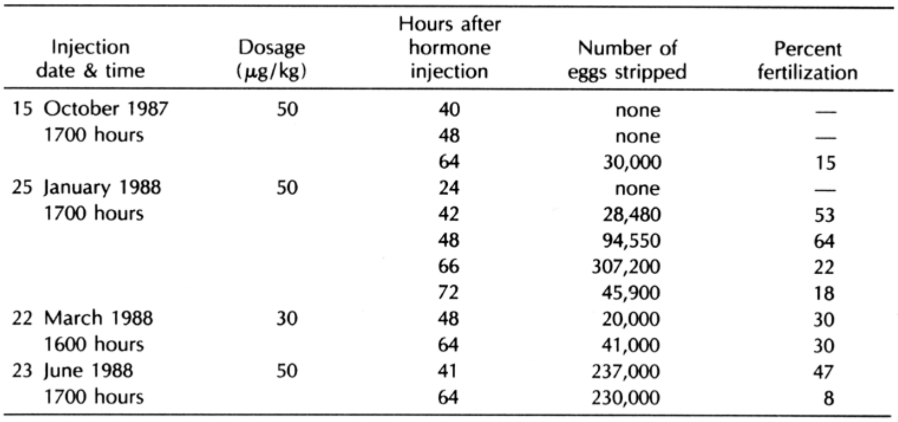
from those that were fertilized and had ceased development at an early stage. However, because fertilized eggs were recovered in most spawns, undeveloped eggs probably were nonviable.

Hormone Injection

Attempts to hormonally induce spawning of captive halibut with carp pituitary were largely unsuccessful. Although eggs were expelled in several trials, resultant eggs appeared abnormal and fertilization was unsuccessful. Experiments employing LHRH-a, however, consistently showed positive results at various dosages. In the first trial ovarian development was evident approximately 40 h after injection and monitored (through catheter insertion) at 40, 48, and 64 h (Table 4). Eggs were successfully stripped at 64 h and fertilization success was about 15%.

On 25 January 1988 eggs were successfully stripped at 42, 48, 66, and 72 h following injection and totaled almost 500,000 (Table 4). Successful ovulation and fertilization rates appeared highly dependent upon time following injection. No eggs could be manually stripped 24 h after injection; egg numbers manually stripped at 42, 48, and 66 h increased with time but fertilization success and survival decreased; by 72 h, both the number of eggs stripped and fertilization success declined. More eggs were stripped the third day than the second day after injection, but many fertilized eggs developed abnormally; all eggs stripped at the last time period died before hatching. Five days after the initial injection the female died, possibly from stress associated with handling and reinjection procedures.

TABLE 4. Egg production from LHRH-a injection trials. Eggs were manually stripped and fertilized.



Injection date & time	Dosage (μg/kg)	Hours after hormone injection	Number of eggs stripped	Percent fertilization
15 October 1987	50	40	none	—
1700 hours		48	none	—
		64	30,000	15
25 January 1988	50	24	none	—
1700 hours		42	28,480	53
		48	94,550	64
		66	307,200	22
		72	45,900	18
22 March 1988	30	48	20,000	30
1600 hours		64	41,000	30
23 June 1988	50	41	237,000	47
1700 hours		64	230,000	8

TABLE 4. ***Egg production from LHRH-a injection trials. Eggs were manually stripped and fertilized.***

To determine dosage effectiveness and avoid hormone-induced fish mortalities, another female was injected in late March with LHRH-a at a lower dose of 30 [u]g/kg. Ovarian swelling was observed 2 d later and a total of approximately 61,000 eggs were taken 48 and 64 h after hormone injection. Normal egg development occurred in 30% of the fertilized eggs.

The fourth trial conducted on a 4.8 kg female successfully produced 237,000 eggs 41 h following injection with a fertilization success of 47%. Although egg buoyancy was abnormal (many developing eggs sank instead of floating), hatched larvae were reared past the stage of first feeding (6–10 d). Eggs obtained 64 h after injection, had extremely low fertilization rates and died within several days.

DISCUSSION

Numerous factors synergistically influence fish reproduction, including adequate nutrition, pheromones, tidal cycles, temperature, photoperiod, water quality, and social interactions. Elucidating the precise reproductive role of each factor through laboratory studies is hindered because the diverse experimental conditions adopted by various investigators lead to inconsistent and often contradictory results (Bye 1984). Laboratory conditions remove numerous environmental variables, possibly elevating the relative importance attributed to individual environmental stimuli. Furthermore, reproductive cycles are adaptive and probably species specific (Scott 1979). Despite these problems, general patterns can be postulated for individual species.

Feeding

Inadequate food availability can seriously inhibit gonad maturation. Tyler and Dunn (1976) reported that winter flounder, Pseudopleuronectes americanus, under conditions of imposed starvation, significantly reduced or eliminated yolk-bearing oocyte production. The authors concluded that this species adopts a strategy favoring somatic anabolism over ovarian development when food supplies are limited. California halibut were fed in excess to avoid this problem. Correlating precise feeding trends with environmental or physiological factors was complicated by the fact that ingestion rates and spawning activity were related to the entire brood stock rather than to individual fish. In general, feeding may be indicative of physiological condition as increased stress adversely affects feeding behavior resulting in reduced ingestion rates, weight loss, and overall poor health (DeGroot 1971). In our studies, length-weight relationships equaled or exceeded those reported from the field (Haaker 1975) indicating brood stock health was adequate.

Temperature and Photoperiod

Temperature and photoperiod are generally regarded as the primary exogenous factors regulating sexual maturation and effecting the timing of teleosteon reproduction (De Vlaming 1972; Scott 1979; Crim 1982; Bye 1984). Spawning of California halibut held under natural environmental conditions (Group I) generally began in later winter (February–March) following the lowest temperatures and shortest photoperiods. Thus, decreasing fall photoperiod and water temperatures may provide the exogenous cue for oogenesis, while the increasing daylengths of early winter induce final maturation and spawning. Based on spawning patterns displayed by Group I and Group II, seasonal temperature cycles appeared less important in stimulating gametogenesis than maintaining water temperatures within a specified range and manipulating photoperiod. These results are comparable with findings from other studies (Bye 1984) where pleuronectiform fishes were successfully spawned by holding temperature constant and increasing photoperiod. Devauchelle et al. (1987) observed with sole, Solea solea, spawning was obtained through cyclic daylength variations only, and annual cyclic temperature variations were unnecessary although adjustment within a specified temperature range was important.

Analysis of environmental parameters suggest for California halibut spawning commences when water temperatures range between 15.0°C and 16.5°C and daylength exceeds 10.5 h. Spawning of Group I halibut in 1988 may have been delayed due to the persistent suboptimal water temperatures. Spawning was also delayed in the wild that year as newly settled larvae were collected through September (Kramer 1990).

Data from the first two spawning seasons of Group I indicated spawning ceased in April–May once average temperatures exceeded 16.5°C. Spawning of Group I in the 1987–88 season appeared less influenced by temperature as spawning continued throughout the summer and well into September when temperatures consistently surpassed 16.5°C and even reached 19.0°C. Likewise, the relationship between reproductive processes and photoperiod remains unclear. Group I spawning in 1986 and 1987 ceased when daylengths exceeded 13 h light but apparently exerted no inhibitory influence during 1988 as spawning continued through the summer when yearly daylengths are the longest. Spawning activity of Group II cannot help resolve photoperiod questions since imposed daylengths rarely exceeded 12.5 h light. Furthermore, the lack of comparable-treatment brood stocks under various simulated environmental regimes limits definitive conclusions.

Based on these results, ascertaining the precise influence environmental factors exert on spawning activity is difficult. Yearly variations in production and spawning behavior must be cautiously interpreted since brood stock composition, temperature regimes, and holding conditions varied. In previous field studies California halibut larvae were found year-round but exhibited a pronounced winter–spring pattern of high abundance (Lavenberg et al. 1986). The interrelationship of temperature and photoperiod and possibly other, as yet, unidentified influences, e.g. behavioral interactions, requires further elucidation before determining the extent of control over spawning behavior.

Holding Conditions

The Group I brood stock spawned throughout this study while Group II fish, under simulated environmental conditions, failed to spawn until the third year. Although not precisely equal, both groups were subjected to equivalent environmental regimes as the major seasonal cycles were duplicated under controlled conditions and synchronized with ambient patterns. The well-developed ovaries of individuals in the artificial brood stock group substantiate the stimulatory effect incurred by simulated environmental regimes. Previous studies with other species demonstrated environmental parameters need only approximate seasonal conditions to induce spawning (Lasker 1974; Arnold et al. 1977; Hoff et al. 1978; Roberts et al. 1978) and suggest minor environmental differences between the experimental groups were not responsible for spawning failure.

Besides environmental parameters, other holding conditions such as tank configuration, size, and color; placement indoors versus outdoors; light quality; captivity period; and brood stock composition and age differed between Group I and Group II and could potentially influence reproductive behavior. Because of limited laboratory space and halibut brood stock numbers, most of these factors could not be controlled and compared between the different brood stock groups, precluding meaningful discussions here. Distinct behavioral differences, however, observed between groups I and II, invoke the tentative hypothesis that reduced tank size, through behavioral modification, inhibited spawning activity of the group II fish.

California halibut in the 3000-L tanks often exhibited frantic swimming motions, occasionally slamming themselves against the tank wall if disturbed. Personnel simply entering the experimental room could elicit this response. When swimming quickly in smaller tanks, halibut constantly rubbed their jaws against the tank walls causing lesions and jaw damage that could be a significant source of stress. On other occasions, swimming fish responded to the observers presence by immediately sinking, darkening, and assuming a rigid posture. Similar behavioral sequences were designated "Fright Responses" by Olla et al. (1972) for Paralichthys dentatus and defined as a response to a sudden stimulus.

Previous investigators noted that flatfish have a predominate or significant diurnal activity pattern (Kruuk 1963; Verheijen and De Groot 1967). Group II brood fish remained buried and were rarely observed swimming or resting above the sand. In contrast, most Group I fish appeared primarily day-active and were frequently observed swimming throughout the water column. Upon visually sighting laboratory personnel, these fish would swim upwards and concentrate near the surface expecting to be fed. This rather domesticated behavior never characterized the Group II fish even though their captivity extended for a period of nearly 2 years. Also no physical damage such as lesions or tank-induced sores were observed on Group I halibut.

One female, whose physical condition progressively deteriorated while confined in the smaller pools, quickly recovered following transfer to the larger redwood tank, where she subsequently spawned. Furthermore, the close attendance of males to a swimming female may be periodically interrupted by striking the tank walls disrupting the synchronous release of gametes or adversely impacting spawning behavior. R. Leong (National Marine Fisheries Service, La Jolla, California, pers. comm.), utilizing larger tanks (5000–41,000 L), successfully induced halibut spawning employing similar artificial environmental regimes. Smigelski (1975b) hypothesized spawning failure of laboratory held Paralichthys dentatus may result from inadequate water depths. Although the vinyl tanks were shallower than the outdoor tanks (1.2 versus 2.5 m), the precise significance, if any, is unknown.

Halibut were transferred from the 3000-L tanks into one 12,780-L tank in the summer of 1986, effectively doubling the living area. No spawning occurred during 1987 but a general reduction of frantic swimming behavior was observed. After acclimating to these modified conditions for approximately 18 months, prolonged natural spawning commenced in 1988.

Diel spawning activity in 1986 became predominately nocturnal as the reproductive season progressed. A similar, but less pronounced spawning pattern was evident in Group I fish during 1988 but most spawning took place in the late afternoon (1430– 1700). Numerous marine fish species exhibit well defined diel spawning patterns (Marshall 1967; Ferraro 1980). One must question whether captive conditions disrupted timing cues or if the observed pattern represents normal behavior. For instance, lunar-dependent reproductive cycles are often influenced by associated processes, such as tides and currents, that laboratory situations remove. Once these environmental factors became decoupled, diel spawning periodicity could become increasingly unsynchronized.

Fluctuating spawning intervals suggest that maturation cycles change during the reproductive season. Maturation rates are influenced by temperature, daylength, food availability, population size, and age structure (Hunter and Leong 1971). Reproductive variations must be cautiously interpreted since laboratory-held brood stock composition changed each year. Spawning frequency varied from 4.7 to 14 d over the 3 year study period with spawning per female occurring approximately once every 7 d. Since spawning events likely involved several females, the longer spawning frequency calculated for Group I in 1988 by assuming each female spawned independently is probably an artifact of the larger female brood stock size rather than less frequent spawning. Another explanation simply entails that numbers of individuals participating in each spawn differs, changing the calculated spawning frequency. Spawning parameters of Group II fish in 1987–88 resulted from one female, indicating California halibut can consistently spawn three to four times each week over several months. However, this may be somewhat deceiving since approximately

35% of these spawns involved less than 100,000 eggs with extremely low viability rates. In addition, small spawns of nonviable eggs by Group I fish probably were undetected because the deeper tank depth and quiescent recirculating water flows would greatly facilitate sinking of nonviable ova.

Hormones

The response of female California halibut to carp pituitary was largely unsuccessful. This failure may result from the quality of the pituitary extract which varies significantly between purchased batches, because pituitary glands are extracted year-round without regard to the female carps' reproductive state. The actual concentration of hormones and relative potency in commonly available pituitary extracts is not standardized, leading to unpredictable (non-repeatable) results. Furthermore, the precise effect pituitary extract has upon fish of different species is poorly understood and even if fish were properly conditioned, successful inducement is not assured.

LHRH-a is a peptide that controls the synthesis and release of gonadotropins by the pituitary (Lee et al. 1986). Thus LHRH-a actually stimulates gonadotropin production of the injected fish, closely approximating the maturation process and reducing complications associated with interspecies hormonal differences. All trials employing this hormone induced halibut spawning with varying levels of success. Results indicate that most viable eggs are extracted approximately 2 d after injection even though greater numbers of eggs were stripped up to 1 d later. LHRH-a could also potentially reduce acclimation times in captivity. The 23 June 1988 spawning trial was particularly noteworthy because the fish was held under artificially simulated conditions less than 8 months, significantly less than normal acclimation periods of 2 years. Thus, a useful egg production strategy may involve conditioning California halibut ovaries through environmental manipulation and completing egg maturation with LHRH-a.

CONCLUSIONS

In conclusion, California halibut can be successfully spawned in captivity under natural (outdoor) and artificially simulated (indoor) conditions. Spawning typically starts after the coldest annual water temperature and shortest daylength. Spawning most often occurs when water temperatures are between 15.0°C and 16.5°C although spawning of Group I fish in 1988 continued in water temperatures well above 18°C. Fluctuating photoperiod appears particularly important as spawning rarely occurs below daylengths of 10.5 h. However, longer daylengths exerted no inhibitory effect on Group I fish during the 1988 spawning season. Concurrently held brood stocks located indoors and subjected to artificially simulated photoperiod and controlled water temperatures failed to spawn for 16 months until placed into a larger tank. Our observations suggest that the initial failure of brood fish to spawn under artificially simulated conditions resulted mostly from inadequate tank size, although inconsistent environmental regimes could also play an important role. LHRH-a injections successfully induced halibut spawning at several dosages and potentially can be used to reduce acclimation times or induce spawning when necessary for egg or larval fish experiments. This study can only be considered preliminary and additional experiments using brood stocks under various environmental regimes are needed to elucidate the precise environmental parameters for sustained spawning. Recommended conditions to induce spawning are presented in Table 5.

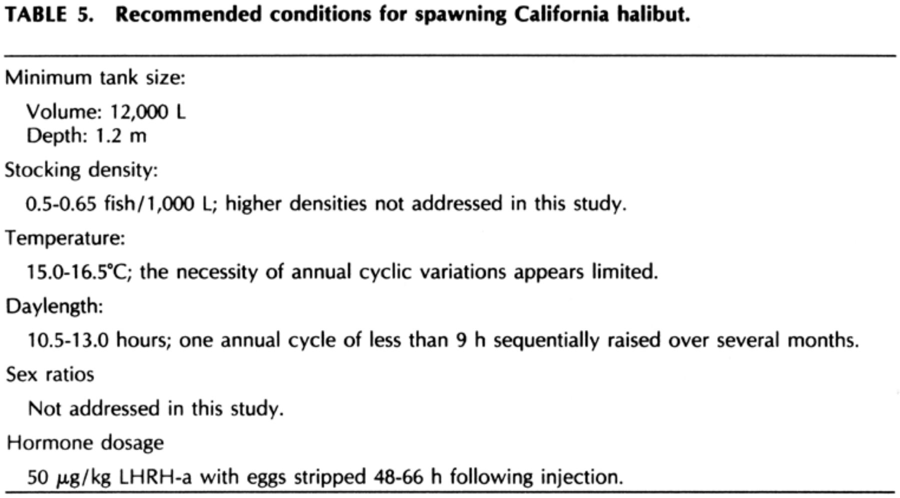


TABLE 5. Recommended conditions for spawning California halibut.

Minimum tank size:
Volume: 12,000 L
Depth: 1.2 m

Stocking density:
0.5-0.65 fish/1,000 L; higher densities not addressed in this study.

Temperature:
15.0-16.5°C; the necessity of annual cyclic variations appears limited.

Daylength:
10.5-13.0 hours; one annual cycle of less than 9 h sequentially raised over several months.

Sex ratios
Not addressed in this study.

Hormone dosage
50 μg/kg LHRH-a with eggs stripped 48-66 h following injection.

TABLE 5. ***Recommended conditions for spawning California halibut.***

ACKNOWLEDGMENTS

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MOVEMENT AND GROWTH OF TAGGED CALIFORNIA HALIBUT, PARALICHTHYS CALIFORNICUS, OFF THE CENTRAL COAST OF CALIFORNIA

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ABSTRACT

To document movement and estimate growth rates, 1052 California halibut, Paralichthys californicus, were tagged and released off the central California coast from April 1987 through December 1988. Based on 42 preliminary recoveries as of 1 January 1989, annual growth averaged 67 mm/year for fish of 428–561 mm total length. Movement data showed that 55% of tag recoveries exhibited no net movement from point of release and that movement distance was not related to time at liberty nor to size at time of tagging. Fifty percent of fish exhibiting movement greater than 1 km from initial tagging location did so in a southward direction. Southward moving fish displayed average movement distances that were over ten times greater than those of northward moving fish.

INTRODUCTION

The California halibut, Paralichthys californicus, is an economically important species of the family Bothidae ranging from Magdalena Bay, Baja California to the Quillayute River, Washington (Kucas and Hassler 1986). Traditionally considered a southern California species, halibut are currently the source of profitable fisheries as far north as Fort Bragg (California Department of Fish and Game [CDFG], unpublished data). In 1988, over 47% of all commercially caught California halibut were landed north of Point Conception (CDFG, unpublished data).

Despite its economic importance, however, information on halibut movement is sparse; all tagging studies to date have concentrated in the southern California regions, south of Point Conception (Young 1962; Haaker 1975; Vojkovich n.d.).

The objective of this study was to gather information on halibut movement and growth off the central coast of California, north of Point Conception (Santa Barbara County).

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MATERIALS AND METHODS

As part of the CDFG's Alternative Gear Development Program (AGDP), 1052 California halibut were tagged between Point Arguello (Santa Barbara County) and Point Sur (Monterey County) from April 1986 to January 1989. The AGDP, mandated by Assembly Bill 2915 (Ch. 910, Stats. 1986, the Nearshore Gill and Trammel Net Fisheries Mitigation Act) commenced in 1986 to assess the use of alternative types of commercial fishing gear in areas closed to the use of gill and trammel nets (Haseltine and Thornton 1990). Onboard observers were provided by the CDFG to monitor fishing operations of program permitees and collect fishery data. Among other functions, observers dedicated substantial time to tagging sublegal halibut (<559 mm) and collecting reproductive information on this species. Otter trawl gear was exclusively used by each of four Morro Bay permitees participating in the program with tow duration ranging from 15 min to 2 h (**x**=1 h).

Catch was sorted by species, with first priority given to sublegal halibut. These were handled as quickly as possible and measured to the nearest millimeter total length (anteriormost extremity to the center lobe of the caudal fin). Fish were tagged using 70 mm bright yellow anchor tags bearing the inscription "REWARD CFG MONTEREY R00000", and later "CDFG CC00000". Tags were applied intramuscularly at midbody, near the dorsal fin on the eyed side of each fish. Topical nitrofurazone (0.2%) was applied to the tagging needle prior to every tag application and also applied to obvious external wounds caused by net abrasion or handling. Most fish (84%) were injected with oxytetracycline hydrochloride (OTC, dilution 100 mg/ml) to fluoresce otolith annuli, using a dosage of 25 mg/kg (Pattison and McAllister 1990). Notes were made for each tagged fish concerning external appearance (e.g. cut, multiple tag wounds, distinguishing marks) and release condition (e.g. poor, good, weak, floater). Fish in apparent terminal condition generally were not tagged.

Major tagging locations were: San Simeon Bay area (*N*=211 fish), south Estero Bay (*N*=521), and San Luis Bay (*N*=122), with additional tag sites scattered throughout the Point Arguello-Point Sur area (Figure 1). All tagged fish were released between the 8 and 28 fm contours (**x**=14 fm). Tagged halibut that were recovered within 5 d of their release were examined and re-released.

Reward posters were used to inform the public of the CDFG's tagged halibut program and to solicit cooperation in returning tags or tagged whole fish along with catch data. Posters were placed in areas that were highly visible to the public (e.g. sporting goods stores, public boat ramps, commercial passenger fishing vessel (CPFV) landings, and public piers). Five dollar rewards were paid to fishermen returning the tags and appropriate information to the CDFG.

Growth rate was determined by posttagging change in length over time at liberty. Growth data was categorized as being either verified or unverified, depending upon the circumstances of the recovery. Fish measured by CDFG biologists were considered verified, while those measured by someone other than CDFG biologists were considered unverified. Fish that were in too poor condition to accurately measure were also considered unverified. The growth rate calculated using unverified lengths was compared by regression analysis with the growth rate calculated using verified lengths. All lengths were then

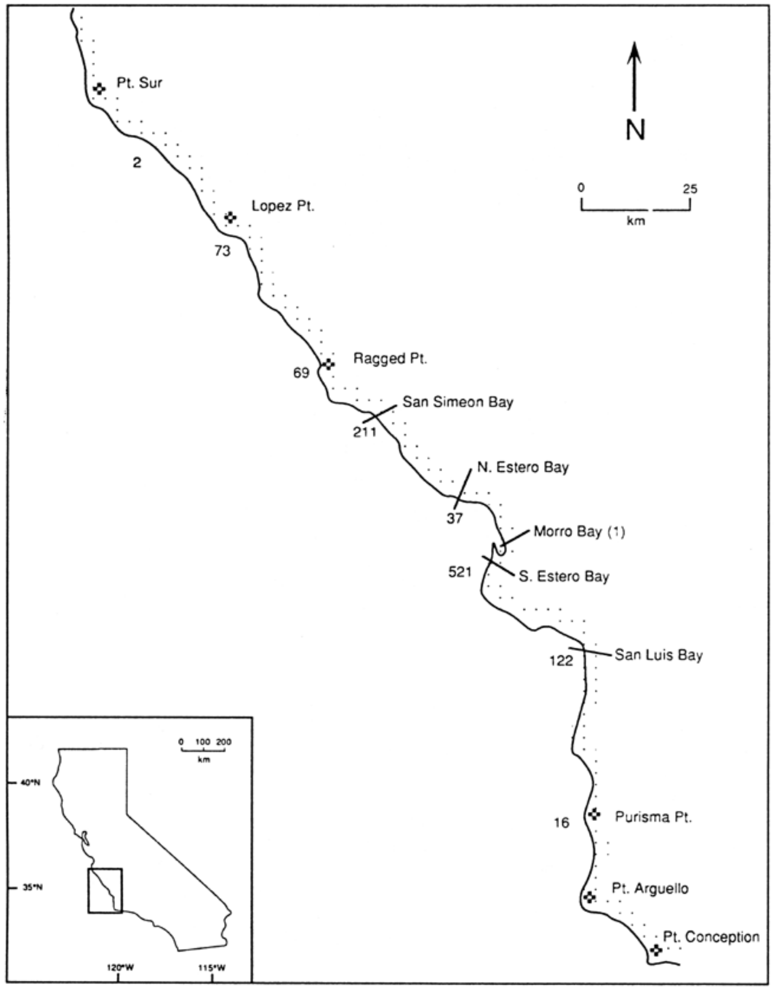

FIGURE 1. Tagging locations for 1052 California halibut and numbers tagged by location off central California during 1987 and 1988.

FIGURE 1. Tagging locations for 1052 California halibut and numbers tagged by location off central California during 1987 and 1988

combined to calculate an annual growth rate by regression analysis of all recovered fish providing growth information.

Otoliths were extracted from recaptured halibut that had been previously injected with OTC. These were packaged along with catch data from individual halibut and sent to CDFG biologists working on age and growth studies (Pattison and McAllister 1990).

Movement was analyzed in terms of direction and distance traveled. Distance moved was tested for correlation with size at tagging and days at liberty using regression analysis. Direction of movements was categorized as: no movement, northward movement, southward movement, or movement into Morro Bay Estuary. Each catagory was then examined for its relation to distance moved, size at tagging, and initial tagging location.

RESULTS

As of 1 January 1989, 56 tagged halibut (5.3%) had been recovered. of these, 11 were re-released, and three displayed evidence of broken or shed tags. of the remaining 42 recoveries, 39 provided growth information and 40 provided movement data (Table 1).

Thirty-nine (69.6%) of the recoveries were captured with trawl gear by fishers working under the guidelines of the AGDP. The balance of recoveries were collected as follows: 10 (17.9%) by sport anglers aboard private vessels, 5 (8.9%) by commercial gillnetters, and 2 (3.6%) by passengers aboard CPFV's.

Twenty-five recoveries providing growth information were categorized as verified while 14 were categorized as unverified. Regression analysis of all 39 growth recoveries produced an annual growth figure of 66.7 mm per year ($y = -7.34 + .20277x$, where y = growth in mm and x = days at liberty). Using only the 25 verified growth recoveries, regression analysis yielded a figure of 68.1 mm per year ($y = -7.66 + .20758x$). Both plots are shown in Figure 2. Thirty-one of these recoveries were of known sex; all but one were female. Length at tagging ranged from 428 to 561 mm for the 39 recoveries with an average tagging length of 532 mm.

Forty halibut provided movement information. Movement distance ranged from 0 to 291 km from point of release with a mean distance traveled of 17.1 km. Most recoveries (55%) occured at the location of original release, with net movement for the remaining fish as follows: 1–10 km, 17.5%; 11–30 km, 12.5%; 31–70 km, 12.5%; > 70 km, 2.5%.

There appeared to be no correlation between net distance moved and time at liberty, as evidenced by regression analysis of the two parameters (N=40, r=.027, $P < .001$). Time at liberty ranged from 6 to 373 d, with an average liberty time of 151 d. Movement per day ranged from 0 to 2.1 km ($\bar{x}$=0.13 km/day).

Distance moved also showed no correlation with size at the time of tagging when the two were plotted against each other in a regression analysis (N=40, r=.086, $P < .001$). Lengths of the 1052 halibut tagged in this study ranged from 330 to 562 mm with a mean tagging length of 500 mm. Length at tagging for the 40 halibut providing movement data ranged from 428 to 561 mm, averaging 529 mm.

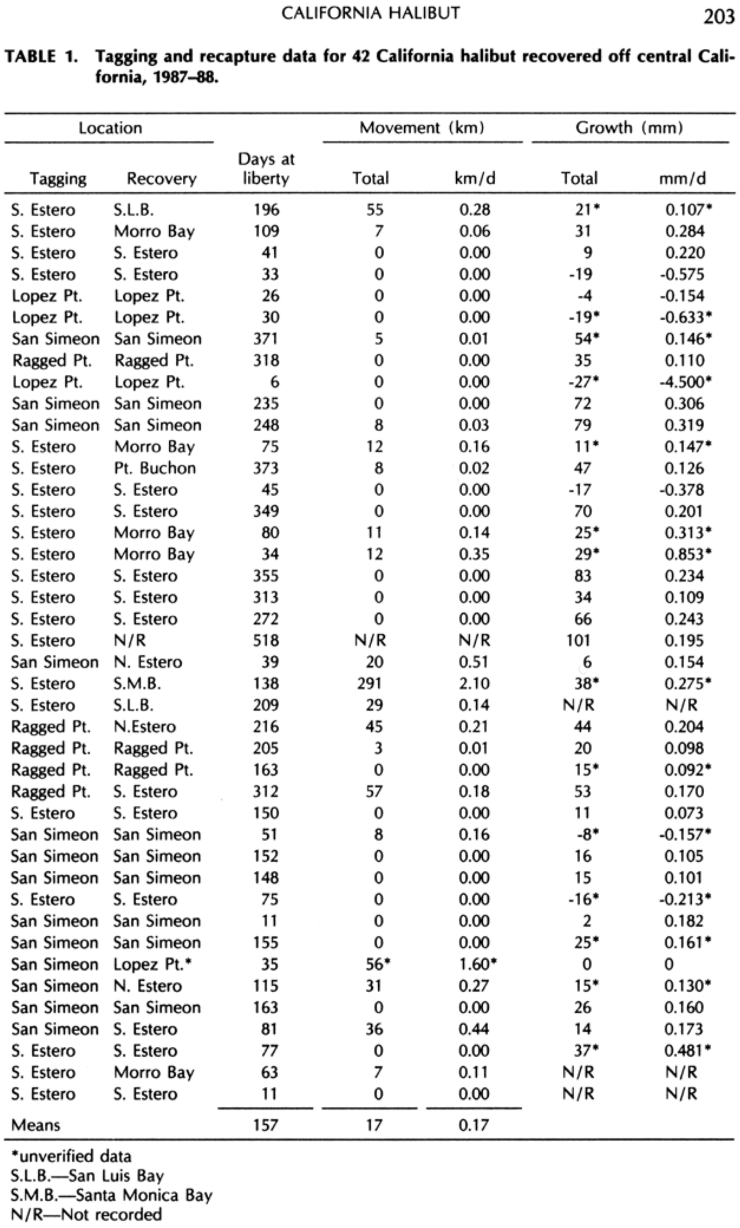

TABLE 1. Tagging and recapture data for 42 California halibut recovered off central California, 1987–88.

Location			Movement (km)		Growth (mm)	
Tagging	Recovery	Days at liberty	Total	km/d	Total	mm/d
S. Estero	S.L.B.	196	55	0.28	21*	0.107*
S. Estero	Morro Bay	109	7	0.06	31	0.284
S. Estero	S. Estero	41	0	0.00	9	0.220
S. Estero	S. Estero	33	0	0.00	-19	-0.575
Lopez Pt.	Lopez Pt.	26	0	0.00	-4	-0.154
Lopez Pt.	Lopez Pt.	30	0	0.00	-19*	-0.633*
San Simeon	San Simeon	371	5	0.01	54*	0.146*
Ragged Pt.	Ragged Pt.	318	0	0.00	35	0.110
Lopez Pt.	Lopez Pt.	6	0	0.00	-27*	-4.500*
San Simeon	San Simeon	235	0	0.00	72	0.306
San Simeon	San Simeon	248	8	0.03	79	0.319
S. Estero	Morro Bay	75	12	0.16	11*	0.147*
S. Estero	Pt. Buchon	373	8	0.02	47	0.126
S. Estero	S. Estero	45	0	0.00	-17	-0.378
S. Estero	S. Estero	349	0	0.00	70	0.201
S. Estero	Morro Bay	80	11	0.14	25*	0.313*
S. Estero	Morro Bay	34	12	0.35	29*	0.853*
S. Estero	S. Estero	355	0	0.00	83	0.234
S. Estero	S. Estero	313	0	0.00	34	0.109
S. Estero	S. Estero	272	0	0.00	66	0.243
S. Estero	N/R	518	N/R	N/R	101	0.195
San Simeon	N. Estero	39	20	0.51	6	0.154
S. Estero	S.M.B.	138	291	2.10	38*	0.275*
S. Estero	S.L.B.	209	29	0.14	N/R	N/R
Ragged Pt.	N.Estero	216	45	0.21	44	0.204
Ragged Pt.	Ragged Pt.	205	3	0.01	20	0.098
Ragged Pt.	Ragged Pt.	163	0	0.00	15*	0.092*
Ragged Pt.	S. Estero	312	57	0.18	53	0.170
S. Estero	S. Estero	150	0	0.00	11	0.073
San Simeon	San Simeon	51	8	0.16	-8*	-0.157*
San Simeon	San Simeon	152	0	0.00	16	0.105
San Simeon	San Simeon	148	0	0.00	15	0.101
S. Estero	S. Estero	75	0	0.00	-16*	-0.213*
San Simeon	San Simeon	11	0	0.00	2	0.182
San Simeon	San Simeon	155	0	0.00	25*	0.161*
San Simeon	Lopez Pt.*	35	56*	1.60*	0	0
San Simeon	N. Estero	115	31	0.27	15*	0.130*
San Simeon	San Simeon	163	0	0.00	26	0.160
San Simeon	S. Estero	81	36	0.44	14	0.173
S. Estero	S. Estero	77	0	0.00	37*	0.481*
S. Estero	Morro Bay	63	7	0.11	N/R	N/R
S. Estero	S. Estero	11	0	0.00	N/R	N/R
Means		157	17	0.17		

*unverified data
S.L.B.—San Luis Bay
S.M.B.—Santa Monica Bay
N/R—Not recorded

TABLE 1. ***Tagging and recapture data for 42 California halibut recovered off central California, 1987–88.***

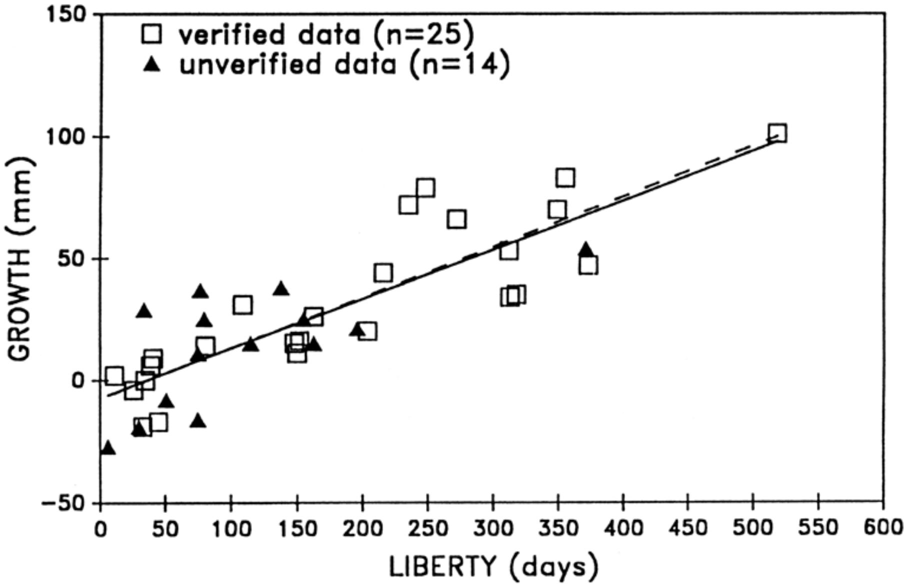

FIGURE 2. Growth versus time at liberty. Dashed plot represents verified data ($y = -7.65 + 0.20758x$, $r=0.873$, $P < 0.001$). Solid plot represents both verified and unverified data combined ($y = -7.34 + 0.20277x$, $r=0.844$, $P < 0.001$).

FIGURE 2. Growth versus time at liberty. Dashed plot represents verified data ($y = -7.65 + 0.20758x$, $r=0.873$, $P < 0.001$). Solid plot represents both verified and unverified data combined ($y = -7.34 + 0.20277x$, $r=0.844$, $P < 0.001$)

Eighteen recoveries were recorded as moving greater than 1 km from the location of tagging. Nine of these moved south, four moved north, and five moved into Morro Bay Estuary. Twenty-two halibut exhibited no net movement from the point of release.

Travel distance of southward moving halibut ranged from 8 to 291 km, with an average of 63.6 km. This is greater than ten times that of fish noted to have moved north ($\bar{x}$=6.0 km, range=3–8 km). Five fish recovered within Morro Bay Estuary had moved distances of 7–12 km from release locations ($\bar{x}$=9.8 km). Mean tagging lengths for each of the four movement groups were: south, 533 mm; north, 531 mm; into Morro Bay Estuary, 514 mm; and none, 531 mm.

Initial tagging locations for fish that displayed southward movement ranged from the Ragged Point area to South Estero Bay. Those of northern moving fish ranged from the Ragged Point area to San Simeon Bay. Fish that exhibited no net movement were tagged from the Lopez Point area to the South Estero Bay area. All fish recovered within Morro Bay Estuary were tagged just outside and south of the harbor mouth, in the South Estero Bay location (Figure 1).

DISCUSSION

Growth

The annual growth rate calculated from the data collected in this study, 66.7 mm/year, is lower than previous calculations in the literature. Frey (1971) reported an annual growth rate of approximately 100 mm/year for female halibut of 438–648 mm total length in fish sampled from the Santa Barbara to Port Hueneme areas of southern California. Haaker (1975), in studying halibut within Anaheim Bay in southern California reported a growth rate of 154.6 mm/year in female fish of 150–460 mm standard length ($\bar{x}$=301.3 mm). Young (1962) provided an overall growth figure of 26.9–88.9 mm/year for both male and female fish of 330–508 mm total length tagged in the areas bordered by Sebastian Viscaino Bay, Baja California and Gaviota, California.

Sources of error exist when calculating growth from tag returns only, as was done in this study. These sources included handling shock, postmortem shrinkage, and differential growth related to size and sex of fish sampled and to seasonal growth rates. It has been shown that the handling-tagging process is, in itself, sufficient to disrupt normal patterns of growth for some species. Holland (1957) noted the lack of growth and sometimes shrinkage of tagged and released spiny dogfish, Squalus acanthias, at liberty up to 303 d. Seven of 39 recoveries yielding growth information in this study were recorded as having decreased in length since the time of tagging (four were unverified). Liberty for these fish ranged from 6 to 75 d, averaging 38 d.

Postmortem shrinkage of halibut in this study may have also contributed to lower than expected growth rates. A recent study revealed that California halibut decrease in length considerably when iced post mortem; shrinkage of up to 12 mm was documented in only 45 h of iced storage time (CDFG unpublished data). Unfortunately, several fish in this study had been iced in fish holds up to 5 d prior to measurement. Most fish, in fact, had been iced at least 1 d prior to examination. Ideally, live recovery lengths would have been preferable.

Although the halibut recovered in this study represented a relatively narrow size range (428–561 mm, $\bar{x}$=532 mm), differential growth may have occurred, skewing the calculated growth rates. Likewise, seasonal variation in growth rates (i.e. summer versus winter rates) may have had a similar effect.

Movement

Movement of halibut within the geographic boundaries of this tagging study were revealing; all halibut displaying significant movement (> 20 km) did so in a southward direction. The four fish recorded to have moved north appeared to display a homing type behavior, returning to locations from which they were conceivably displaced during trawling operations. No southward moving fish were noted to have displayed such homing behavior; all moved substantial distances from initial trawl locations.

Young (1962) found that smaller halibut (< 559 mm) in southern California tended to move south from point of release while larger halibut (> 559 mm) tended to move north. All fish tagged in this study were less than 563 mm, with fish larger than this size marketed by the fishermen. Data collected in this study appear to suggest that smaller halibut (< 563 mm) off the central coast of California may behave similarly to southern California fish.

Young (1962) reported a majority of tagged fish (87%) moved less than 10 naut mi (18.5 km); which compares favorably with the results of this study in which eighty percent (N=32) of tagged fish moved less than 10 naut mi. Haaker (1975) reported that of fish tagged within Anaheim Bay, 85% of recoveries were made at the station of original release.

Young (1962) also reported that his data suggested a positive correlation between distance moved, by fish that did move, and time at liberty. This study did not show such correlation in fish tagged off the central California coast.

All five fish recovered within Morro Bay Estuary were caught by sport anglers during July through September, reflecting increased sportfishing effort during the summer. Halibut are believed to migrate seasonally into Morro Bay in response to increased densities of prey, primarily northern anchovy, Engraulis mordax.

Although providing valuable data, this paper reconfirms the need for more extensive tagging work on this species off central and northern California.

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AGE DETERMINATION OF CALIFORNIA HALIBUT, PARALICHTHYS CALIFORNICUS

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ABSTRACT

Our study's purpose was to determine the most reliable ageing method and structure for California halibut, Paralichthys californicus. Specimens were collected from California waters during 1955–66 and 1984–88. Sagittal otoliths, scales, opercula, preopercula, and subopercula were collected, examined, and compared, and ages assigned to 2216 halibut. Precision was determined by comparing within-reader and between-reader age assignments. We validated ages by noting banding patterns on oxytetracycline-treated structures, documenting edge types, comparing within- and between-reader age determinations, correlating ages from different structures, and analyzing length- frequency modes. Broken-and-burned, cut-and-burned, and sectioned-and-burned otoliths were comparable to age 10 with surface-read whole otoliths, scales, opercula, preopercula, and subopercula. Beyond age 10, broken-and-burned, cut-and-burned, and sectioned-and- burned otoliths yielded older ages than the other methods or structures. The ageing technique of choice is the cut-and-burned otolith viewed with a coating of water. If edge-type determination is needed, the operculum is recommended.

INTRODUCTION

Age, length, and weight data are needed to provide information on stock composition, age at maturity, life span, mortality, growth, and production of fish. All of these elements are necessary to make sound management decisions.

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Management of California halibut, Paralichthys californicus, has been hampered by lack of information concerning many of these important elements. Increasing landings of this species by both the commercial and recreational fisheries has precipitated the need for additional information concerning halibut biology.

Age determination of halibut was first attempted in 1918 due to concern over high fishing levels and declining catches. Thompson (1918) examined scales and otoliths from four halibut and reported "The rate of growth was obtained from the age marks on both scales and otoliths, the latter being plainest." Higgins (1919) also examined the scales and otoliths from a number of halibut. He concluded that otoliths could not be used for age determination ". . . on account of the indefinite nature of the rings. . . ," and that scale annuli were well defined by the crowding of circuli. Although he expended considerable effort in scale circuli density measurements, a determination of age was not achieved.

The next major study involving the age and growth of California halibut was conducted during 1955–66 (Schott n.d.). Schott retired from the California Department of Fish and Game (CDFG) before publishing the results of his study. Because of the unavailability of his data to the scientific community, we have combined his age data with ours from southern and central California.

Haaker (1975) determined ages using otoliths but aged only halibut of less than 3 years of age.

The purpose of our study was to determine the most reliable methods and structures for determining age throughout the life span of halibut in southern and central California. Halibut sagittal otoliths, scales, opercula, preopercula, and subopercula were collected, examined, and compared. A number of preparation techniques and ageing methods were applied to the different structures in an attempt to clarify growth rings and increase readability. Formation of annual growth zones on ageing structures was validated from oxytetracycline-injected, tagged and recaptured fish. Ages were assigned to 2216 halibut. Precision was determined by comparing ages assigned within and between readers.

MATERIALS AND METHODS

Halibut ageing structures were collected from San Francisco to Morro Bay 1984–86, *N* = 157) and from Point Conception to San Diego (1955–66, *N* = 903 and 1985–88, *N* = 1156). A variety of collection methods (trawl, gill net, beach seine, hook and line, and spearfishing) were used to obtain specimens of all sizes. Fish were measured (total length) and sex was determined. Sagittal otoliths, scales (from 10 areas of both the sinistral and dextral sides), opercula, preopercula, and subopercula were taken. Opercula were cleaned in boiling water within 2 h of collection. All ageing structures were stored in coin envelopes after being cleaned.

Various preparation and ageing methods were applied to the collected structures to clarify growth rings and to increase readability. Water, vegetable oil, or anise oil was used as a coating on ageing surfaces to decrease glare and increase contrast. Scales were viewed between glass. Most opercula, preopercula, and subopercula were viewed while submerged in water. Otoliths were viewed: 1) whole while submerged in either water or anise oil (those in anise oil were soaked for a minimum of 2 weeks); 2) broken in half, burned, and brushed with either water or vegetable oil; 3) cut in half, burned, and brushed with either water or vegetable oil; 4) sectioned, after soaking in anise oil for a minimum of 2 weeks; and 5) sectioned, burned, and brushed with either water or vegetable oil.

All ageing structures were viewed on a dark background by use of a stereomicroscope with magnification of 6-50x. Lighting ranged from reflected fiber optic to incandescent to polarized.

A birth date of 1 January was assigned (Williams and Bedford 1974). We defined the annulus as the combination of an inner opaque and adjacent outer translucent zone (Casselman 1983).

Validation

We followed Beamish and McFarlane (1983) for verifying and validating ages. We compared or determined the following:

Ring formation frequency based on fishes injected with oxytetracycline hydrochloride (OTC)

Many investigators have used OTC injection for validating fish ages (Kobayashi et al. 1964; Holden and Vince 1973; Wild and Foreman 1980; and Campana and Neilson 1982). To test the effectiveness of OTC in marking bony parts of halibut, 10 halibut collected from Elkhorn Slough were held at the CDFG's Granite Canyon Mariculture Laboratory. Five halibut were injected with OTC at a dosage of 25 mg/kg of body weight into the middorsal musculature midway between the base of the dorsal fin and the lateral line on the eyed side. The captive halibut were offered anchovies, squid, and rockfish during the holding period of 102–171 days. Otoliths and other bony structures collected at the end of this period were viewed under ultraviolet light.

We also obtained OTC-marked otoliths from halibut which had been injected at time of tagging in a separate movement study (Tupen 1990). Syringes were preloaded with a solution of OTC at an aqueous concentration of 100 mg/ml and injected into the wound created by the tagging needle at a dosage of 25 mg/kg. We examined otoliths from 20 OTC-treated halibut recaptured after being at liberty up to 357 days.

Comparison of margin type by month from otoliths and opercula

We examined 194 otoliths and 176 opercula to determine if the margin was translucent or opaque. We then calculated the percentage of translucent margins occurring on otoliths and opercula during each month of the year.

Comparison of within- and between-reader age assignments

Three readers read a total of 143 otoliths from one to three times (Table 1A) for comparison of within-reader precision (Beamish and Fournier 1981). The time between readings ranged from 48 h to several months. We measured the precision using average percent error as described by Beamish and Fournier (1981). This method takes into consideration the range of year classes being aged and is dependent upon the age of the fish.

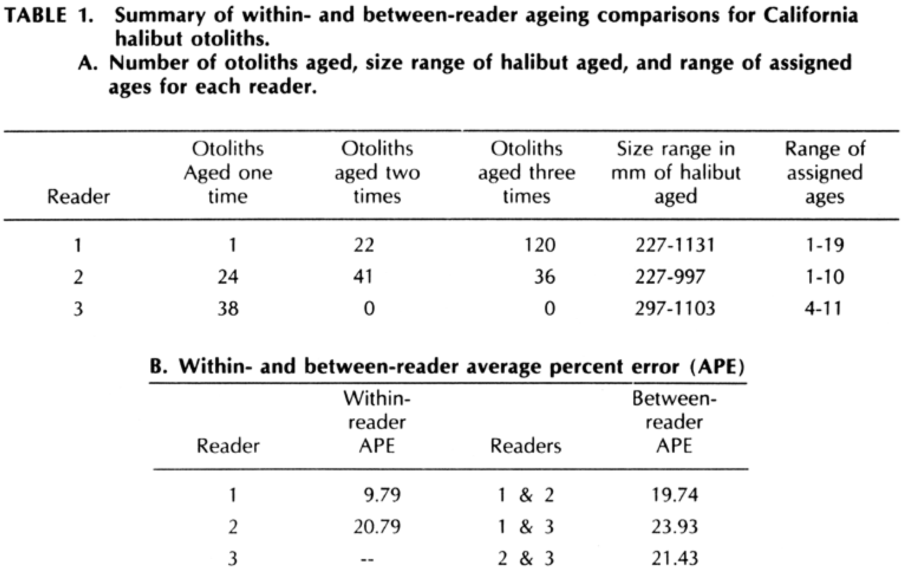

TABLE 1. Summary of within- and between-reader ageing comparisons for California halibut otoliths.

A. Number of otoliths aged, size range of halibut aged, and range of assigned ages for each reader.

Reader	Otoliths Aged one time	Otoliths aged two times	Otoliths aged three times	Size range in mm of halibut aged	Range of assigned ages
1	1	22	120	227-1131	1-19
2	24	41	36	227-997	1-10
3	38	0	0	297-1103	4-11

B. Within- and between-reader average percent error (APE)

Reader	Within-reader APE	Readers	Between-reader APE
1	9.79	1 & 2	19.74
2	20.79	1 & 3	23.93
3	--	2 & 3	21.43

*TABLE 1. **Summary of within- and between-reader ageing comparisons for California halibut otoliths.***

Comparison of ages derived from whole (surface read), cut-and-burned, and sectioned-and-burned otoliths

We used regression analysis to compare ages derived from 175 whole otoliths, 59 cut-and-burned otoliths, and 57 sectioned-and- burned otoliths.

Comparison of length at age derived from otoliths and opercula

We compared assigned ages derived from otoliths from 115 females and 40 males and opercula from 90 females and 32 males. Analysis of variance was used to test the difference between regression lines of length at age between structures.

Determination of age classes using length-frequency analysis

Many investigators have used length-frequency analysis for age verification of the first several years of life (Miller 1955; Westrheim 1972; Campbell and Collins 1975; Haaker 1975; Gregory and Jow 1976; Kimura et al. 1979; Mayo et al. 1981) when age classes are sometimes distinct.

A total of 1173 juvenile halibut were collected and measured (not aged) in southern California over a 2-year period in a seperate study by Schott (unpublished). Length frequencies were compared with 421 otoliths assigned the ages of 0, 1, and 2 years.

RESULTS

Otoliths proved to be the most reliable age indicator. Whole otoliths were examined; however, whole otolith surface ageing does not account for asymmetrical growth. We attempted the break- and-burn method, but the otolith often crumbled so that there was no readable surface remaining. The cut-and-burn and the section- and-burn methods revealed 2 to 5 more annular zones than had been found on whole otoliths in a number of the large halibut.

Broken-and-burned, cut-and-burned, and sectioned-and-burned otoliths were comparable up to age 10 with surface-read whole otoliths, scales, opercula, preopercula, and subopercula. Beyond age 10, however, broken-and-burned, cut-and-burned, and sectioned-and-burned otoliths often yielded older ages than the other methods or structures.

The best marked scales were found on the eyed side, dorsal to the lateral line, and immediately anterior to the caudal peduncle, but it was difficult to distinguish annular zones from checks. The average length at age for 0-, 1-, and 2-year halibut as determined from reading scales was smaller than indicated by the monthly length frequencies.

The suboperculum was the best marked skeletal element for age determination but was not useful in medium- or large-size fish as older rings were obliterated by internal bone erosion and vascular encroachment.

of 2216 halibut for which ages were determined, 1662 (75%) were female and 554 (25%) were male. The halibut age groups ranged from 1 to 30 and lengths from 131 to 1270 mm. Female age groups ranged from 1 to 30 and from 155 to 1270 mm. Male age groups ranged from 1 to 23 and from 131 to 1085 mm (Table 2). The largest female sampled was 17 years old and 1270 mm, the oldest aged was 30 at a length of 1180 mm. The largest male was 12 years old and 1085 mm, the oldest was 23 at a length of 910 mm. The smallest maturing female observed was 409 mm, the smallest maturing male 229 mm.

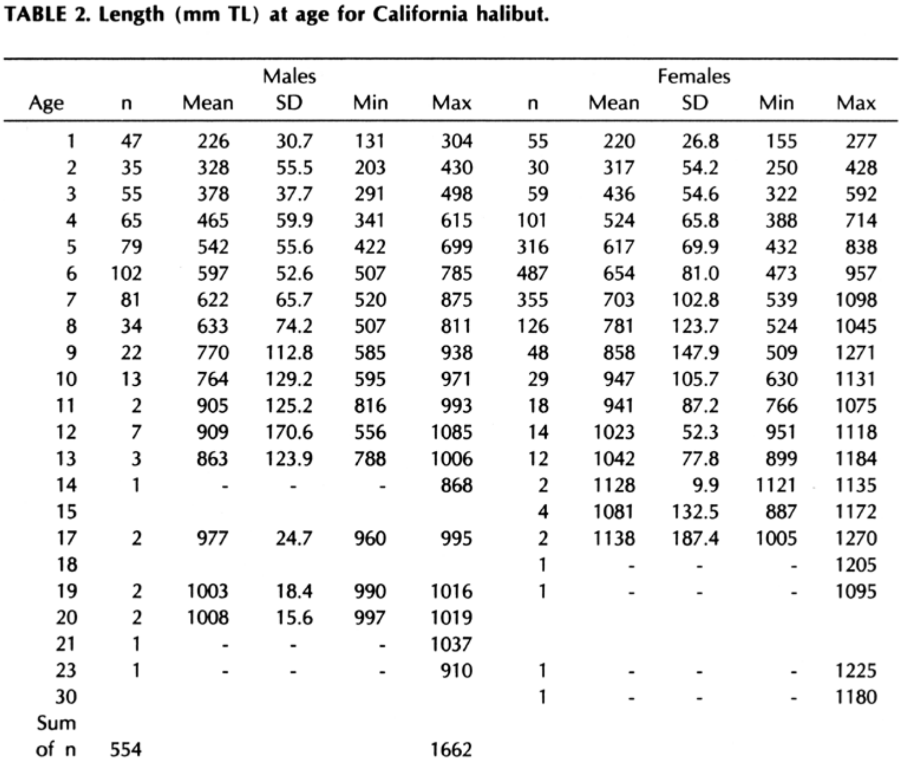

TABLE 2. Length (mm TL) at age for California halibut.

	Males					Females				
Age	n	Mean	SD	Min	Max	n	Mean	SD	Min	Max
1	47	226	30.7	131	304	55	220	26.8	155	277
2	35	328	55.5	203	430	30	317	54.2	250	428
3	55	378	37.7	291	498	59	436	54.6	322	592
4	65	465	59.9	341	615	101	524	65.8	388	714
5	79	542	55.6	422	699	316	617	69.9	432	838
6	102	597	52.6	507	785	487	654	81.0	473	957
7	81	622	65.7	520	875	355	703	102.8	539	1098
8	34	633	74.2	507	811	126	781	123.7	524	1045
9	22	770	112.8	585	938	48	858	147.9	509	1271
10	13	764	129.2	595	971	29	947	105.7	630	1131
11	2	905	125.2	816	993	18	941	87.2	766	1075
12	7	909	170.6	556	1085	14	1023	52.3	951	1118
13	3	863	123.9	788	1006	12	1042	77.8	899	1184
14	1	-	-	-	868	2	1128	9.9	1121	1135
15						4	1081	132.5	887	1172
17	2	977	24.7	960	995	2	1138	187.4	1005	1270
18						1	-	-	-	1205
19	2	1003	18.4	990	1016	1	-	-	-	1095
20	2	1008	15.6	997	1019					
21	1	-	-	-	1037					
23	1	-	-	-	910	1	-	-	-	1225
30						1	-	-	-	1180
Sum of n	554				1662					

TABLE 2. ***Length (mm TL) at age for California halibut.***

Validation

Ring formation frequency based on fishes injected with OTC

Three of the 10 fish held at the Granite Canyon Mariculture Laboratory died during the holding period. Five of the remaining seven had been injected with OTC. The halibut did not visibly feed during the holding period and lost from 20.3 to 45.1% of their body weight. No growth was observed. However, all injected specimens exhibited fluorescence on the otolith edge.

We analyzed OTC-marked otoliths from 20 recaptured halibut provided by Tupen (1990). of note was that in four of these fish (20%) one otolith of a pair did not fluoresce. These tagged fish had been at liberty from 11 to 357 days. of these 20, we examined otoliths from four fish at liberty from 313 to 357 days for frequency of ring formation. We assumed that halibut which had completed nearly one year of growth would best test the formation of a yearly ring. In all cases one ring was laid down. All four halibut were females and ranged from 579 to 608 mm and from 4 to 6 years of age.

Comparison of margin type by month from otoliths and opercula

We read otolith margins easily up to 6 or 7 years of age. In contrast, we could usually read operculum margins for any age. We found no significant difference at [a]=0.05 between margin type by structure using a paired *t* test.

We were unable to read 11 of 194 otolith and operculum margins (6%). Most readings came from samples collected between May and August. We determined margin type from as few as one individual in January and November to 53 in August. Although few readings were obtained in winter, we noted a general pattern of growth increase in spring (increase in percentage of opaque margins) to a maximum in summer and gradual cessation of growth into late fall. We identified rapid growth beginning in spring and continuing into fall by opaque growth beyond a translucent ring on both structures. We noted a slowing of growth in October by the increasing percentage of translucent otolith margins. The percentage of translucent margins remained above 50% from November through March. Opaque margins are prevalent from April to October and translucent margins from November to March. Rapid growth in spring and summer corresponds with opaque margin formation. It appears only one complete ring is formed per year on all structures examined.

Comparison of within- and between-reader age assignments

The within-reader average percent error (APE) for the two readers tested was 9.79 and 20.79 (Table 1B). This means that Reader 1 assigned the same age to an otolith 90.21% of the time and Reader 2 assigned the same age 79.21% of the time. This indicates that Reader 1 is more precise than Reader 2 by 11%. The between-reader APE for the three readers tested ranged from 19.74 to 23.93 (Table 1B). We feel that the low degree of error in assigning ages to 12 different age groups indicates that age determination of halibut from otoliths is acceptably precise.

Comparison of ages derived from whole, cut-and-burned, and sectioned-and-burned otoliths

We compared ages of 109 whole, 60 cut-and-burned, and 59 sectioned-and-burned otoliths. Regression line analysis indicated no significant difference between ages assigned by the cut-and- burn or section-and-burn methods (*P*=0.89 for the overall test, *P*=0.63 for equality of slope, and *P*=0.97 for equality of elevations between regression lines). A significant difference was found between both cut-and-burn and section-and-burn ages when compared to surface-read ages ($P < 0.0001$ for the overall test and for equality of slope, and *P*=0.01 for the equality of elevations between regression lines).

Comparison of length at age derived from otoliths and opercula

We found no significant difference for length at age between structures for either sex using analysis of variance (*P*=0.16 for males and 0.30 for females for the overall test, *P*=0.06 for males and 0.74 for females for the equality of slopes, and *P*=0.75 for males and 0.13 for females for equality of elevations between regression lines).

Determination of age classes using length-frequency analysis

Lengths of 421 halibut were assigned ages of 0, 1, and 2 from whole otoliths. The 421 lengths were superimposed upon the monthly length frequencies of 1173 halibut. The superimposed lengths fit the growth progression. In a separate study, a halibut in captivity increased in length from 8 to 34 mm in a 3 month period (E.H. Ahlstrom, U.S. Fish and Wildlife Ser., pers. comm. to Schott). The captive halibut's growth rate closely paralleled the growth trend of both the monthly length frequencies and the halibut otoliths assigned the ages of 0, 1, and 2 years.

DISCUSSION

The sample of OTC-tagged halibut otoliths and the analysis of margin type support our assumption that one annulus is formed per year. The lack of growth in laboratory-held fish is directly attributable to their inability to feed. However, even in these five injected halibut, fluorescence was observable on the otolith, indicating normally feeding fish should incorporate the chemical to an even greater degree. The 25 mg/kg dosage was adequate to mark otoliths of recaptured tagged fish. A yellow band was observable on the otoliths under ultraviolet light. Strength of fluorescence was variable and may have been linked to the amount of chemical injected, the amount incorporated, or the otolith cleaning or storage technique. We have no explanation for the four injected fish which each had one otolith which did not fluoresce.

We found the cut-and-burn method of ageing halibut otoliths superior in many ways to all other ageing methods used in this study. We used water, vegetable oil, and anise oil to coat the viewing surface. While all three coatings are satisfactory for viewing, the advantage of water is that it leaves no residue.

Seven reasons for preferring the cut-and-burn method follow: 1) Otoliths grow fairly symmetrically up to a certain size after which growth may become asymmetrical in either or both length and width (Williams and Bedford 1974; Beamish 1979; Boehlert and Yoklavich 1984; and Campana 1984). Surface ageing of whole otoliths does not allow for examination of asymmetrical growth (Beamish 1979; Boehlert and Yoklavich 1984; and Campana 1984). 2) Burning the otolith produces distinct dark translucent zones because of the greater concentration of organic matter in these zones. The darkened translucent zones contrast with the lighter opaque zones, and checks tend to be obscured

(Williams and Bedford 1974; Chilton and Beamish 1982; Campana 1984; Calliet et al. 1986). 3) An advantage of cut-and-burn over break-and-burn is the ability to insure that the cut passes through the center of the otolith nucleus. Failure to pass through the nucleus center will result in an age being misinterpreted by at least one year (Williams and Bedford 1974). 4) The cut-and-burn method provided two good halves with smooth viewing surfaces while a break-and-burn otolith often crumbled and left an irregular viewing surface (Chilton and Beamish 1982). 5) The section-and-burn method offers no advantage over the cut-and-burn method. 6) Operculum, preoperculum, and suboperculum ageing is unreliable in older fish due to the rings being obliterated by internal bone erosion and vascular encroachment. 7) Scale ageing is unreliable due to the difficulty of distinguishing annular zones from checks.

We believe either an otolith or an operculum could be used to determine margin type. However, the operculum margin type was much easier to determine and much less likely to be obscured. The operculum's thin flat surface allowed margin type determination more readily than did the otolith from the same halibut.

We strongly recommend the collection of both opercula and otoliths for determination of margin type and age, respectively, in any future halibut ageing studies. The recommended ageing structure is the sagittal otolith prepared using the cut-and-burn method, viewed on a dark background with reflected fiber-optic lighting with water brushed lightly across the cut surface. If determination of edge type is desired, the operculum should be viewed submerged in water on a dark background with reflected fiber-optic lighting.

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HISTORY OF THE COMMERCIAL CALIFORNIA HALIBUT FISHERY

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ABSTRACT

The commercial fishery for California halibut, Paralichthys californicus, is concentrated in varying degrees from the Bodega Bay area to San Diego and on into Mexican waters. The California fishery has shifted northward from the Baja California-Los Angeles area and is now centered off the Santa Barbara region. Otter trawls and set gill and trammel nets are the commercial fishing gears most commonly used to harvest halibut. The dominant gears in southern California are now set gill and trammel nets. The gear types and regulations governing commercial harvest are reviewed. Trends in commercial landing figures are discussed and suggest that the natural population peaks every 20 years.

INTRODUCTION

The California halibut, Paralichthys californicus, has been a sport and commercial species for more than a century. Its geographic range is from the Quillayute River, Washington to Magdalena Bay, Baja California (Miller and Lea 1972). The commercial fishery is concentrated in varying degrees from the Bodega Bay area to San Diego and on into Mexican waters. Commercial fishing gears most commonly used to harvest halibut are otter trawls and set gill and trammel nets. This paper provides an overview of trends in the commercial landings since the early 1920s, and changes in gear and geographic extent of this fishery.

HALIBUT FISHING GEAR

Trawl Nets

The original type of trawl or drag net used in California, the paranzella, was towed by two vessels. It was introduced in San Francisco in 1876, and was the standard in California for the next 50 years (Clark 1935). In the late 1930s and early 1940s, California fishermen started using the otter trawl. In this method "otter boards" or "doors" are attached at the mouth of the net to keep it open, eliminating the necessity of a second boat (Scofield 1948).

Entangling Nets

Entangling nets, which are set or anchored at both ends, have been used continuously since the 1880s to catch halibut and shark (Ueber 1988). Originally entangling nets were made of cotton or hemp. A traditional halibut entangling net is the trammel net, which consists of three walls of multifilament webbing attached to common cork and lead lines (Clark 1931; Herrick and Hanan 1988; Ueber 1988).

The set gill net is the other type of entangling net used today in the halibut fishery. The single panel of monofilament webbing is designed to catch fish when they attempt to swim through it. Halibut are generally wedged in the net—held by a mesh at the widest part of their bodies (Philip Beguhl, gill net fisherman, pers. comm.).

When a line or "suspender" is used on a gill net and causes the webbing of the net to bag or hang slack, the net is designated a trammel net under California law (Herrick and Hanan 1988; Ueber 1988). Today multipanel trammel nets are being replaced by monofilament, single-panel suspendered nets.

Historically, most California halibut landed were taken by trammel nets or trawl. Set gill nets in southern California have replaced the trawl as a dominant gear in the fishery.

Hook and Line

A small amount of the total commercial landings have traditionally been taken by hook and line. In 1988, 8% (89,700 lb) of the landings were made by hook and line.

CHANGES IN THE FISHERY

Set entangling nets are the dominant gear in southern California (Point Conception to the Mexican border) for the halibut fishery (Herrick and Hanan 1988). Trammel nets have been the gear used exclusively by the San Diego and San Pedro halibut fleet (Clark 1931) since legislation in the early 1900s prohibited the use of trawl nets off Los Angeles and San Diego Counties.

In the Santa Barbara area prior to 1969, the trawl fishery produced the greatest catch. By the 1970s the majority of the halibut caught in the area was by set gill and trammel nets (Karpov 1981; Methot 1983). Since then, entangling nets have continued to be the dominant gear in the Santa Barbara area. Several factors may have accounted for this shift. First, new regulations were placed on the commercial trawl fishery early in the 1970s (area and season closures). Second, trawling is an expensive method of fishing when compared to the efficiency and effectiveness of fishing entangling nets from small vessels (Karpov 1981; Methot 1983).

The geographic center of the halibut fishery has changed. Historically the fishery was centered off southern and Baja California. When collection of fish statistics began (1916), large catches of halibut were made by the San Pedro fleet in local waters from January to June. From June to December the fleet fished Mexican waters and made large catches, most of which were landed in San Diego (Clark 1931). North of Ventura County, the fishery was much smaller.

In recent years, the center of the fishery has shifted north (Roedel and Frey 1968; Frey 1971; MBC 1987). For the past decade, the greatest landings have been made in Ventura and Santa Barbara Counties. The exception was in 1983, the second year of an El Niño event, when the greatest landings were made in the San Francisco area (Appendix I).

REGULATIONS AND MANAGEMENT

The halibut fishery is managed by the California Department of Fish and Game in state waters (0–3 naut mi). In federal waters, the Fishery Conservation Zone (3–200 naut mi), no restrictions exist on the halibut fishery except the minimum mesh size requirement for trawl nets. Presently bottom trawls must have a minimum mesh size of 4.5 inches (114 mm).

Trawl nets were prohibited in Monterey Bay and state waters off Ventura, Los Angeles, Orange, and San Diego Counties in 1913. In 1915 this legislation was amended to prohibit trawling anywhere in state waters. Legislation in 1925 legalized trawling off the coast of Santa Barbara County inside the 3-naut-mi limit, but 1953 legislation prohibited it. Once again, the entire coast of California was closed to trawling within the 3-naut-mi limit.

In 1968 the use of trawl nets was authorized between Point Sur and Cape San Martin in waters not less than 1 naut mi from the mainland. Trawl use was also permitted between Point Arguello and El Capitan Point (Santa Barbara County), in waters not less than 25 fm or 1 naut mi from shore. Since much of the nearshore coastal area in the northern portion of Santa Barbara County is rocky bottom (precluding the use of trawl gear) this allowance had little effect on the fishery.

The low catch in the late 1960s prompted the California Legislature to designate an area not less than 1 naut mi from the mainland shore, between a line running due west from Point Arguello and a line running due south from Point Mugu, in waters not more than 25 fm deep as "California halibut trawl grounds" (Figure 1), effective 1971 (Fish and Game Code, sec. 8495). This expansion of the traditional trawl grounds was accompanied by additional regulations. A 4-month closure on the trawl grounds from February through May was made to protect spawning adults. In 1973 this closure was shifted from 15 March to 15 June to encompass the peak of the season and provide a window when halibut spawning could occur without interference from trawl fishing activities. Also in 1972 a 7.5-inch (190 mm) mesh trawl cod end was required on the trawl grounds to allow for the escape of undersize halibut. Schott's (1975) evaluation of this regulation was that it was effective, and that most fishermen were pleased that a large number of undersize halibut and "junk" fish were escaping through the trawl cod end. In 1988 the definition of the trawl grounds was amended and the 25 fm clause was removed, effective 1 January 1989. Trawling is now allowed between Point Arguello and Point Mugu in waters farther than 1 naut mi from the mainland.

The use of trammel nets was prohibited in state waters in 1911. In 1913 trammel nets were again permitted, but were required to be pulled within 6 h. As early as 1917, some of the state's fishing districts required 8-inch (203 mm) mesh in any trammel net used. In a 1985 legislative bill, the mesh size was increased to 8.5 inches (216 mm) between Point Dume (Los Angeles County) and Ragged Point (San Luis Obispo County). In 1989 the 8.5-inch mesh size provision was adopted coastwide. Presently gill and trammel nets are prohibited in Santa Monica Bay. Gill and trammel nets are also subject to various depth, area, and season closures throughout the state that are too numerous to list (however, see e.g. Wild 1990).

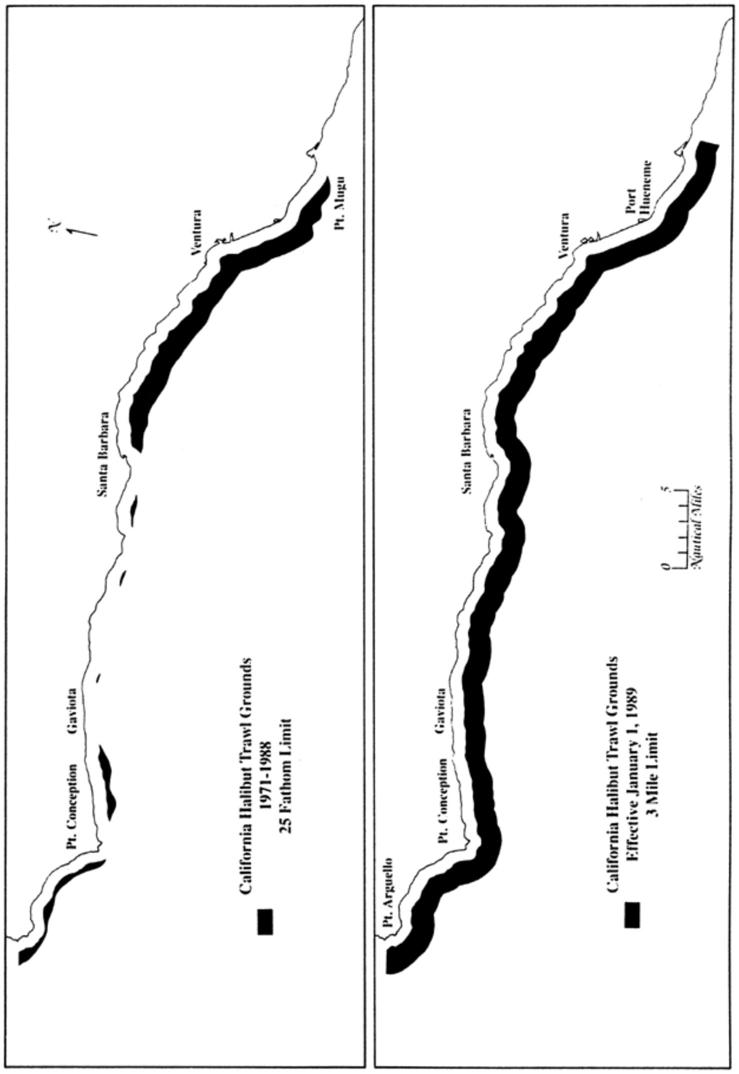

FIGURE 1. Map of the California Halibut Trawl Grounds as originally established, and after amendment effective 1 January 1989. Maps done by Deborah Morrisset.

FIGURE 1. Map of the California Halibut Trawl Grounds as originally established, and after amendment effective 1 January 1989. Maps done by Deborah Morrisset

In 1915 a regulation was passed that halibut less than 4 lb (1.8 kg) in the round (whole) could not be bought or sold. In 1931 it was further specified that halibut less than 3.5 lb (1.6 kg) dressed with the head on, or 3 lb (1.4 kg) dressed with the head off were not to be taken. However, up to 30 lb (13.5 kg) of halibut under the specified weights could be possessed for personal use but not for sale. In 1979 a law went into effect prohibiting the take, possession, or sale of halibut under 22 inches (559 mm) in total length. A 1985 law reduced the number of halibut that could be retained for personal use to four (about 12 lb [5.4 kg]).

COMMERCIAL CATCH

The halibut fishery is year-round in southern California, but is most active during the winter and spring. off the central California coast most of the catch is taken in the summer (Herrick and Hanan 1988). Halibut are generally delivered to the buyers intact with only the viscera removed. However, in the Monterey Bay area, most halibut are delivered in the round.

California halibut has always had to compete with Pacific halibut, Hippoglossus stenolepis, in the market place. Demand for California halibut in southern California usually exceeds supply, so prices are consistently high except when California's markets are flooded with Pacific halibut from Alaska at the opening of that season. In 1989 California halibut imported from Mexico depressed the market price and demand for local halibut. This may become a trend as Mexico increases its fishing efforts. Presently, the average price per pound to southern California fishermen for California halibut is $2.25.

California's statistical records on fish landings began in 1916. Prior to 1936, market receipts were simply made out as halibut, whether the species was California halibut or Pacific halibut. The two species overlapped in the San Francisco Bay area. Department field surveys in the 1930s determined a ratio of Pacific to California halibut of 9:1 at various times in this port. The early landing figures were corrected using this ratio (Holmberg 1949). Presently, Pacific halibut show up infrequently in catches in the San Francisco Bay area.

In this discussion, "total landings" include halibut caught in state waters and those caught in Mexican waters and landed in California. "California landings" exclude the catch from Mexican waters. In 1937 the Bureau of Commercial Fisheries (the fisheries branch of the Division of Fish and Game) reported that on average, 35% of the landings made in Los Angeles and San Diego were from Mexico, although they fluctuated greatly. After 1966 Mexican-caught fish were no longer a significant component of the total landings of halibut. This was due to financial and logistical considerations (Tony West, California Gillnetters Association, pers. comm.). A fishing trip to Mexico was no guarantee of large profits. When Mexican fishermen increased their fishing effort via small "cooperativas" (cooperatives), competition for the localized fishing areas in Mexico next to the kelp beds increased. The response of California fishermen was to extend their season by going to the Channel Islands and farther north rather than fishing in Mexican waters.

Total landings and California landings tend to mirror each other (Figure 2). Due to this and a lack of documentation of the fishery in Mexican waters, the landing trend discussion has been confined to California landings. California's landing figures are also presented in tabular form (Appendix II).

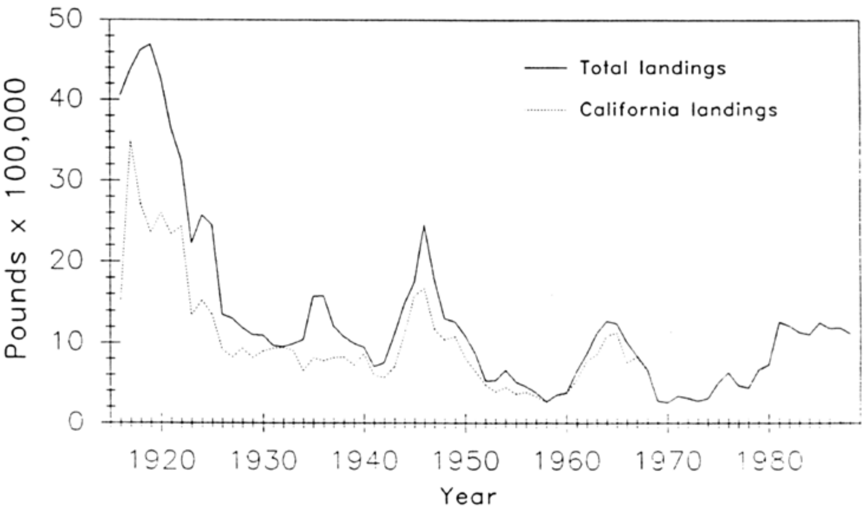

FIGURE 2. Commercial California halibut landings. The upper curve is total landings which includes fish caught in Mexican waters and landed in California. The lower curve is California landings, only fish caught in state waters.

FIGURE 2. Commercial California halibut landings. The upper curve is total landings which includes fish caught in Mexican waters and landed in California. The lower curve is California landings, only fish caught in state waters

Commercial catches of halibut have fluctuated over the years. The overall trend was thought to be one of decline (Frey 1971; Karpov 1981). However, landings peaked in 1981 and have exceeded 1 million pounds for the eighth straight year. Moser and Watson (1990) found that halibut larval abundance and the commercial landings mirror each other, with natural population peaks every 20 years. Without catch-per-unit-of-effort data, stock abundance cannot be accurately assessed. Catch data does allow one to observe trends and make reasonable first approximations of what has been happening, especially if it is correlated with human activities and notable oceanic events.

The record landing of halibut was 3.5 million pounds in 1917 which was followed by an 11-year decline. World War I contributed to this decline by reducing the number of fishermen, significantly limiting supplies for civilian use, and restricting boat activity. It is also possible that the Department's monitoring of fish landings was initiated just as this fishery had finished its growth phase (Gulland 1983).

When this country entered World War II, security regulations went into effect prohibiting noncitizens from fishing off the California coast. Since many California fishermen were Italian citizens, the halibut fishery was severely affected. From 1941 through 1943, landings were the lowest recorded since 1916.

After the war, California experienced a tremendous growth in population. The initial wartime fishing restraints probably allowed the halibut stocks to increase, and the postwar population growth fueled a large demand for fish resulting in sizable landings in the latter half of the decade. The rapid decline of the catch in the 1950s was probably an effect of this exploitation. Concurrently, there were nine consecutive years of subnormal temperatures, followed by a notable

El Niño (1957–59) that resulted in abnormally warm ocean temperatures (Radovich 1961). In 1958, only 256,000 lb of halibut were landed, the lowest ever recorded. The warm water of an El Niño event is often associated with an increase in juvenile recruitment of halibut and a decrease in landings of adults, as the population ranges farther north with the warm waters. However, since each El Niño event is unique, the effects are variable.

The next peak in the fishery was in 1965, the year after a major El Niño event. In 1969 another El Niño event occurred, and the halibut landings were very low in 1969 and 1970. The landings remained depressed throughout the 1970s. Two El Niño events occurred in this decade—in 1972–73 and 1976–77. The landings peaked again in 1981, and in 1988 exceeded 1 million pounds for the eighth straight year.

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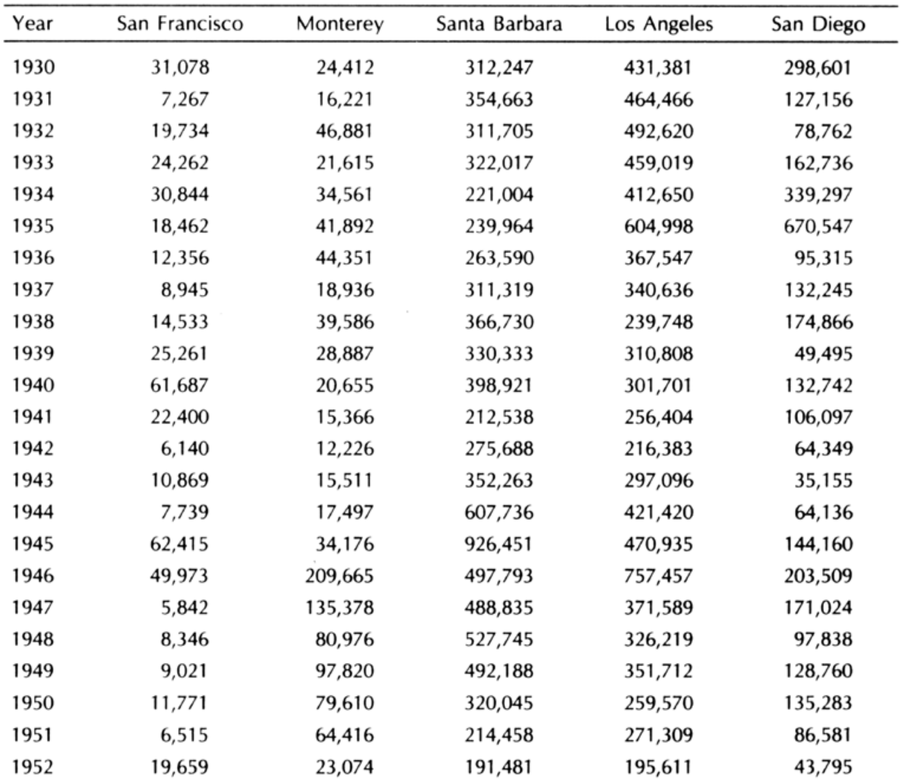
APPENDIX I



Year	San Francisco	Monterey	Santa Barbara	Los Angeles	San Diego
1930	31,078	24,412	312,247	431,381	298,601
1931	7,267	16,221	354,663	464,466	127,156
1932	19,734	46,881	311,705	492,620	78,762
1933	24,262	21,615	322,017	459,019	162,736
1934	30,844	34,561	221,004	412,650	339,297
1935	18,462	41,892	239,964	604,998	670,547
1936	12,356	44,351	263,590	367,547	95,315
1937	8,945	18,936	311,319	340,636	132,245
1938	14,533	39,586	366,730	239,748	174,866
1939	25,261	28,887	330,333	310,808	49,495
1940	61,687	20,655	398,921	301,701	132,742
1941	22,400	15,366	212,538	256,404	106,097
1942	6,140	12,226	275,688	216,383	64,349
1943	10,869	15,511	352,263	297,096	35,155
1944	7,739	17,497	607,736	421,420	64,136
1945	62,415	34,176	926,451	470,935	144,160
1946	49,973	209,665	497,793	757,457	203,509
1947	5,842	135,378	488,835	371,589	171,024
1948	8,346	80,976	527,745	326,219	97,838
1949	9,021	97,820	492,188	351,712	128,760
1950	11,771	79,610	320,045	259,570	135,283
1951	6,515	64,416	214,458	271,309	86,581
1952	19,659	23,074	191,481	195,611	43,795

APPENDIX I—*(continued)*

Year	San Francisco	Monterey	Santa Barbara	Los Angeles	San Diego
1953	5,838	29,079	156,775	118,035	78,012
1954	2,782	41,346	193,116	138,670	68,629
1955	41,754	31,147	136,337	84,933	69,663
1956	15,801	14,615	143,505	116,140	91,770
1957	14,310	19,981	118,328	47,808	132,157
1958	10,253	12,663	109,611	63,836	59,681
1959	34,282	9,218	178,886	60,807	62,093
1960	21,981	3,926	206,875	85,722	47,604
1961	50,050	9,957	191,674	127,695	165,880
1962	74,016	47,181	149,070	313,239	192,571
1963	125,801	62,361	278,040	268,424	120,101
1964	183,690	42,919	371,218	350,897	142,952
1965	162,517	94,065	396,291	355,408	119,777
1966	234,026	92,656	285,596	87,515	49,647
1967	264,960	100,622	304,967	110,411	43,959
1968	191,003	79,340	231,718	129,958	27,256
1969	90,238	24,149	51,582	70,183	36,121
1970	81,598	10,430	77,396	70,508	16,747
1971	63,664	47,812	134,198	78,454	12,217
1972	107,162	49,556	89,054	40,164	23,027
1973	34,522	52,046	137,609	19,749	28,490
1974	51,472	25,522	113,513	75,378	36,300
1975	53,613	22,684	185,919	138,672	102,855
1976	38,132	36,812	406,171	102,208	44,121
1977	40,517	14,913	296,072	74,566	41,501
1978	46,483	30,726	227,029	102,121	35,081
1979	89,637	30,569	371,663	124,540	48,751
1980	129,402	69,505	349,270	92,434	86,105
1981	317,965	40,709	680,175	173,316	49,008
1982	423,948	39,042	546,338	163,197	40,001
1983	551,806	22,510	372,584	131,331	51,965
1984	307,386	37,574	487,802	174,286	100,074
1985	236,195	73,207	499,820	315,121	131,363
1986	202,773	68,916	600,635	221,456	89,241
1987	97,769	94,362	607,945	307,911	79,555
1988	136,302	79,275	583,655	235,718	78,005

APPENDIX II

Year	Total	California	Mexico
1916	4,052,173	ca 1,500,000	ca 2,500,000
1917	4,379,312	ca 3,500,000	ca 800,000
1918	4,624,218	2,708,514	1,915,704
1919	4,698,123	2,362,520	2,335,603
1920	4,279,582	2,602,043	1,677,539
1921	3,653,861	2,340,428	1,313,433
1922	3,254,505	2,437,966	816,539
1923	2,229,381	1,347,243	882,138
1924	2,576,882	1,528,399	1,048,483
1925	2,452,551	1,352,248	1,100,303
1926	1,349,031	916,794	432,237
1927	1,303,559	818,517	485,042
1928	1,187,651	932,289	255,362
1929	1,102,573	811,427	291,146
1930	1,097,760	896,062	201,698
1931	969,773	929,306	40,467
1932	949,702	939,001	10,701
1933	989,649	904,829	84,820
1934	1,037,008	648,516	388,492
1935	1,575,863	810,291	765,572
1936	1,582,907	776,634	806,273
1937	1,207,235	812,365	394,870
1938	1,078,229	822,447	255,782
1939	991,621	722,084	269,537
1940	948,457	861,908	86,549
1941	706,650	592,911	113,739
1942	750,539	569,245	181,294
1943	1,111,998	701,219	410,779
1944	1,485,463	1,111,880	373,583
1945	1,748,821	1,582,150	166,671
1946	2,457,187	1,675,280	781,907
1947	1,787,901	1,172,638	615,263
1948	1,306,613	1,041,124	265,489
1949	1,262,514	1,079,501	183,013
1950	1,092,745	806,279	286,466
1951	865,933	643,279	222,654
1952	525,311	473,620	51,691
1953	530,315	387,739	142,576
1954	661,331	444,543	216,788

APPENDIX II—*(continued)*

Year	Total	California	Mexico
1955	509,802	363,834	145,968
1956	455,799	382,006	73,793
1957	376,815	332,584	44,231
1958	267,446	256,075	11,371
1959	354,242	345,286	8,956
1960	376,263	366,191	10,072
1961	654,554	545,472	109,082
1962	863,086	776,077	87,009
1963	1,120,369	855,092	265,277
1964	1,276,105	1,092,068	184,037
1965	1,243,718	1,128,348	115,370
1966	1,011,412	749,555	261,857
1967	838,058	824,919	13,139
1968	671,654	659,425	12,229
1969	274,277	272,331	1,946
1970	257,444	256,898	546
1971	336,871	336,416	455
1972	309,245	309,003	242
1973	273,526	272,466	1,060
1974	306,479	306,290	189
1975	508,913	507,785	1,128
1976	628,370	627,574	796
1977	467,862	463,760	4,102
1978	441,440	432,884	8,244
1979	665,546	658,892	6,399
1980	726,852	724,590	2,120
1981	1,262,265	1,259,029	3,236
1982	1,214,375	1,211,232	1,324
1983	1,130,581	1,130,543	38
1984	1,107,332	1,107,332	0
1985	1,256,375	1,255,913	204
1986	1,184,090	1,183,110	205
1987	1,188,881	1,186,272	2,609
1988	1,114,559	1,114,559	0

THE CALIFORNIA HALIBUT TRAWL FISHERY

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ABSTRACT

The catch of California halibut, Paralichthys californicus, by trawl gear is an important part of the total halibut catch. Examination of trawler data from logbooks and landing receipts provide information on halibut distribution, abundance, ecology, and biology.

The trawl fishery for halibut is centered off San Francisco in northern California and from Point Sal to Point Dume in southern California. From 1945 to 1979, southern California trawler landings were higher than those from northern California in most years. Since 1980, northern California landings have exceeded those from southern California.

Over the past 20 years, halibut abundance was high in the late 1960s, declined in the 1970s, and increased in the 1980s. The intense 1982–83 El Niño coincides with higher abundance and landings of halibut.

Questions are raised from examination of the trawler data set on stocks, ecology, and biology which require further work to answer.

INTRODUCTION

California halibut, Paralichthys californicus, is extremely important in commercial and recreational fisheries of the state. The commercial catches of halibut are taken in gill and trammel nets, in trawls, and by hook and line. Gill and trammel nets have produced most of the halibut catch, but trawl catches have been significant throughout the history of the fishery.

Trawling began in California in 1876 when a bottom fishing net, called a paranzella, was towed by a pair of lateen sail boats in San Francisco Bay. By 1880, the fishery moved outside the bay to the ocean. Sail power was replaced by steam, gasoline, and finally diesel engines (Clark 1935a). The two-boat or paranzella method persisted until the 1940s when one vessel otter trawling became the only method (Scofield 1948). The current fleet of 141 trawlers fish between southern California and southern Oregon in nearshore shoals to depths of over 915 m (500 fm). In the 1980s, trawlers landed 35,000 tonnes (77,000,000 lb) of groundfish annually of which 97 tonnes (214,000 lb) or 0.28% were halibut.

Early in the development of the trawl fishery, halibut were caught coincidentally with the target species English sole, Parophrys vetulus; petrale sole,

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Eopsetta jordani; and rockfish, Sebastes spp. off San Francisco. Small boats were successful in trawling halibut off Santa Barbara, San Pedro, and San Diego after 1900 (Scofield 1948). By 1915, regulation changes eliminated trawling and possession of trawls in southern California and prohibited trawling in all state waters inside 3 naut mi from shore. In 1917, trawling was allowed in state waters between the Carmel River and the San Luis Opisbo-Santa Barbara County line. State waters off Santa Barbara County were open to trawling in 1925. In 1953, trawling in state waters was prohibited. In 1971, trawlers could fish in the halibut trawl grounds between Point Arguello and Point Mugu (Santa Barbara Channel) in waters not more than 46 m (25 fm) deep and not less than 1 naut mi from shore with nets with 191-mm (7.5-inch) mesh cod ends. The open season in this area was from 1 June to 30 January. In 1972 the season was changed to 16 June to 14 March.

As halibut inhabit nearshore areas and are most abundant in shallow depths, the early southern California closure and prohibition of trawling in state waters curtailed trawler catches. The opening of state waters to trawling had the opposite effect.

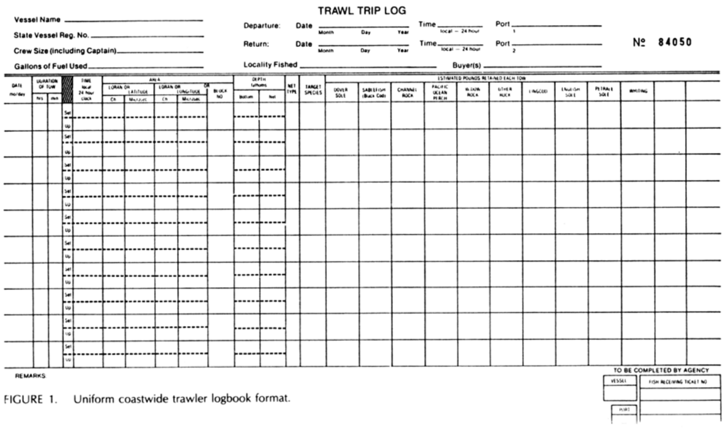
Halibut management could have the objective of promoting use, maintaining the resource, or rehabilitating the resource. Information is lacking to properly manage halibut. Data and analyses from each sector of the fishery to determine the halibut unit stock or stocks, biology, ecology, and status of stock are required for the basis of a rational management program. Here, I identify the trawler data set and provide analyses which define properties of the fishery and of the halibut resource. The trawler data can complement other available information as a start on a needed comprehensive resource assessment.

METHODS

Trawler Logbook Data

The trawler data system consists of logbook and landing receipt records, both required by law. Trawler logbooks have been required since 1934 (Clark 1935a). Trawler captains record catch location, depth, duration, and species caught on logbooks provided by the California Department of Fish and Game (CDFG). Several changes in log format have been made; a uniform coastwide logbook format is now used (Figure 1). When fish dealers buy fish they record weights and prices by species on forms provided by the CDFG (Figure 2). Logs and landing receipts are sent to the CDFG on a monthly and biweekly basis, respectively.

The basic catch location is the Fish and Game block, 10 min latitude by 10 min longitude rectangles. Each block has an unique block number (Clark 1935b). Log data are integrated with landing receipt data to provide species caught by block, depth, and time. For the years 1934 to 1975 each trip was assigned to a block and depth based on the area and depth of highest catch. From 1976 to the present, data from each tow with block, depth, time, and catch have been compiled. The data are compiled by block, depth, month, and year.



TRAWL TRIP LOG

Vessel Name ____________

State Vessel Reg. No. ____________

Crew Size (including Captain) ____________

Gallons of Fuel Used ____________

Departure: Date ____________ (Month Day Year) Time ________ (local — 24 hour) Port ________ 1

Return: Date ____________ (Month Day Year) Time ________ (local — 24 hour) Port ________ 2

Locality Fished ____________ Buyer(s) ____________

№ 84050

DATE mo/day	DURATION OF TOW			TIME local 24 hour clock	AREA					DEPTH fathoms		NET TYPE	TARGET SPECIES	ESTIMATED POUNDS RETAINED EACH TOW											
					LORAN OR LATITUDE		LORAN OR LONGITUDE		OR BLOCK NO					DOVER SOLE	SABLEFISH (Black Cod)	CHANNEL ROCK	PACIFIC OCEAN PERCH	WIDOW ROCK	OTHER ROCK	LINGCOD	ENGLISH SOLE	PETRALE SOLE	WHITING		
	hrs	min			Ch	Microsec	Ch	Microsec		Bottom	Net														
			Set Up																						
			Set Up																						
			Set Up																						
			Set Up																						
			Set Up																						
			Set Up																						
			Set Up																						
			Set Up																						
			Set Up																						
			Set Up																						

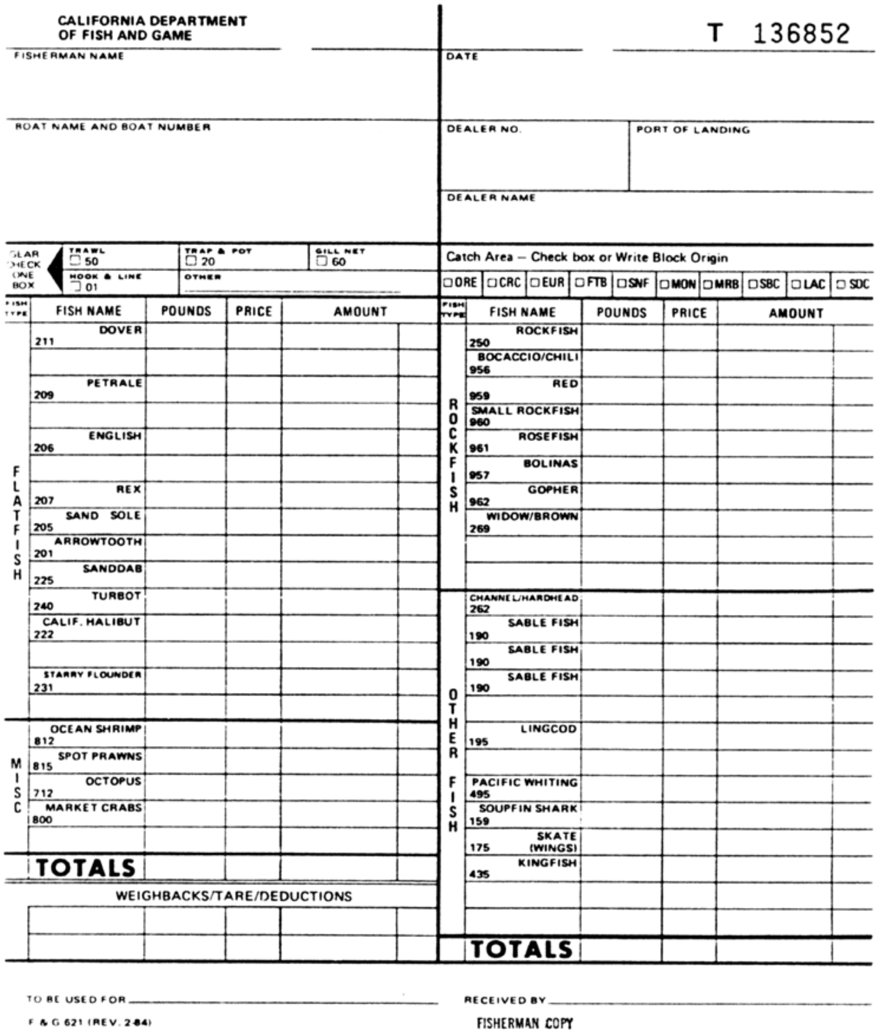
REMARKS

TO BE COMPLETED BY AGENCY

VESSEL	FISH RECEIVING TICKET NO
PORT	

FIGURE 1. Uniform coastwide trawler logbook format.

FIGURE 1. Uniform coastwide trawler logbook format



CALIFORNIA DEPARTMENT OF FISH AND GAME

T 136852

FISHERMAN NAME

DATE

BOAT NAME AND BOAT NUMBER

DEALER NO.

PORT OF LANDING

DEALER NAME

GEAR CHECK ONE BOX: TRAWL ☐ 50 · TRAP & POT ☐ 20 · GILL NET ☐ 60 · HOOK & LINE ☐ 01 · OTHER

Catch Area – Check box or Write Block Origin

☐ ORE ☐ CRC ☐ EUR ☐ FTB ☐ SNF ☐ MON ☐ MRB ☐ SBC ☐ LAC ☐ SDC

FISH TYPE	FISH NAME	POUNDS	PRICE	AMOUNT
FLATFISH	DOVER 211			
	PETRALE 209			
	ENGLISH 206			
	REX 207			
	SAND SOLE 205			
	ARROWTOOTH 201			
	SANDDAB 225			
	TURBOT 240			
	CALIF. HALIBUT 222			
	STARRY FLOUNDER 231			
MISC	OCEAN SHRIMP 812			
	SPOT PRAWNS 815			
	OCTOPUS 712			
	MARKET CRABS 800			
	TOTALS			

WEIGHBACKS/TARE/DEDUCTIONS

FISH TYPE	FISH NAME	POUNDS	PRICE	AMOUNT
ROCKFISH	ROCKFISH 250			
	BOCACCIO/CHILI 956			
	RED 959			
	SMALL ROCKFISH 960			
	ROSEFISH 961			
	BOLINAS 957			
	GOPHER 962			
	WIDOW/BROWN 269			
OTHER FISH	CHANNEL/HARDHEAD 262			
	SABLE FISH 190			
	SABLE FISH 190			
	SABLE FISH 190			
	LINGCOD 195			
	PACIFIC WHITING 495			
	SOUPFIN SHARK 159			
	SKATE (WINGS) 175			
	KINGFISH 435			
	TOTALS			

TO BE USED FOR ____________

RECEIVED BY ____________

F & G 621 (REV. 2-84)

FISHERMAN COPY

FIGURE 2. California fish dealer's landing receipt format.

FIGURE 2. California fish dealer's landing receipt format

Annual summarized block data are used to describe the halibut trawl fishery. Monthly block data for four randomly chosen, recent years provide seasonal trends.

RESULTS

Halibut Trawl Catch By Time and Area

The trawler catch of halibut is a small part of the trawl fishery; however, it is a significant part of total halibut landings. Percentages of total annual halibut catches taken by trawls from 1945 to 1986 have ranged from 7 to 61% and averaged 26% (Table 1).

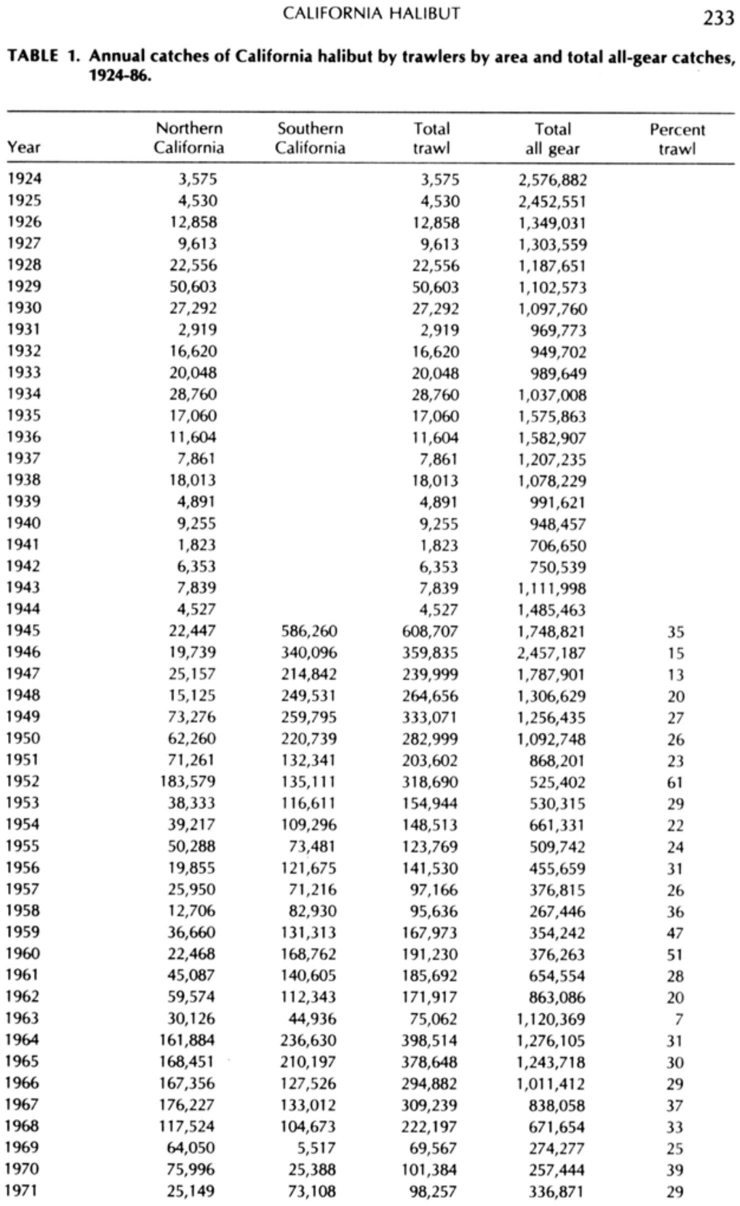


TABLE 1. Annual catches of California halibut by trawlers by area and total all-gear catches, 1924-86.

Year	Northern California	Southern California	Total trawl	Total all gear	Percent trawl
1924	3,575		3,575	2,576,882	
1925	4,530		4,530	2,452,551	
1926	12,858		12,858	1,349,031	
1927	9,613		9,613	1,303,559	
1928	22,556		22,556	1,187,651	
1929	50,603		50,603	1,102,573	
1930	27,292		27,292	1,097,760	
1931	2,919		2,919	969,773	
1932	16,620		16,620	949,702	
1933	20,048		20,048	989,649	
1934	28,760		28,760	1,037,008	
1935	17,060		17,060	1,575,863	
1936	11,604		11,604	1,582,907	
1937	7,861		7,861	1,207,235	
1938	18,013		18,013	1,078,229	
1939	4,891		4,891	991,621	
1940	9,255		9,255	948,457	
1941	1,823		1,823	706,650	
1942	6,353		6,353	750,539	
1943	7,839		7,839	1,111,998	
1944	4,527		4,527	1,485,463	
1945	22,447	586,260	608,707	1,748,821	35
1946	19,739	340,096	359,835	2,457,187	15
1947	25,157	214,842	239,999	1,787,901	13
1948	15,125	249,531	264,656	1,306,629	20
1949	73,276	259,795	333,071	1,256,435	27
1950	62,260	220,739	282,999	1,092,748	26
1951	71,261	132,341	203,602	868,201	23
1952	183,579	135,111	318,690	525,402	61
1953	38,333	116,611	154,944	530,315	29
1954	39,217	109,296	148,513	661,331	22
1955	50,288	73,481	123,769	509,742	24
1956	19,855	121,675	141,530	455,659	31
1957	25,950	71,216	97,166	376,815	26
1958	12,706	82,930	95,636	267,446	36
1959	36,660	131,313	167,973	354,242	47
1960	22,468	168,762	191,230	376,263	51
1961	45,087	140,605	185,692	654,554	28
1962	59,574	112,343	171,917	863,086	20
1963	30,126	44,936	75,062	1,120,369	7
1964	161,884	236,630	398,514	1,276,105	31
1965	168,451	210,197	378,648	1,243,718	30
1966	167,356	127,526	294,882	1,011,412	29
1967	176,227	133,012	309,239	838,058	37
1968	117,524	104,673	222,197	671,654	33
1969	64,050	5,517	69,567	274,277	25
1970	75,996	25,388	101,384	257,444	39
1971	25,149	73,108	98,257	336,871	29

TABLE 1. ***Annual catches of California halibut by trawlers by area and total all-gear catches, 1924–86.***

In the 1930s, the halibut trawl fishery was concentrated in northern California off Bodega Bay and off San Francisco with minor catches in Monterey Bay. Since 1945, the southern California area, south of latitude 36° N (Lopez Point), has become a major halibut trawl area. In most years from 1945 until 1980, southern California halibut catches exceeded those of northern California. An anomolous year was 1969 when only 5517 lb of halibut were caught in the southern California area. The Santa Barbara oil spill occurred in early 1969 and caused a reduction in trawl effort and halibut catch in the Santa Barbara Channel area. Since 1980, northern California catches of halibut have been higher than southern California catches (Table 1; Figure 3).

Year	Northern California	Southern California	Total trawl	Total all gear	Percent trawl
1972	55,160	41,067	96,227	309,245	31
1973	23,339	62,575	85,914	273,526	31
1974	31,023	64,386	95,409	306,479	31
1975	27,323	72,250	99,573	508,913	20
1976	43,135	116,623	159,758	628,400	25
1977	25,476	69,111	94,587	467,862	20
1978	30,459	42,815	77,289	441,400	18
1979	39,405	49,496	88,901	665,546	13
1980	80,154	51,933	132,087	726,852	18
1981	176,207	130,804	307,011	1,262,265	24
1982	156,329	77,289	233,598	1,214,375	19
1983	218,613	58,204	276,817	1,130,581	24
1984	94,358	29,609	123,967	1,107,332	11
1985	95,273	26,891	122,164	1,256,375	10
1986	90,378	80,137	170,515	1,184,090	14

TABLE

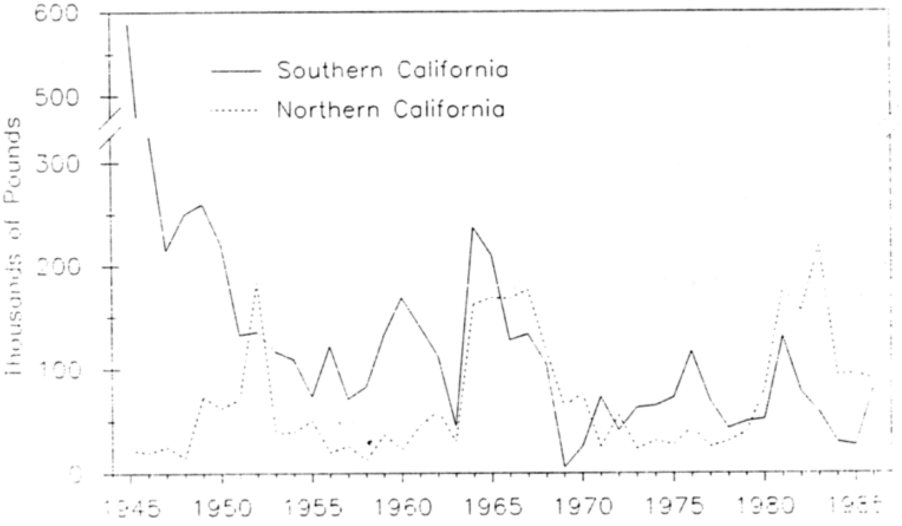


FIGURE 3. Annual trawler landings of California halibut by area, 1945-86.

FIGURE 3. Annual trawler landings of California halibut by area, 1945–86

Annual trawler halibut catches of 45 kg (100 lb) or more per Fish and Game block have occurred from northwest of Eureka to Santa Barbara. Block areas with annual catches of 4545 kg (10,000 lb) or more are located off San Francisco and adjacent to Point Arguello (Figure 4).

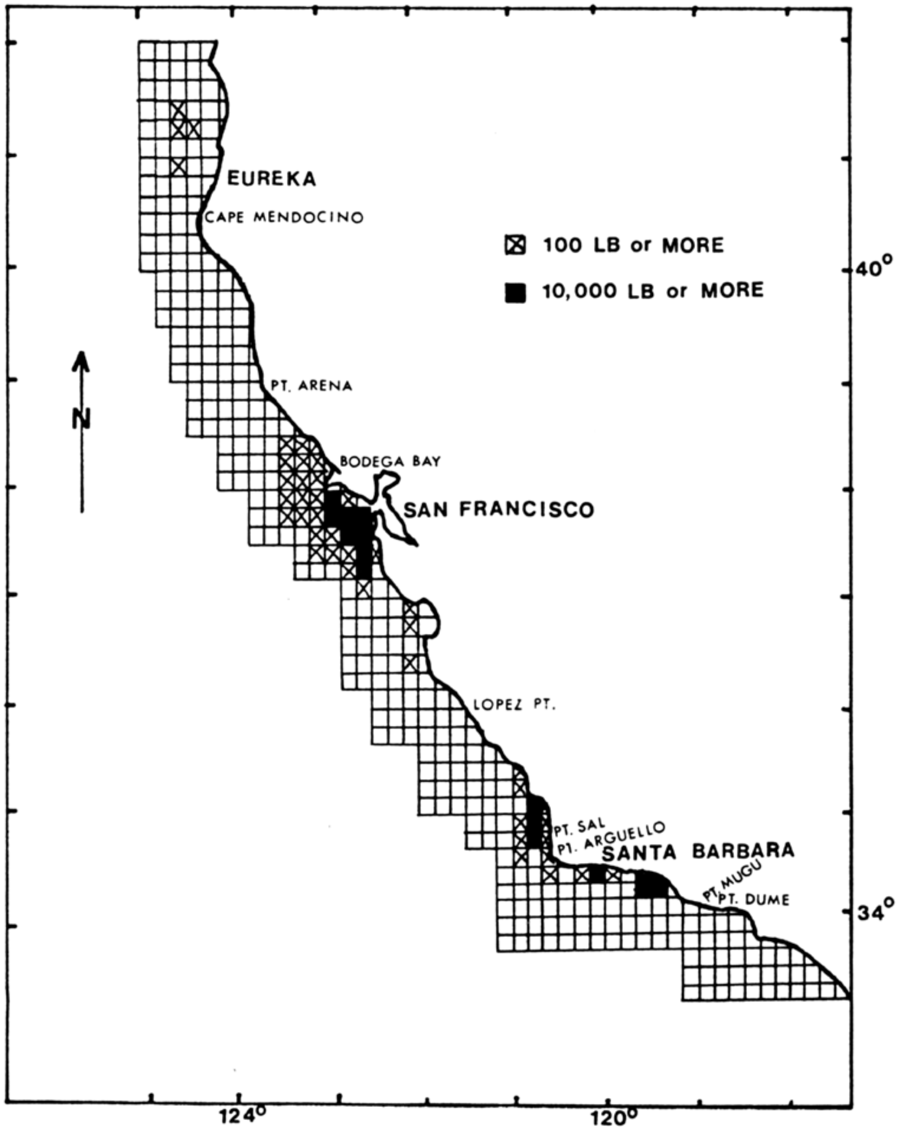


FIGURE 4. Fish and Game block areas where annual catches of California halibut exceed 100 pounds and 10,000 pounds in any single year.

FIGURE 4. Fish and Game block areas where annual catches of California halibut exceed 100 pounds and 10,000 pounds in any single year

Seasonal catch trends in trawl catches are evident in both northern and southern California. Monthly catches of halibut are high in January, February, August, September and October in northern California. In southern California, monthly catches are high in January, November, and December (Table 2). Halibut are caught in trawls mainly in shallow depths. In northern and southern California, 89% and 87% of the halibut catch respectively occurred in depths of 55 m (30 fm) or less.

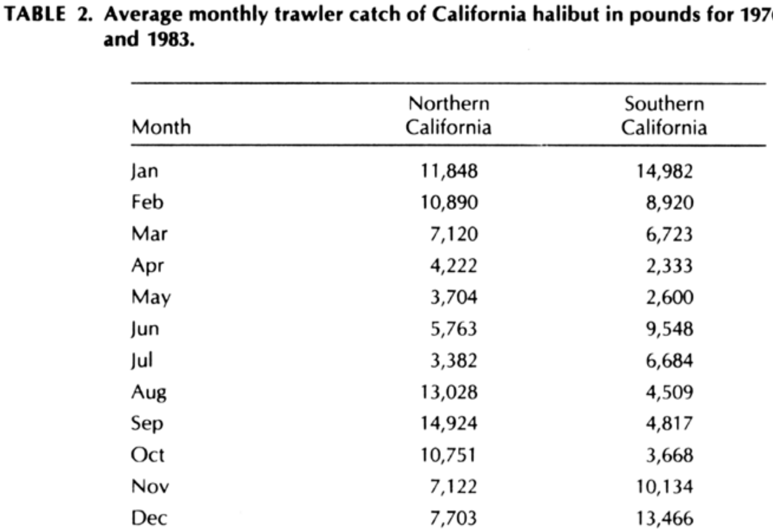


TABLE 2. Average monthly trawler catch of California halibut in pounds for 1976, 1977, 1982, and 1983.

Month	Northern California	Southern California
Jan	11,848	14,982
Feb	10,890	8,920
Mar	7,120	6,723
Apr	4,222	2,333
May	3,704	2,600
Jun	5,763	9,548
Jul	3,382	6,684
Aug	13,028	4,509
Sep	14,924	4,817
Oct	10,751	3,668
Nov	7,122	10,134
Dec	7,703	13,466

TABLE 2. ***Average monthly trawler catch of California halibut in pounds for 1976, 1977, 1982, and 1983.***

Fourteen market species or species groups occurred in significant poundages in trawl landings with halibut (Table 3). Species assemblages taken in trawls differ in the two major fishing areas. In northern California the predominant five species in order of abundance consisted of starry flounder, Platichthys stellatus; English sole; sand sole, Psettichthys melanostictus; halibut; and Pacific sanddab, Citharichthys sordidus. In southern California, halibut dominated the trawl assemblage and was followed by skates, Raja spp.; starry flounder; English sole; and sand sole (Figure 5). Other demersal species, in addition to those of Table 3, are present in both fishing areas but are not caught because of escapement through trawls, or are not kept because of lack of markets.

Abundance

A data set of trawl catch per unit of effort (CPUE), 1967 to 1986, was examined (Table 4). Data for 1976 were not available. In northern California, CPUE was high in 1967. A declining trend occurred through 1975. CPUE increased thereafter to a high in 1983. The trend was downward after 1983. In southern California, CPUE was high in 1967, 1968, and 1986. CPUE trends are consistent with the trends of annual trawl landings (Figure 6). Generally, CPUE is high when landings are high and CPUE declines as landings decline.

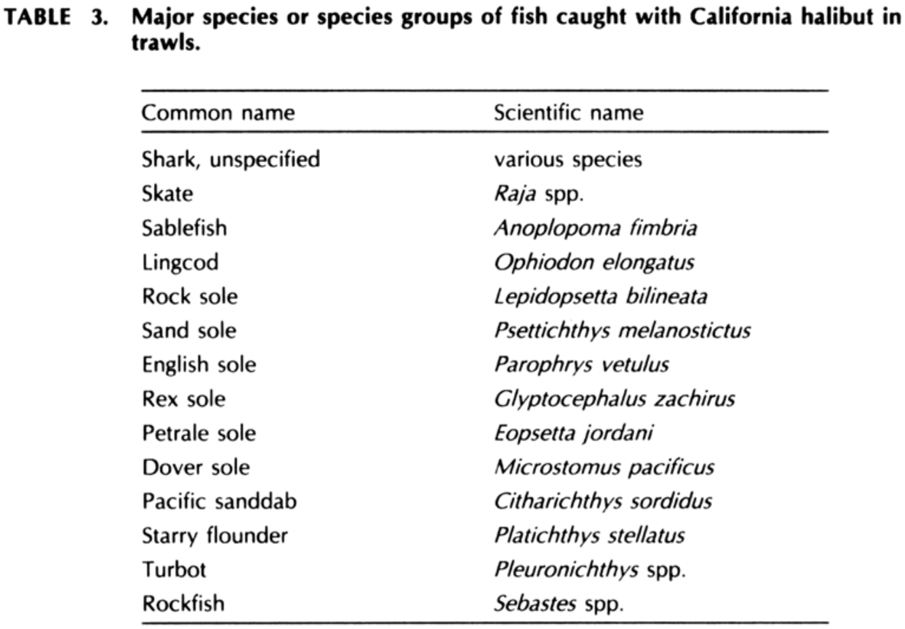


TABLE 3. Major species or species groups of fish caught with California halibut in trawls.

Common name	Scientific name
Shark, unspecified	various species
Skate	*Raja* spp.
Sablefish	*Anoplopoma fimbria*
Lingcod	*Ophiodon elongatus*
Rock sole	*Lepidopsetta bilineata*
Sand sole	*Psettichthys melanostictus*
English sole	*Parophrys vetulus*
Rex sole	*Glyptocephalus zachirus*
Petrale sole	*Eopsetta jordani*
Dover sole	*Microstomus pacificus*
Pacific sanddab	*Citharichthys sordidus*
Starry flounder	*Platichthys stellatus*
Turbot	*Pleuronichthys* spp.
Rockfish	*Sebastes* spp.

TABLE 3. ***Major species or species groups of fish caught with California halibut in trawls.***

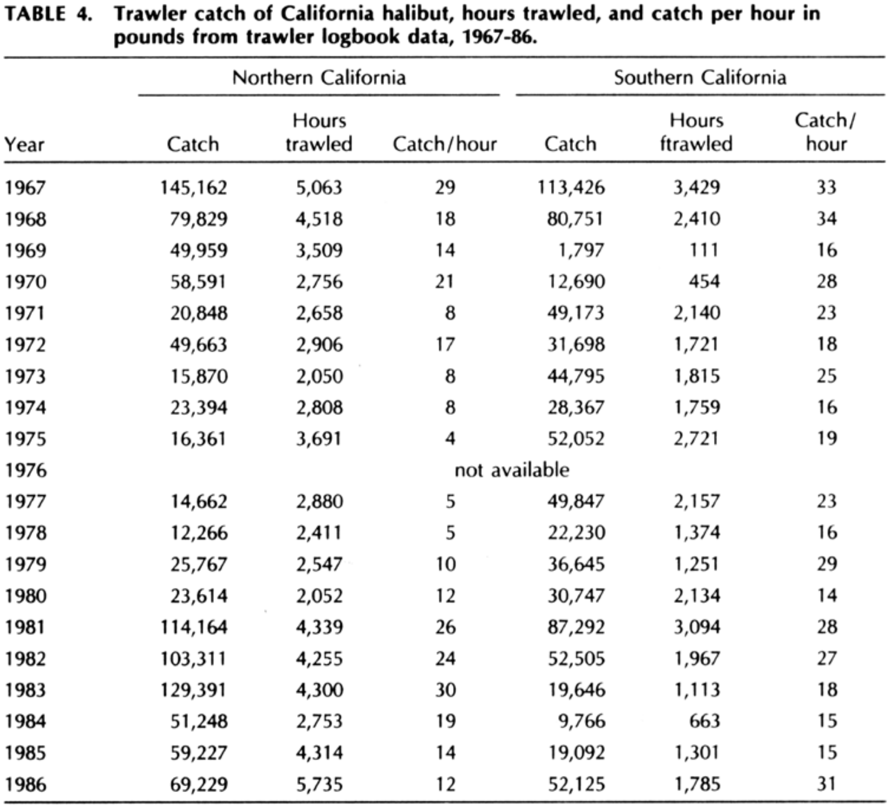


TABLE 4. Trawler catch of California halibut, hours trawled, and catch per hour in pounds from trawler logbook data, 1967-86.

	Northern California			Southern California		
Year	Catch	Hours trawled	Catch/hour	Catch	Hours ftrawled	Catch/ hour
1967	145,162	5,063	29	113,426	3,429	33
1968	79,829	4,518	18	80,751	2,410	34
1969	49,959	3,509	14	1,797	111	16
1970	58,591	2,756	21	12,690	454	28
1971	20,848	2,658	8	49,173	2,140	23
1972	49,663	2,906	17	31,698	1,721	18
1973	15,870	2,050	8	44,795	1,815	25
1974	23,394	2,808	8	28,367	1,759	16
1975	16,361	3,691	4	52,052	2,721	19
1976			not available			
1977	14,662	2,880	5	49,847	2,157	23
1978	12,266	2,411	5	22,230	1,374	16
1979	25,767	2,547	10	36,645	1,251	29
1980	23,614	2,052	12	30,747	2,134	14
1981	114,164	4,339	26	87,292	3,094	28
1982	103,311	4,255	24	52,505	1,967	27
1983	129,391	4,300	30	19,646	1,113	18
1984	51,248	2,753	19	9,766	663	15
1985	59,227	4,314	14	19,092	1,301	15
1986	69,229	5,735	12	52,125	1,785	31

TABLE 4. ***Trawler catch of California halibut, hours trawled, and catch per hour in pounds from trawler logbook data, 1967–86.***

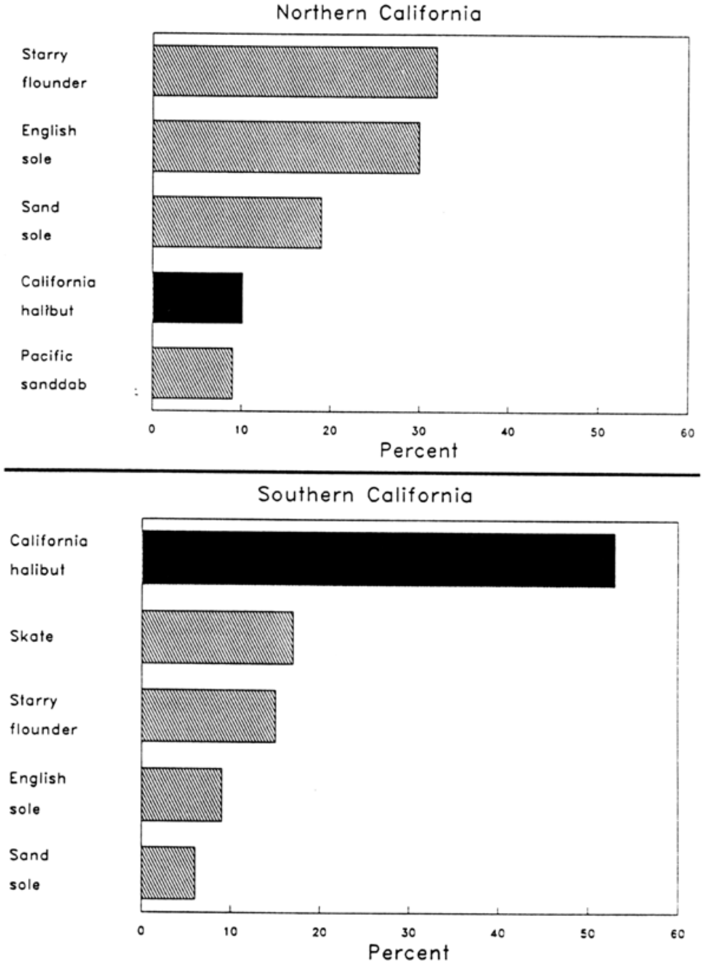


FIGURE 5. Percentage of predominant species or species groups taken with California halibut in trawls.

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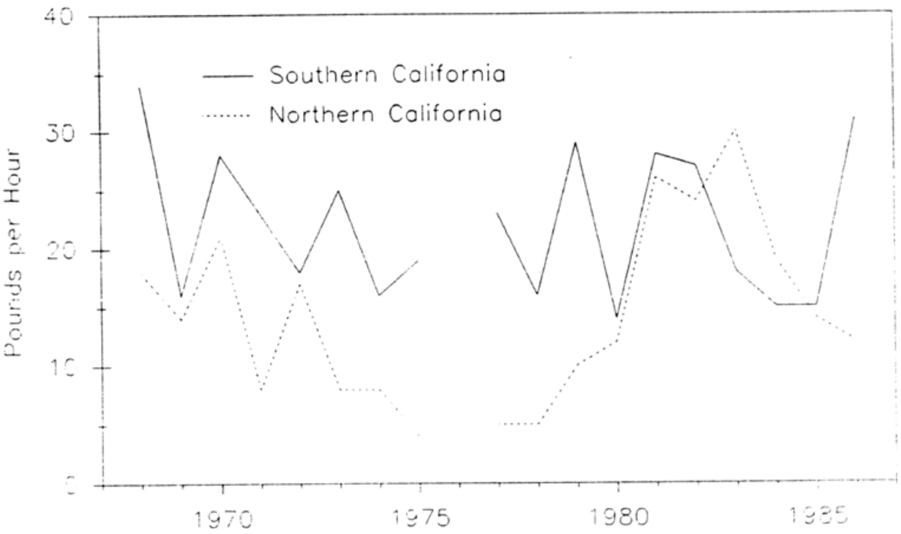

FIGURE 6. California halibut catch per hour by trawlers, 1967-86.

FIGURE 6. California halibut catch per hour by trawlers, 1967–86

DISCUSSION

This examination of annual trawler data raises questions on stock separation, biology, ecology, and movements and migrations. Bottom topography and substrate differ between main trawl areas of northern and southern California. The area off San Francisco in the Gulf of the Farallons has a broad continental shelf with shallow depths and with gray sand and sand as the predominant bottom types. The southern California area has a narrow shelf with mud, green mud, and sand as the major substrate types.

The wide separation of the two major halibut trawl fishing areas and the ecological differences between them are suggestive of separate populations. Contrary information is the lack of significant numbers of juvenile and subrecruit-size halibut in northern California. In his study of the trawl fishery, Clark (1935a) found that no small halibut were taken in trawls off San Francisco. Aplin (1967) caught only six halibut in over 500 trawl tows in San Francisco Bay between 1963 and 1966. In the CDFG's Bay Delta Study, only 84 halibut were caught in 2500 otter trawl tows in San Francisco Bay during 1980–85 (Department of Fish and Game 1987). Five were less than 190 mm total length and probably young of the year while seven juveniles measured 191 to 230 mm. (R.D. Baxter, CDFG, pers. comm.). In observations of the bay shrimp fishery in south San Francisco Bay in July 1989, eight juveniles, 230 to 355 mm, were measured from three trawls (P.N. Reilly, CDFG, pers. comm.). The alternative gear fishery off San Francisco, a directed trawl fishery for halibut, has produced few prerecruit-size halibut (D. Thomas, CDFG, pers. comm.). With the lack of growth recruitment to the population in northern California, the halibut fishery could be supported by northward movement or migration within a common stock.

Clark (1930) defined the halibut spawning season as late February to July with a peak in May. He gave the size of first maturity at 230 mm (9 inches) and stated that halibut moved into shallow depths of 4 to 9 m (2 to 5 fm) to spawn. Doubtlessly, halibut spawn in both northern and southern California because of the catches of mature, legal-size halibut, [>]559mm (22 inches), throughout the year in both areas. In northern California, the movement of halibut into shallow water coincides with catch declines in May as halibut move inside 3 naut mi from shore where trawling is prohibited. In the southern California halibut trawl grounds, an area of shallow depths, trawling is prohibited between 15 March and 15 June during the peak halibut spawning period.

The lack of juveniles in northern California may be due to the influence of the California current. Sverdrup et al. (1942) described the circulation pattern of the California current in central and northern California where upwelled water in spring and summer moves offshore and southward a long distance and returns inshore south of Point Dume. Spawning peaks in May at the time of upwelling and offshore movement of water. Halibut eggs and larvae, if similar to those of other flatfish, are up in the water column and are moved offshore, but then returned to the southern California bight where known nursery areas exist.

Environmental conditions such as warm water periods, El Niños, seem to have relationship to halibut distribution in some years but not in others. Strong warming events occurred in 1957–58, 1972–73, and 1982–83 (Mysak 1986). Norton et al. (1985) described the 1982–83 El Niño as part of one of the most intense ocean-atmosphere events of the century. Only during the 1982–83 El Niño did a halibut distribution response occur. The most northerly catches of halibut off Eureka (Figure 4) occurred in 1982 and 1983. Higher all-gear and higher northern California halibut catches have persisted from 1981 through 1986. Further work on stock discrimination is needed. Current halibut tagging work is opportunistic, and a larger effort is needed along with emphasis on other methods of stock separation. An overall halibut program which incorporates fishery and biological data from existing and new sources to determine the stock or stocks, population dynamics, and status of stocks is needed on which to base management alternatives.

Trawl catch records show concentrations of halibut in shallow waters with major catch areas adjacent to the large urban areas of San Francisco and Santa Barbara. Human uses of the nearshore environment can result in degradation. Therefore habitat protection has to be part of the overall halibut management scheme.

ACKNOWLEDGMENTS

The vision of the late G.H. "Hoke" Clark made the current logbook system possible. Past and present CDFG Biometrics staff members too numerous to mention performed data processing tasks. Ed Greenhood, Leo Pinkas, Dick Heimann, Joyce Underhill, Connie Pauig, Gloria Hawkes, Dixie Novell, and Rosa Madrid require special mention. John Geibel, Bernice Hammer, and especially Michelle Goodrich were instrumental in computerizing the trawler log system. Trawl biologists, Frank Henry, Dave Thomas, Larry Quirollo, Bob Leos, and Sandy Owen through their fishery interactions and log and ticket work made the current system possible. Marija Vojkovich and two anonymous reviewers provided comments which were extremely helpful. John Sunada constantly provided encouragement. Pete Haaker and Bob Leos helped with the graphics, and Jacqueline Phuvanatnaranubala provided word processing support.

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THE CALIFORNIA HALIBUT CATCH BY THE SOUTHERN CALIFORNIA HALIBUT GILL NET FLEET, 1984–1986

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ABSTRACT

Between 1981 and 1983, recreational catches and commercial landings of California halibut, Paralichthys californicus, decreased over 40%. Recreational fishermen, troubled by decreased catches and recent increases in gill net activity, began more actively to voice concerns about the gill net fishery. In response, the California Department of Fish and Game began an on-board observation program of gill net boats in 1983. Through this program, information on the catch of all fishes including halibut was collected.

In this study, various aspects of the halibut catch from gill net boats targeting halibut in southern California for 1984–86 were examined. These included the size and disposition of the catch and the number of halibut caught per observed boat day (catch-per-unit- effort = CPUE). CPUE was then used along with halibut fleet effort to estimate the catch of halibut by the halibut gill net fleet in southern California. Four different catches were estimated: total catch, saleable catch, retained catch, and discarded catch. Retained and discarded catch estimates were subsequently converted to numbers for comparison with catch estimates from the recreational fishery.

Examination of the halibut catch from observed gill net boats revealed that, by number, approximately 75% of the halibut caught were legal and thus were subsequently sold. Sublegal halibut brought aboard were generally kept for personal use or discarded live; fewer than 16% were discarded dead.

The highest total CPUE, saleable CPUE, and retained CPUE were recorded in 1985. The highest fleet effort, 7929 boat days, was also recorded in 1985. As a consequence, estimates of total catch (total CPUE * fleet effort) were highest in 1985 and ranged from 199,000 kg halibut in 1984 to 294,000 kg in 1985. From 12% to 15% of this total catch was kept for personal use or discarded; the remainder was sold.

The number of halibut retained ranged from 56,800 in 1984 to 79,000 in 1985. This number was greater than the number of halibut retained by southern California anglers for each of the 3 years; however, the proportion

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of halibut taken by anglers increased from 28% in 1984 to 49% in 1986.

INTRODUCTION

Prior to the early 1970s, periods of high recreational catches of the California halibut, Paralichthys californicus, generally coincided with periods of high commercial landings (Karpov 1981; Methot 1983; Reed and MacCall 1988). off southern California, nearly all reported recreational catches were taken aboard commercial passenger fishing vessels (CPFVs), while most commercial landings came from gill-netters and trawlers (Karpov 1981; Methot 1983).

In 1971, the California Legislature established new regulations for both the recreational and commercial halibut fisheries. These regulations included a 22-inch (559-mm) minimum size limit, a reduced bag limit for the recreational fishery, an allowance of 30 lb (14 kg) of undersize fish for the commercial fishery, and special restrictions on trawlers (Karpov 1981; Methot 1983; Reed and MacCall 1988).

During the following 10 years, the coinciding pattern of recreational and commercial catches changed: recreational catches from CPFVs decreased and then leveled off while commercial landings gradually increased. The new regulations may have contributed to this change in pattern. For instance, the decrease in recreational catches may have been partly due to the reduced bag limit (Karpov 1981). However, it is difficult to say how much the new regulations contributed to the pattern change because of the changes that also occurred in the fisheries. For example, in the recreational fishery, the proportion of halibut taken aboard CPFVs dropped while the proportion taken aboard private boats increased (Methot 1983); CPFVs may have switched to other target species (Karpov 1981). Also, in the commercial fishery, the proportion of halibut taken by gill nets in the Santa Barbara region increased, while the proportion taken by trawls decreased (Karpov 1981; Barsky 1990); gill nets proved an effective gear and were not subject to the same seasonal and areal restrictions as were trawls (Karpov 1981; Methot 1983).

In 1979, the National Marine Fisheries Service (NMFS) began to study the catch of recreational fishermen from CPFVs, private boats, man-made structures, and shorelines. These studies indicate that the total recreational catch of halibut in the 1970s may have been somewhat larger than the CPFV data alone would suggest, but that it did not reach previous levels of high catch (NMFS 1984, 1985, 1986; Reed and MacCall 1988).

Then, between 1981 and 1983, recreational catches of halibut in southern California decreased over 50% (NMFS 1984, 1985), while commercial landings in this area decreased by approximately 41% (Pacific Fisheries Information Network [PACFIN] Special Report on California Halibut 1988). Recreational fishermen, already troubled by increased gill net fishing, now began more actively to voice their concerns. Some of these concerns centered around the total catch of the gill net fleet (composed of fish kept for personal use, fish discarded, and fish landed).

Because information necessary to address these concerns was not available through such sources as the commercial landing receipts (pink tickets), the California Department of Fish and Game (CDFG) began in 1983 an on-board observation program of the set gill net fishery. Through this program, information on the total catch of all fishes as well as other pertinent aspects of the fishery were collected.

This paper presents the results of an analysis of catch data for halibut collected by observers on gill net boats targeting halibut in southern California for the years 1984–86. It provides information on the size distribution and disposition of the total catch; estimates of the total catch, saleable catch, retained catch (to be compared with the retained catch of recreational fishermen), and discarded catch (Table 1); and comparisons between saleable, total, and retained catch estimates. These comparisons provide information on the amount of halibut brought aboard the boats and retained, over the amount sold (landed).

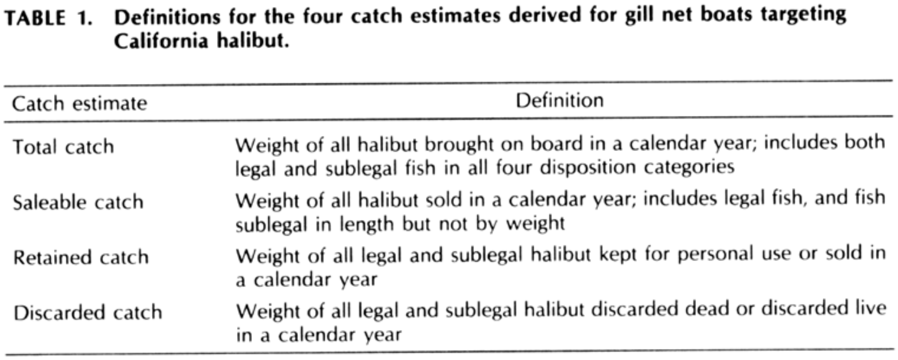

TABLE 1. Definitions for the four catch estimates derived for gill net boats targeting California halibut.

Catch estimate	Definition
Total catch	Weight of all halibut brought on board in a calendar year; includes both legal and sublegal fish in all four disposition categories
Saleable catch	Weight of all halibut sold in a calendar year; includes legal fish, and fish sublegal in length but not by weight
Retained catch	Weight of all legal and sublegal halibut kept for personal use or sold in a calendar year
Discarded catch	Weight of all legal and sublegal halibut discarded dead or discarded live in a calendar year

TABLE 1. ***Definitions for the four catch estimates derived for gill net boats targeting California halibut.***

To evaluate the validity of the four catch estimates obtained from observations, saleable catch estimates are compared to the landed catch of gill-netters in southern California. Factors that might cause the four catch estimates to be overestimated or underestimated are then discussed.

Finally, the relative distribution of the halibut catch is examined by comparing the retained catch estimates of the halibut gill net fleet with corresponding NMFS catch estimates for the recreational fishery.

METHODS

Collection of Observer Data

The following sampling procedure was designed to collect as representative a sample as possible from those fishermen willing to participate in the CDFG's voluntary gill net observation program. Observers contacted fishermen at major docks from Santa Barbara to San Diego as they returned from tending their nets. (Gill-netters normally leave their set nets in place overnight, retrieve them the next day, then remove the catch and reset the nets.) Each observer asked permission to observe fishing from the first gill-netter contacted, even if this person had previously refused to take observers. If refused, the observer continued to contact fishermen until granted permission. Once granted, the observer attempted to arrange a trip within 24 h so that nets already in the water would be sampled. This reduced the effect that observer presence had on normal fishing patterns.

The observer boarded the fishing boat when it left the dock and remained aboard until it returned. Information on target species (the primary species sought), net construction, fishing location, and the environment (e.g. water depth, presence of kelp, etc.) in which the nets were set was obtained for each net retrieved. Fish and other animals brought aboard were identified, counted, and their final disposition (discarded live or dead, kept for personal use, or sold) recorded. Halibut were measured (total length) whenever possible.

Portions of the halibut fishery take place at a considerable distance from port, mostly around the northern Channel Islands, along the mainland between Gaviota and Point Arguello, and between Point Mugu and Malibu Point. Boats fishing in these areas often remain on the fishing grounds for several days and can accommodate only their normal crew. Beginning in 1985, a boat was chartered to taxi observers out to gill net boats working in these remote fishing grounds. Observation procedures were the same as those used by shore based personnel.

Calculation of Catch

Sample Criteria

Only observations from gill net sets targeting halibut were used in this analysis. Halibut were taken incidentally by boats targeting other species (e.g. angel shark, Squatina californica, and white seabass, Atractoscion nobilis) , but these observations were excluded from the analysis because a fleet effort estimate for this nondirected take was not available. The CDFG staff estimate that the incidental take of halibut by gill-netters targeting on other species makes up from 10% to 15% of the landed gill net catch.

For the remainder of this paper, "halibut fleet" will refer to that portion of the gill net fleet targeting halibut.

Definitions of Effort and Catch

A "boat day" was chosen as the measure of effort for this analysis and was defined as all halibut nets pulled by one boat in one calendar day. This measure of effort was chosen over other measures (e.g. number of nets or fathoms of net fished) because fewer assumptions were used in calculating the fleet effort estimate for this measure. Weight of halibut was chosen as the measure of catch. Catch-per-unit-effort (CPUE) was defined as the weight (kg) of halibut caught per boat day.

Catch Equation

Estimates of catch for the halibut fleet were calculated using the following equation:

$$C_F = \overline{CPUE} \times BD_F$$

where

$$C_F = \text{catch for halibut fleet for given calendar year}$$

EQUATION

where C_F = catch for halibut fleet for given calendar year

$\overline{CPUE}$ = mean catch per boat day for a given calendar year; calculated from observer data

TABLE

BD_F = total number of boat days for halibut fleet for given calendar year

Calculations of Mean CPUE

Calculation of Weights

For each boat day, the number of halibut caught, the number measured, and the number not measured were calculated for each of the four disposition categories. Numbers of measured and unmeasured halibut were then converted to weights as follows. Weights were calculated for measured halibut using length-weight coefficients derived by Schott and described by Reed and MacCall (1988). Measured halibut were categorized as legal or sublegal according to the 559-mm size limit. Totals of weights for measured fish per boat day (MW_{BD}) were then calculated for legal and sublegal fish in each of the four disposition categories.

Weights were estimated for unmeasured halibut as follows. An analysis of the final dispositions of the measured halibut from 1984 to 1986 showed that on average 99% of the halibut discarded live were sublegal, 98% of the halibut sold were legal, and 51% of the halibut discarded dead were legal. Thus, unmeasured halibut discarded live were categorized as sublegal. Unmeasured halibut sold were categorized as legal. Unmeasured halibut discarded dead were equally divided between the two categories for each boat day. This analysis also showed that 93% of the halibut kept for personal use were sublegal. The number of halibut in this disposition was relatively small; therefore, this proportion was rounded to 100%. As a consequence, unmeasured halibut kept for personal use were categorized as sublegal.

The weight of unmeasured legal and sublegal halibut was then estimated for each of the four disposition categories for each boat day using the following equation:

$$UWT_{ij} = UN_{ij} \times \overline{MWT}_{ij}$$

EQUATION

where UWT_{ij} = weight of unmeasured halibut of size category i and disposition j for each boat day UN_{ij} = number of unmeasured halibut of size category i and disposition j for each boat day

$\overline{MWT}_{ij}$ = average weight of measured halibut of size category i and disposition j

EQUATION

for each boat day
i= 1 sublegal 2 legal
j= 1 sold
2 kept for personal use
3 discarded alive
4 discarded dead

For some boat days, no measurements were available for legal or sublegal halibut. The weight of these halibut was estimated for each of the four disposition categories for each boat day using the following equation:

$$UWT_{ij} = UN_{ij} \times \overline{MMWT}_{ij}$$

EQUATION

where

$$\overline{MMWT}_{ij} = \text{average weight of measured halibut of size category } i \text{ and disposition } j \text{ for each month}$$

EQUATION

Totals of weights for unmeasured fish per boat day (UW_{BD}) were then calculated for legal and sublegal fish in each of the four dispositions.

By summing weights of measured (MW_{BD}) and unmeasured (UW_{BD}) fish, grand totals of weights per boat day (TW_{BD}) were obtained for legal and sublegal fish in each of the four disposition categories.

Calculation of CPUE

Four different catches for each boat day (CPUE) were calculated. Total CPUE was calculated by summing all TWBD (legal and sublegal fish over all four dispositions). Saleable CPUE was calculated by summing the TW_{BD} from sold fish. Retained CPUE was calculated by summing the TW_{BD} from fish kept for personal use or sold. Discarded CPUE was calculated by summing TW_{BD} from fish discarded dead or discarded live. These CPUE are related as follows: $CPUE_T = CPUE_S + CPUE_U$ $CPUE_T = CPUE_R + CPUE_D$ where $CPUE_T$ = total CPUE $CPUE_S$ = saleable CPUE $CPUE_U$ = unsold CPUE (not calculated) $CPUE_R$ = retained CPUE $CPUE_D$ = discarded CPUE

Bootstrap Analysis

Examination of the distributions of CPUE_T, CPUE_S, CPUE_R, and CPUE_D for each calendar year showed that in all cases they were severely nonnormal. Therefore, nonparametric estimates of standard errors and confidence intervals for each of the CPUE listed above were generated using a bootstrap.

The bootstrap simulates multiple sampling of the population by repeated resampling, with replacement, of the actual sample (Efron and Tibshirani 1986). The statistic of interest, in this case mean CPUE, is computed for each of the bootstrap samples. It is assumed the actual data are an unbiased random sample of the population.

The following bootstrap procedure was used for each of the four different CPUE discussed above. From each sample of CPUE for each calendar year (where sample size = number of boat days observed for the selected calendar year), 1000 bootstrap samples were generated. Mean CPUE was then calculated for each bootstrap sample. Finally, from these 1000 values of mean CPUE, an overall mean CPUE and a 95% confidence interval were calculated.

Estimates of Halibut Fleet Effort

Estimates of the number of boat days expended by the halibut fleet in southern California (Point Conception to the Mexican border) for 1984, 1985, and 1986 were obtained by compiling effort data from three sources: gill net fishing logs, commercial landing receipts, and gill net observer data. The method used to combine these three sources is described by Diamond and Vojkovich (1990).

Halibut Fleet Catch

Using the four different mean CPUE calculated in a previous section and the estimates of halibut fleet effort, four different catch estimates were calculated for each calendar year. These four catch estimates are defined in Table 1.

Conversion of Weight to Numbers

To compare sport and halibut fleet catches, retained and discarded catch estimates for the halibut fleet were converted from weight to numbers as follows:

$$\overline{WT}_i = \Sigma CPUE_i \,/\, \Sigma N_i$$

$$CN_i = CW_i \,/\, \overline{WT}_i$$

EQUATION

where

$\overline{WT}_i$ = average weight for all halibut for catch type i for a given calendar year

$\Sigma CPUE_i$ = catch per boat day for catch type i summed over given calendar year

EQUATION

RESULTS

Size Distribution of Catch

The mode for the total lengths of all halibut measured aboard observed boats was the same for all 3 years (Figure 1). The proportion of sublegals in this measured catch increased from 20% in 1984 to 28% in 1986. However, the highest proportion of 800-mm and larger halibut occurred in 1985. As a consequence, the average length of halibut was highest in 1985.

Disposition of Catch

Most of the halibut brought aboard by observed boats, whether by number or weight, were legal and were subsequently sold (Tables 2 and 3). The sublegal halibut that were brought aboard were generally kept for personal use or discarded live. Some of the legal halibut were discarded dead. Most of these fish were damaged.

Temporal Distribution of Observed Catch and Effort

From 70% to 85% of the total observed catch, by weight, was taken in February through July. Much of the landed gill net catch was also taken during these months (Figures 2 3 4).

The temporal distribution of the observed catch closely mirrored that for observed effort except for 1986 (Figures 2–4).

The temporal distribution of observed effort was similar to that for the halibut fleet except for 1984 which was significantly different ($x^2 = 25.5$, df=11, P=0.008).

Mean CPUE and Halibut Fleet Effort

The highest mean total CPUE, saleable CPUE, and retained CPUE was recorded in 1985 (Table 4). The highest mean discarded CPUE was recorded in 1984.

The highest effort for the halibut fleet was recorded in 1985 (Table 5). Observers sampled from 1.8% to 2.7% of the estimated halibut fleet effort.

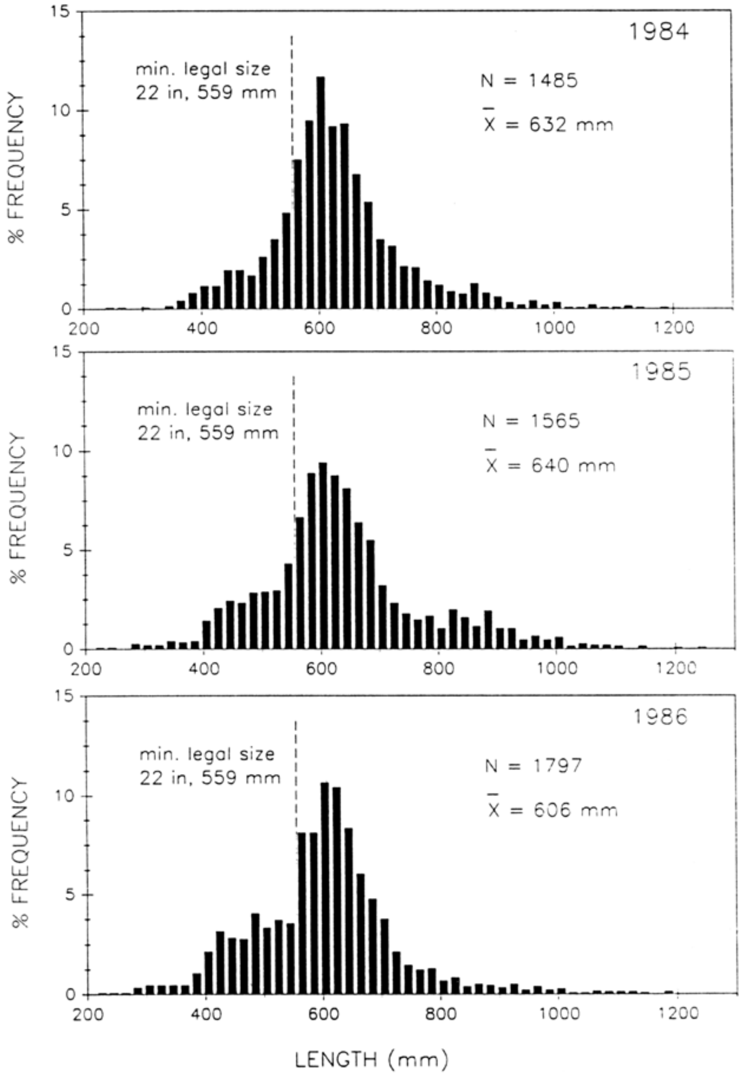

FIGURE 1. Length-frequency distributions for all California halibut measured on gill net boats targeting halibut in southern California, 1984-86.

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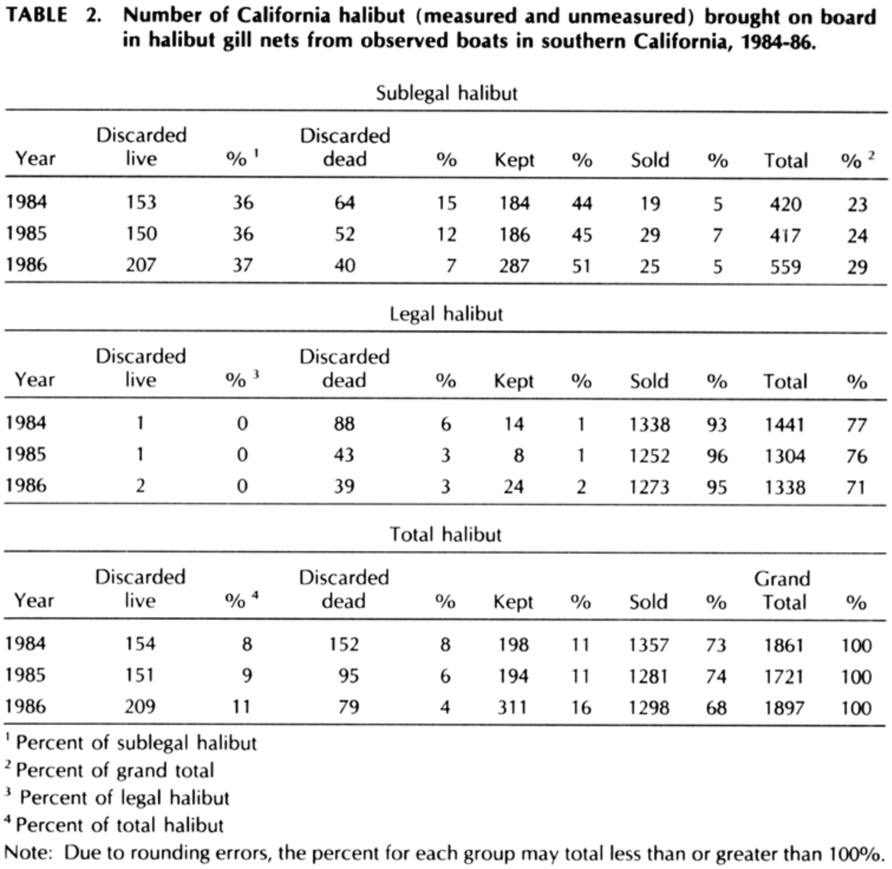

TABLE 2. Number of California halibut (measured and unmeasured) brought on board in halibut gill nets from observed boats in southern California, 1984-86.

Sublegal halibut

Year	Discarded live	%[1]	Discarded dead	%	Kept	%	Sold	%	Total	%[2]
1984	153	36	64	15	184	44	19	5	420	23
1985	150	36	52	12	186	45	29	7	417	24
1986	207	37	40	7	287	51	25	5	559	29

Legal halibut

Year	Discarded live	%[3]	Discarded dead	%	Kept	%	Sold	%	Total	%
1984	1	0	88	6	14	1	1338	93	1441	77
1985	1	0	43	3	8	1	1252	96	1304	76
1986	2	0	39	3	24	2	1273	95	1338	71

Total halibut

Year	Discarded live	%[4]	Discarded dead	%	Kept	%	Sold	%	Grand Total	%
1984	154	8	152	8	198	11	1357	73	1861	100
1985	151	9	95	6	194	11	1281	74	1721	100
1986	209	11	79	4	311	16	1298	68	1897	100

[1] Percent of sublegal halibut

[2] Percent of grand total

[3] Percent of legal halibut

[4] Percent of total halibut

Note: Due to rounding errors, the percent for each group may total less than or greater than 100%.

TABLE 2. ***Number of California halibut (measured and unmeasured) brought on board in halibut gill nets from observed boats in southern California, 1984–86.***

Halibut Fleet Catch

Because fleet effort and total, saleable, and retained CPUE were highest in 1985, estimates of total catch, saleable catch, and retained catch were also highest in 1985 (Tables 6 and 7). Comparisons of the saleable catch estimates with total catch estimates indicate that from 12% to 15% of the total catch was kept for personal use or discarded. Similar comparisons of saleable catch with retained catch reveal that 91–94% of the halibut brought aboard the boats and retained was sold.

Conversion of Weight to Numbers

The average weight ([WT]) for halibut retained or discarded by gill-netters varied slightly between years (Table 8). Because of the high proportion of sublegals in the discarded catch, the average weight for this catch was lower than the average weight for the retained catch.

The number of halibut retained by the halibut fleet ranged from 56,800 fish in 1984 to 79,900 in 1985 (Table 7). The number discarded ranged from 11,200 in 1984 to 13,400 in 1985.

TABLE 3. Weight (kg) of California halibut (measured and unmeasured) brought on board in halibut gill nets from observed boats in southern California, 1984-86.

Sublegal halibut

Year	Discarded live	% [1]	Discarded dead	%	Kept	%	Sold	%	Total	% [2]
1984	183.1	34	65.3	12	252.8	47	32.0	6	533.2	10
1985	161.3	32	57.3	11	242.3	48	46.1	9	507.0	9
1986	208.3	33	36.8	6	350.8	55	39.1	6	635.0	13

Legal halibut

Year	Discarded live	% [3]	Discarded dead	%	Kept	%	Sold	%	Total	%
1984	2.6	0	264.3	5	57.9	1	4584.5	93	4909.3	90
1985	2.1	0	157.0	3	35.9	1	4737.6	96	4932.6	91
1986	4.0	0	92.7	2	85.4	2	4140.6	96	4322.7	87

Total halibut

Year	Discarded live	% [4]	Discarded dead	%	Kept	%	Sold	%	Grand total	%
1984	185.7	3	329.6	6	310.7	6	4616.5	85	5442.5	100
1985	163.4	3	214.3	4	278.2	5	4783.7	88	5439.6	100
1986	212.3	4	129.5	3	436.2	9	4179.7	84	4957.7	100

[1] Percent of sublegal halibut

[2] Percent of grand total

[3] Percent of legal halibut

[4] Percent of total halibut

Note: Due to rounding errors, the percent for each group may total less than or greater than 100%.

TABLE 3. ***Weight (kg) of California halibut (measured and unmeasured) brought on board in halibut gill nets from observed boats in southern California, 1984–86.***

DISCUSSION

Total Catch

The total catch of halibut by the halibut fleet in 1984–86 had specific characteristics. Length frequency data show that approximately 60% of the catch consisted of fish in the 560-mm to 700-mm size range (Figure 1). Fish in this size range are almost all mature fish at between 4 and 10 years of age (Love and Brooks 1990; Pattison and McAllister 1990). These length-frequency data also have a mode for legal halibut that is about 20 mm (0.8 in) larger than that for legal halibut caught and retained by southern California anglers (Figures 1 and 5).

Most of the total catch by weight was sold. Little of it was wasted even though approximately one-quarter of the total catch by number consisted of sublegal fish. Some of these sublegals were sold. This is permitted if a fish weighs more than 4 lb (1.8 kg) in the round. However, it is not possible to determine whether the sublegals sold met this criteria from the data available. An average weight of these sublegals can be calculated from the numbers and

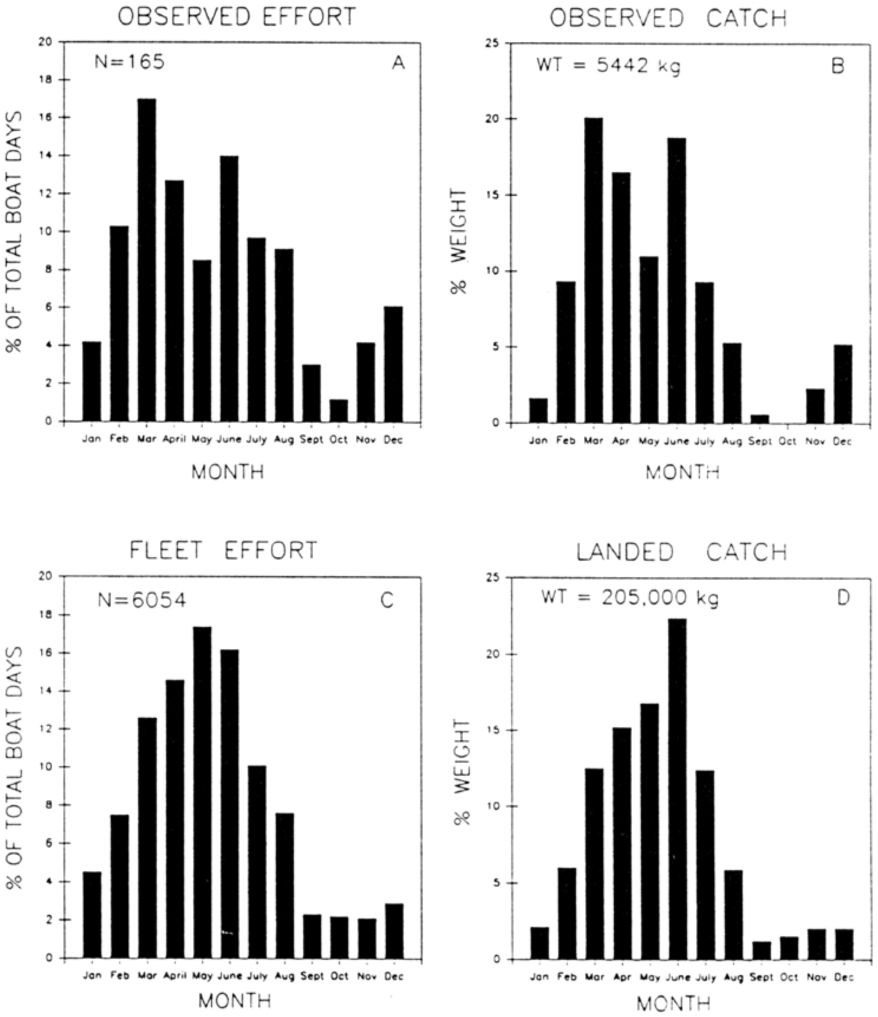

FIGURE 2. Temporal distribution of effort and catch for California halibut in southern California: 1984.
A. Observed effort of gill net boats targeting halibut;
B. Observed catch of gill net boats targeting halibut;
C. Fleet effort for gill net boats targeting halibut;
D. Landed catch for all gill net boats.

FIGURE 2. Temporal distribution of effort and catch for California halibut in southern California: 1984

weights in Tables 2 and 3, but this average is misleading because the weights in Table 3 are based on Schott's length-weight conversions.

Nearly half of the sublegals in the total catch were kept for personal use. This is not unexpected because until January 1986, gill-netters could keep for their own personal use up to 30 lb (14 kg) of undersized halibut. After this date, this allowance of undersized fish was reduced to 4 fish (about 5.5 kg).

About 75% of the total catch was taken in February through July (Figures 2–4) when halibut are spawning in shallow nearshore waters (Clark 1931).

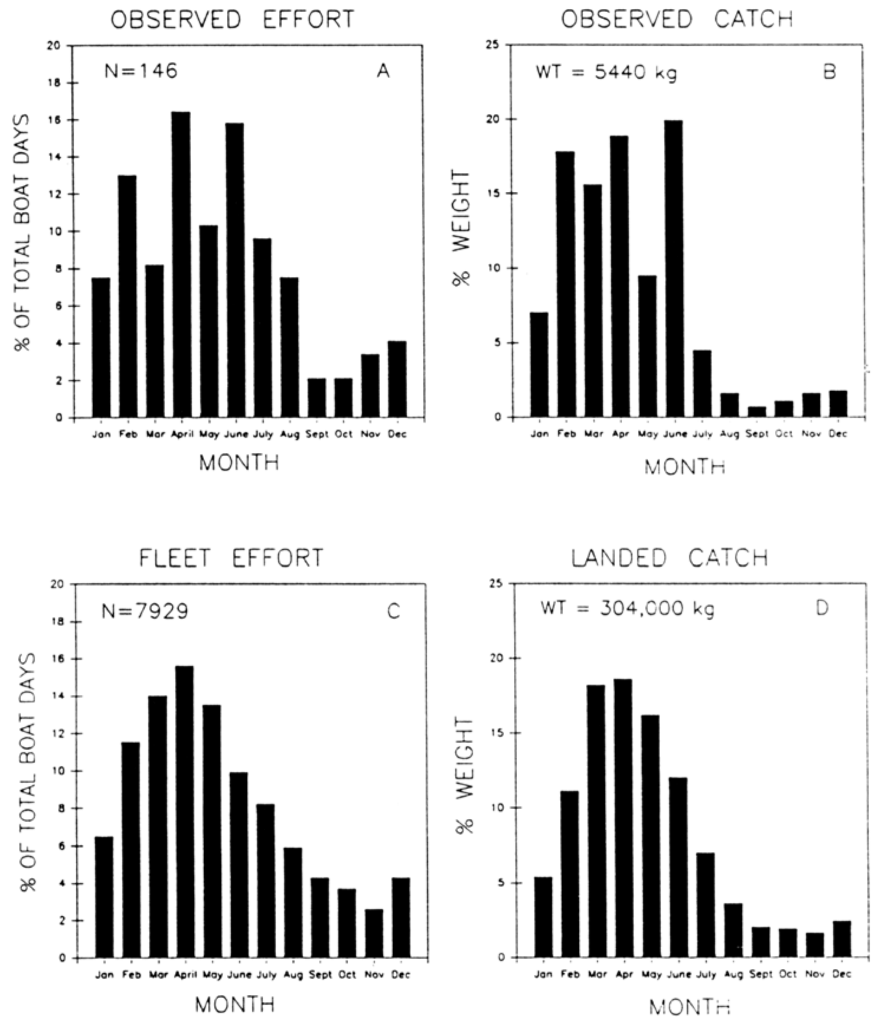

FIGURE 3. Temporal distribution of effort and catch for California halibut in southern California: 1985.

A. Observed effort of gill net boats targeting halibut;
B. Observed catch of gill net boats targeting halibut;
C. Fleet effort for gill net boats targeting halibut;
D. Landed catch for all gill net boats.

FIGURE 3. Temporal distribution of effort and catch for California halibut in southern California: 1985

Validation of Catch Estimates

Landed catch of halibut from commercial landing receipts for gill-netters includes both halibut taken by the halibut fleet and halibut taken incidentally by the remainder of the fleet (e.g. gill-netters targeting angel shark and white seabass). The saleable catch estimate calculated from the observer data can not be directly compared to that part of the landed catch taken by the halibut fleet

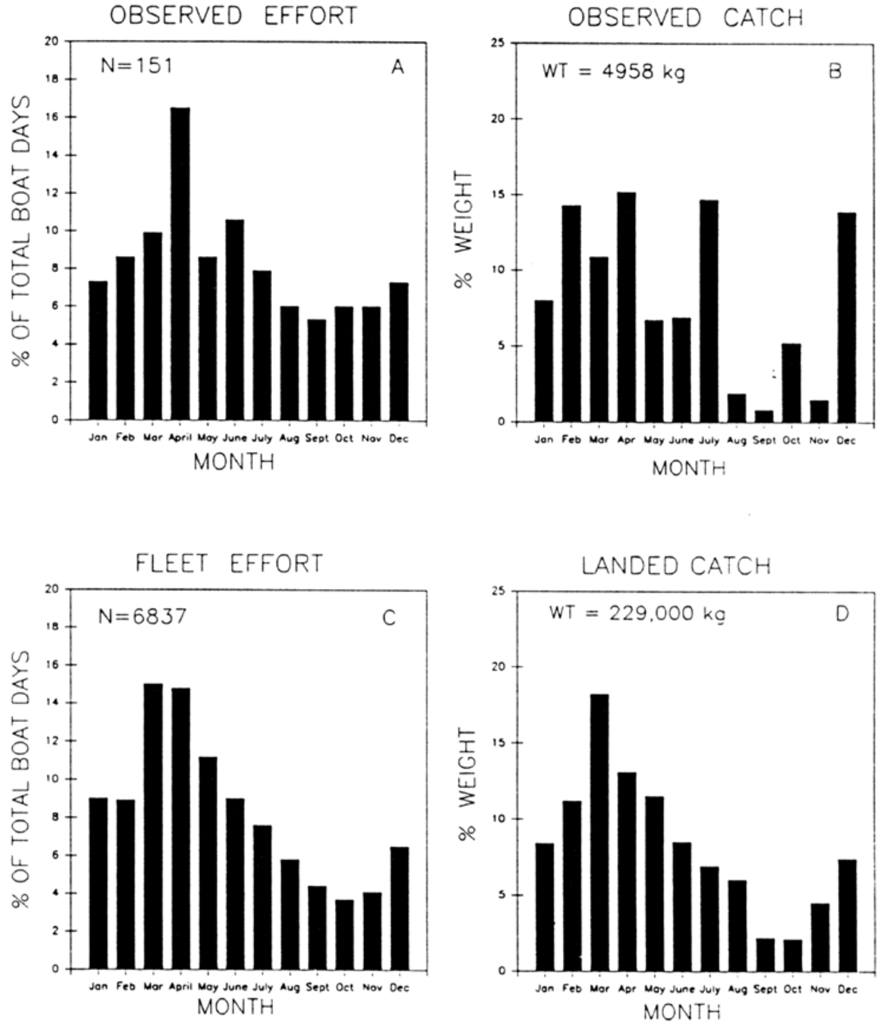

FIGURE 4. Temporal distribution of effort and catch for California halibut in southern California: 1986.
A. Observed effort of gill net boats targeting halibut;
B. Observed catch of gill net boats targeting halibut;
C. Fleet effort for gill net boats targeting halibut;
D. Landed catch for all gill net boats.

FIGURE 4. Temporal distribution of effort and catch for California halibut in southern California: 1986

because landed catch for the halibut fleet only cannot be calculated. As previously stated, incidental take by the remainder of the fleet is estimated to be from 10% to 15% of the landed catch. Thus, saleable catch estimates expanded by 15% for incidental take (hereafter referred to as expanded saleable catch) should be comparable to landed catch for all gill-netters in southern California.

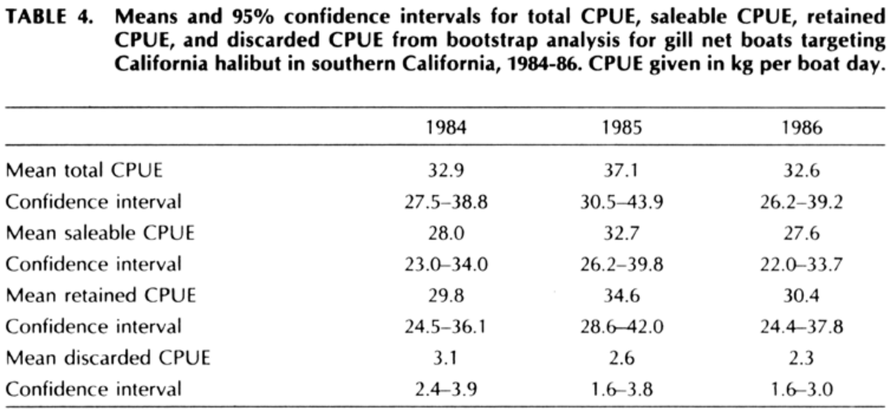

TABLE 4. **Means and 95% confidence intervals for total CPUE, saleable CPUE, retained CPUE, and discarded CPUE from bootstrap analysis for gill net boats targeting California halibut in southern California, 1984-86. CPUE given in kg per boat day.**

	1984	1985	1986
Mean total CPUE	32.9	37.1	32.6
Confidence interval	27.5–38.8	30.5–43.9	26.2–39.2
Mean saleable CPUE	28.0	32.7	27.6
Confidence interval	23.0–34.0	26.2–39.8	22.0–33.7
Mean retained CPUE	29.8	34.6	30.4
Confidence interval	24.5–36.1	28.6–42.0	24.4–37.8
Mean discarded CPUE	3.1	2.6	2.3
Confidence interval	2.4–3.9	1.6–3.8	1.6–3.0

TABLE 4. **Means and 95% confidence intervals for total CPUE, saleable CPUE, retained CPUE, and discarded CPUE from bootstrap analysis for gill net boats targeting California halibut in southern California, 1984–86. CPUE given in kg per boat day.**

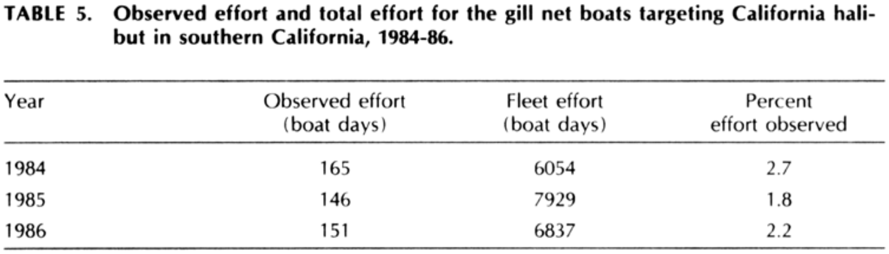

TABLE 5. **Observed effort and total effort for the gill net boats targeting California halibut in southern California, 1984-86.**

Year	Observed effort (boat days)	Fleet effort (boat days)	Percent effort observed
1984	165	6054	2.7
1985	146	7929	1.8
1986	151	6837	2.2

TABLE 5. **Observed effort and total effort for the gill net boats targeting California halibut in southern California, 1984–86.**

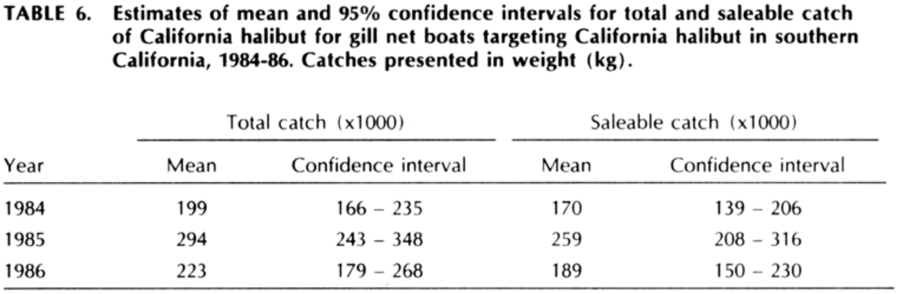

TABLE 6. **Estimates of mean and 95% confidence intervals for total and saleable catch of California halibut for gill net boats targeting California halibut in southern California, 1984-86. Catches presented in weight (kg).**

	Total catch (x1000)		Saleable catch (x1000)	
Year	Mean	Confidence interval	Mean	Confidence interval
1984	199	166 – 235	170	139 – 206
1985	294	243 – 348	259	208 – 316
1986	223	179 – 268	189	150 – 230

TABLE 6. **Estimates of mean and 95% confidence intervals for total and saleable catch of California halibut for gill net boats targeting California halibut in southern California, 1984–86. Catches presented in weight (kg).**

Over 87% of the halibut landed by known gear in southern California in 1984, 1985, and 1986 were caught in gill nets (PACFIN Special Report on California Halibut 1988); thus halibut caught by unknown gear in southern California during these 3 years were likely also caught by gill nets. Because of this, comparisons of expanded saleable catch estimates were made with landed catch for gill nets and unknown gear combined.

Comparisons of expanded saleable catch estimates with landed catch indicate that the saleable catch estimates presented in this paper are underestimated (Table 9). Landed catch fell just at the upper limit of the 95% confidence interval in 1984, above the mean, but within the 95% confidence

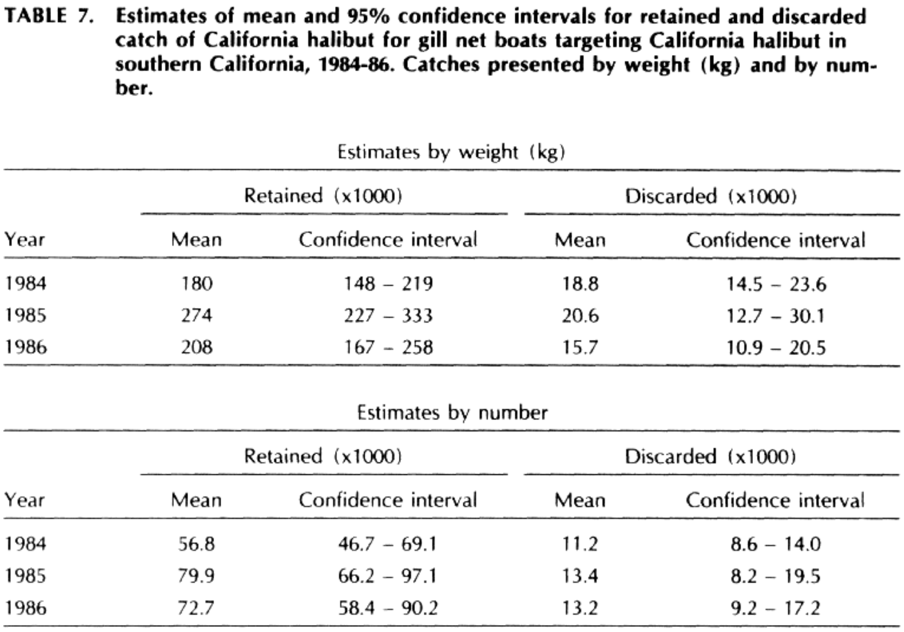

TABLE 7. Estimates of mean and 95% confidence intervals for retained and discarded catch of California halibut for gill net boats targeting California halibut in southern California, 1984-86. Catches presented by weight (kg) and by number.

Estimates by weight (kg)

	Retained (x1000)		Discarded (x1000)	
Year	Mean	Confidence interval	Mean	Confidence interval
1984	180	148 – 219	18.8	14.5 – 23.6
1985	274	227 – 333	20.6	12.7 – 30.1
1986	208	167 – 258	15.7	10.9 – 20.5

Estimates by number

	Retained (x1000)		Discarded (x1000)	
Year	Mean	Confidence interval	Mean	Confidence interval
1984	56.8	46.7 – 69.1	11.2	8.6 – 14.0
1985	79.9	66.2 – 97.1	13.4	8.2 – 19.5
1986	72.7	58.4 – 90.2	13.2	9.2 – 17.2

TABLE 7. ***Estimates of mean and 95% confidence intervals for retained and discarded catch of California halibut for gill net boats targeting California halibut in southern California, 1984–86. Catches presented by weight (kg) and by number.***

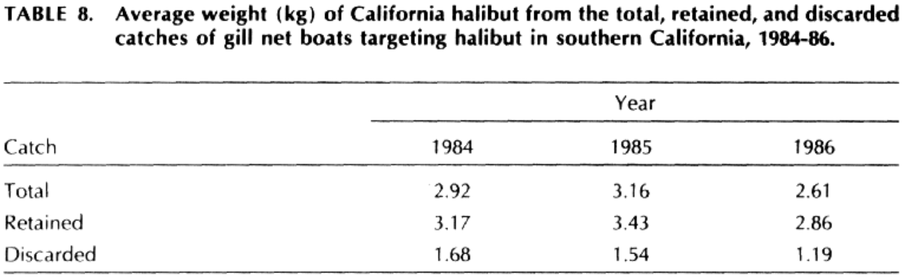

TABLE 8. Average weight (kg) of California halibut from the total, retained, and discarded catches of gill net boats targeting halibut in southern California, 1984-86.

	Year		
Catch	1984	1985	1986
Total	2.92	3.16	2.61
Retained	3.17	3.43	2.86
Discarded	1.68	1.54	1.19

TABLE 8. ***Average weight (kg) of California halibut from the total, retained, and discarded catches of gill net boats targeting halibut in southern California, 1984–86.***

interval in 1985, and slightly above the upper limit of the 95% confidence interval in 1986. These results suggest that the upper limit of the 95% confidence interval probably provides a more realistic approximation of saleable catch than does the mean.

Because saleable catch was found to be underestimated, the total, retained, and discarded catch estimates presented in this paper should also be considered underestimated. The upper limit of the 95% confidence interval should be used as a more realistic approximation for each of these catches.

Underestimation of the catch estimates could have resulted from an underestimation of mean CPUE or fleet effort. Mean CPUE could have been affected by several factors. First, weights were calculated from total lengths using the coefficients as derived by Schott (Reed and MacCall, 1988). These coefficients were calculated using halibut collected in trawls with a female:male ratio of approximately 2:1. In some areas along the southern California

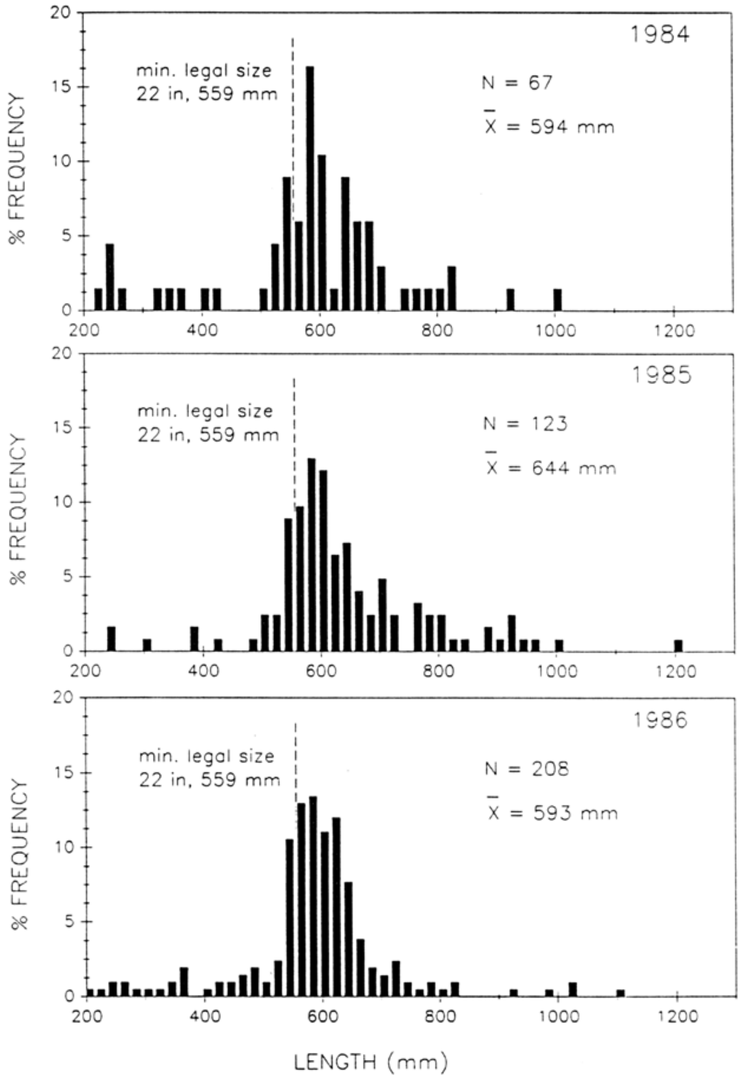

FIGURE 5. Length-frequency distributions of California halibut retained by southern California anglers, 1984-86. NMFS Marine Recreational Fishery Statistics Survey data.

FIGURE 5. Length-frequency distributions of California halibut retained by southern California anglers, 1984–86. NMFS Marine Recreational Fishery Statistics Survey data

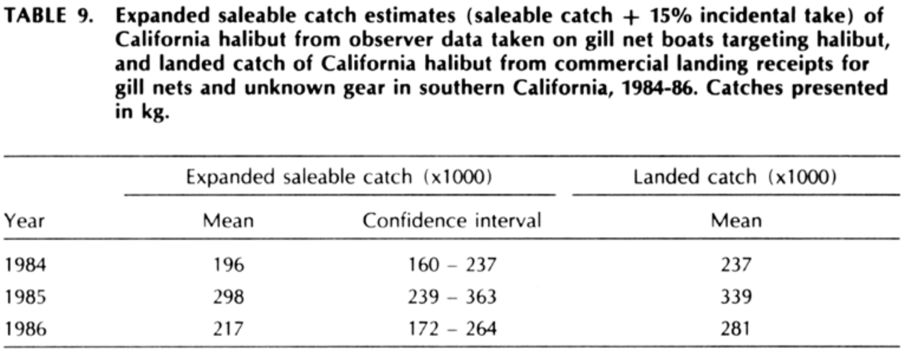

TABLE 9. Expanded saleable catch estimates (saleable catch + 15% incidental take) of California halibut from observer data taken on gill net boats targeting halibut, and landed catch of California halibut from commercial landing receipts for gill nets and unknown gear in southern California, 1984-86. Catches presented in kg.

	Expanded saleable catch (x1000)		Landed catch (x1000)
Year	Mean	Confidence interval	Mean
1984	196	160 – 237	237
1985	298	239 – 363	339
1986	217	172 – 264	281

TABLE 9. ***Expanded saleable catch estimates (saleable catch + 15% incidental take) of California halibut from observer data taken on gill net boats targeting halibut, and landed catch of California halibut from commercial landing receipts for gill nets and unknown gear in southern California, 1984–86. Catches presented in kg.***

mainland, the female:male ratio now may be close to 5:1 (Sunada et al. 1990). Females are heavier than males for a given length (Pattison and McAllister 1990). Thus, if the female:male ratio for the sampled halibut was higher than that ratio for Schott's sample, halibut weights calculated from the observed data would have been underestimated.

Second, mean CPUE could have been underestimated if gill- netters retained and sold a higher proportion of sublegal halibut during trips without observers than during trips with them.

Finally, mean CPUE could have been underestimated if an unrepresentative group of gill net boats were sampled. A biased sample could occur if the temporal or spatial distribution of sampling effort was different from that of the fleet. As shown earlier, the temporal distribution of observed effort was not significantly different from the temporal distribution of halibut fleet effort in 1985 and 1986. However, a significant difference did occur in 1984. This was the only year analyzed which did not include sampling in remote fishing areas. This suggests that the spatial distribution of sampling effort may have been different than that of fleet effort. However, it was not possible to compare these two spatial distributions because fleet effort, as calculated, could not be stratified by area.

A biased sample could also occur if samplers rode boats which consistently caught fewer halibut than those boats not sampled. Observers did sample a core group of boats all 3 years; however, approximately 60% of the observed trips were on boats that were sampled for only 1 or 2 of the 3 years examined. Even so, different data sets such as the disposition of the catch and the proportion of sport-only species in the catch remained fairly consistent across all 3 years (Collins et al. 1985, 1986; Vojkovich et al. 1987).

Several factors probably affected the estimation of fleet effort. First, estimation of fleet effort was dependent upon distinguishing the logs of the halibut fleet from the logs of the remainder of the fleet. If the information needed to distinguish between these groups—gear size, landed catch, fishing depth—was not available, estimation of fleet effort could be affected. Second, if a gill net log was missing, but a commercial landing receipt for that boat was available, 1 d of effort was counted (Diamond and Vojkovich 1990). However, landing receipts for multiple day trips are generally indistinguishable from receipts for single day trips. Thus, fleet effort could have been underestimated because of missing logs.

In summary, it is very likely that both mean CPUE and fleet effort were underestimated. Mean CPUE was probably underestimated because length-to-weight conversions were calculated using coefficients based on low female:male ratios. Changes in fishing patterns because of observer presence and biases in the spatial distribution of sampling effort may also have contributed. Fleet effort was probably underestimated because of missing and incomplete logs.

Relative Distribution of the Halibut Catch

The relative distribution of the halibut catch was examined by comparing the number of halibut retained by the halibut fleet with the number of halibut retained by southern California anglers. As mentioned earlier, the estimates of retained catch for the halibut fleet are probably underestimated with the upper limit of the 95% confidence interval providing a better estimate. On the other hand, the estimated number of halibut caught by southern California anglers is probably overestimated by up to 40% (S.J. Crooke, CDFG, pers. comm.). The NMFS Marine Recreational Fishery Statistics Survey (MRFSS) does not sample moored boats (e.g. in or from marinas) because many of these are behind locked gates or are on private property. Calculations of recreational catch have been based on the assumption that anglers on these moored boats target halibut as often as anglers on boats in sampled areas; however, recent preliminary data indicate that this is probably not true. The lower limit of the 95% confidence interval for the NMFS estimate of mean angler catch is about 20% to 30% below the mean (NMFS 1985, 1986, 1987). Thus, it may provide a more realistic approximation of the number of halibut caught by southern California anglers than does the mean.

Comparisons of retained catch using the upper limit of the confidence intervals for the halibut fleet and the lower limit of the confidence intervals for anglers show that the number of halibut retained by the halibut fleet was greater than the number retained by southern California anglers for each of the 3 years; however, in 1986, the difference between the number of halibut retained by the halibut fleet and the number retained by anglers was small (Tables 7 and 10). Comparison of the percent of fish retained by southern California anglers with the retained catch of the halibut fleet and anglers together reveals that the proportion of halibut taken by anglers increased from 28% in 1984 to 49% in 1986.

SUMMARY

 # 1. Estimates of total catch for the halibut fleet ranged from 199,000 kg halibut in 1984 to 294,000 kg in 1985. From 12% to 15% of this total catch was kept for personal use or discarded; the remaining catch was sold.

 # 2. Comparisons of expanded saleable catch with landed catch (landing receipts) indicate that the catch estimates in this paper are underestimated. This underestimation is probably a result of an underestimation of both mean CPUE and fleet effort. The upper limit of the 95% confidence interval is considered a more realistic approximation of catch.

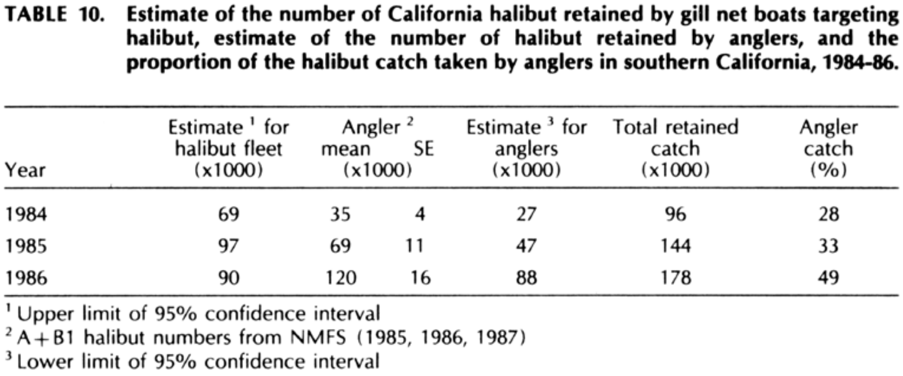

TABLE 10. **Estimate of the number of California halibut retained by gill net boats targeting halibut, estimate of the number of halibut retained by anglers, and the proportion of the halibut catch taken by anglers in southern California, 1984–86.**

Year	Estimate [1] for halibut fleet (x1000)	Angler [2] mean (x1000)	Angler [2] SE (x1000)	Estimate [3] for anglers (x1000)	Total retained catch (x1000)	Angler catch (%)
1984	69	35	4	27	96	28
1985	97	69	11	47	144	33
1986	90	120	16	88	178	49

[1] Upper limit of 95% confidence interval

[2] A + B1 halibut numbers from NMFS (1985, 1986, 1987)

[3] Lower limit of 95% confidence interval

TABLE 10. Estimate of the number of California halibut retained by gill net boats targeting halibut, estimate of the number of halibut retained by anglers, and the proportion of the halibut catch taken by anglers in southern California, 1984–86.

 # 3. The number of halibut retained by the halibut fleet ranged from 56,800 halibut in 1984 to 79,900 in 1985; the number discarded ranged from 11,200 in 1984 to 13,400 in 1985.

 # 4. The number of halibut retained by the halibut fleet was greater than the number retained by southern California anglers for each of the 3 years; however, the proportion of halibut taken by anglers increased from 28% in 1984 to 49% in 1986.

ACKNOWLEDGMENTS

Rich Dixon provided the bootstrap program used to generate the means and confidence intervals presented in this paper and provided the initial draft of the bootstrap methods section. Sandy Diamond provided the raw materials from which the fleet effort estimates were generated. I thank Julie McCormick, Cate Fahey, and Marina Busatto for their assistance with the data analysis and graphics as well as all the scientific aides who so diligently collected the gill net data. Finally, I thank Marija Vojkovich, Ken Miller, and Steve Torres for their constructive and invaluable emendations. This project was supported by Dingell-Johnson/Wallop-Breaux Federal Aid in Sport Fish Restoration Act funds (California Project F-50-R).

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ESTIMATING TOTAL EFFORT IN THE GILL AND ENTANGLING NET FISHERY FOR CALIFORNIA HALIBUT, 1980–1986

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ABSTRACT

Some prohibited and unmarketable species, especially seabirds and marine mammals, are captured incidentally in the gill and entangling net fishery for California halibut, Paralichthys californicus, along the California coast. To assess the magnitude of this incidental catch and to evaluate the effectiveness of regulations enacted to lessen this take, total fishing effort estimates were needed. To calculate these estimates, a unique method utilizing three different and distinct data sources was developed and is presented here.

Total effort estimates were calculated for the entire state as well as four distinct fishing areas: San Francisco, Monterey Bay, Morro Bay, and Southern California. These estimates indicate that total fishing effort by the gill and entangling net fleet approximately doubled for halibut from 1980 to 1986. However, distinct fluctuations in effort were noted in each area. Total effort in the San Francisco area peaked in 1983 and then declined to a level slightly less than that in 1981. In the Monterey area, effort declined more than 90% from 1980 to 1983 and then peaked in 1985. The Morro Bay area showed the greatest increases in effort from 1984 to 1986. Likewise, total effort in the Southern California area showed its greatest increase in 1984 and remained at that level. Possible causes for effort fluctuations are given as well as suggestions for increased reliability of the estimates.

INTRODUCTION

Gill and entangling nets have been traditionally used to fish for California halibut, Paralichthys californicus, in shallow waters off the coast of California (Methot 1983). Gill nets are vertical curtains of webbing designed primarily to catch fish by the opercula (Bullis and Captiva 1969). Entangling nets are modified gill nets that use suspenders or clips to create vertical slack, or that use several layers of webbing with different mesh sizes (trammel nets) to ensnare animals. Gill and entangling nets for halibut are weighted to fish the ocean bottom and anchored in place (set nets).

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Gill and entangling nets are constructed to capture specific fish or fishes (target species), but they also incidentally catch animals that are unmarketable or whose capture is prohibited by law. These animals include marine mammals, seabirds, and fishes set aside for recreational use. Public concern about the incidental catch, and increased competition between recreational and commercial fishermen for limited fishery resources have created a controversy regarding the use of gill and entangling nets. This controversy has resulted in a series of regulations designed to restrict the use of set nets.

Refined estimates of total fishing effort were needed initially to assess the magnitude of the incidental catch of marine mammals and seabirds in set nets (Diamond and Hanan 1986; Marine Resources Division 1987). As regulations were implemented, effort estimates were used to evaluate the effectiveness of area and depth closures in reducing the incidental catch, and to determine the effects of restrictions on commercial fishing. Effort estimates have since been utilized to determine the total number of fishes, both prohibited and target species, caught in set nets (Vojkovich et al. 1989; Aseltine 1990).

This report describes the methods used to estimate the total annual fishing effort in the halibut set net fishery in California, and presents the estimates obtained for the 1980–86 fishing years. Observed trends in fishing effort are discussed, and ideas for improving the data are suggested.

METHODS

The basic unit of effort is defined as one net fished, regardless of net length, type, material, or length of time fished (soak time). Total fishing effort corresponds to the total number of nets fished for halibut in California during a commercial fishing year, which extends from 1 April through 31 March. The legal range of fishing halibut with set nets in California between 1980 and 1986 extended from the Sonoma-Mendocino County line, located north of Bodega Bay, southward to the Mexican border. Because of natural geographic boundaries, regional differences in fishing techniques, and localized concerns about the impacts of set nets, the halibut fishery was divided into four areas for monitoring and analysis: San Francisco (Sonoma-Mendocino County line to Pigeon Point); Monterey Bay (Pigeon Point to Point Sur); Morro Bay (Point Sur to Point Arguello); and Southern California (south of Point Arguello; Figure 1).

Total Halibut Fishing Effort

Total fishing effort was estimated by area and year, as follows:

$$TE_y = \Sigma (D_a \times N_a)$$

TABLE

where:

TE_y = total fishing effort in California for fishing year y;

D_a = total number of days fished by all vessels in area a; and

FIGURE 1. The four fishing areas for California halibut with gill and entangling nets (set nets). Set nets are illegal in California north of the San Francisco area.

FIGURE 1. The four fishing areas for California halibut with gill and entangling nets (set nets). Set nets are illegal in California north of the San Francisco area

N_a = average number of nets fished daily per vessel in area a.

Although this equation was used to calculate TE_y each year, D_a and N_a were derived differently in 1980–82 due to differences in available data. The procedures used to estimate 1983–86 effort will be presented first because they form the basis for the 1980–82 estimates.

1983–1986 Halibut Fishing Effort

Data Used to Estimate TE_y

Three data sources were used to estimate total fishing effort: fishing logs, landing receipts, and observations by California Department of Fish and Game (CDFG) personnel. Three sources were needed because no single source provided a complete record of total effort, and because of problems with conflicting, erroneous, and missing data. Each data base was examined to identify data pertaining to the halibut set net fishery as described below.

Fishing Logs. Gill net fishermen are required by law to submit fishing logs. Required log information includes vessel identification (boat number), fishing date and location, water depth, soak time, net length, and catch. Information about mesh size has been required since 1984.

Target species were assigned to each log using guidelines based on fishing location, net characteristics, and catch; these guidelines changed slightly as regulations changed. Generally, halibut was the assigned target species for nets that were fished in water less than 20 fm (37 m) deep, had stretched mesh sizes of 8–8.5 inches (203–216 mm), and soaked 48 h or less. The catch composition that identified halibut as the target species consisted of halibut and associated species such as: Pacific angel shark, Squatina california; starry flounder, Platichthys stellatus; shovelnose guitarfish, Rhinobatos productus; bat ray, Myliobatis californica; skates, Raja spp.; leopard shark, Triakis semifasciata; soupfin shark, Galeorhinus zyopterus; thresher shark, Alopias vulpinus; spiny dogfish, Squalus acanthias; white seabass, Atractoscion nobilis; and brachyuran crabs.

Identifying halibut effort was sometimes difficult because the same net was often used to fish for other marketable species with similar habitat requirements, behavior, and body shape, such as starry flounder in the San Francisco area and Pacific angel shark in Southern California. Flounder effort could not be separated from halibut effort, and was therefore included in the estimates. Pacific angel shark effort could often be separated from halibut effort by differences in fishing location or mesh size, consistently large catches of angel shark, or personal knowledge of individual fishing habits. Thus, when possible, angel shark effort was excluded from the estimates.

Landing Receipts. Wholesale fish buyers and fishermen who sell directly to restaurants or to the public are required by law to submit landing receipts to the CDFG. Information recorded on the landing receipt includes boat number, date, fishing location, gear type, price, and pounds bought or sold, by species.

Receipts from all known or suspected set net vessels were evaluated to identify fish caught with set nets because gear type was often omitted or erroneously recorded. Set net receipts were distinguished by differences in catch composition, recognizable patterns of gear use by fishermen, or personal knowledge of particular fishing vessels.

As with the fishing logs, a target species was assigned to each landing receipt for fish caught with set nets. For the 1983–85 data, assignment of target species was based on the relative pounds of each species landed, each vessel's pattern of landings, and personal knowledge of individual fishing habits. For the 1986 data, a computer program was written that incorporated the information gained from evaluating the 1983–85 data. The program logic was derived by comparing target species assigned by the computer to those assigned manually. Halibut was assigned as a target species by the computer in various ways, depending on: i) the pounds of halibut landed that day, ii) the number of recent halibut landings by that vessel, iii) the pounds landed of associated species as listed above, iv) recent assignments of halibut as a target species, and v) other possible target species (Figure 2). Thus, halibut could be the target species even if no halibut were landed that day.

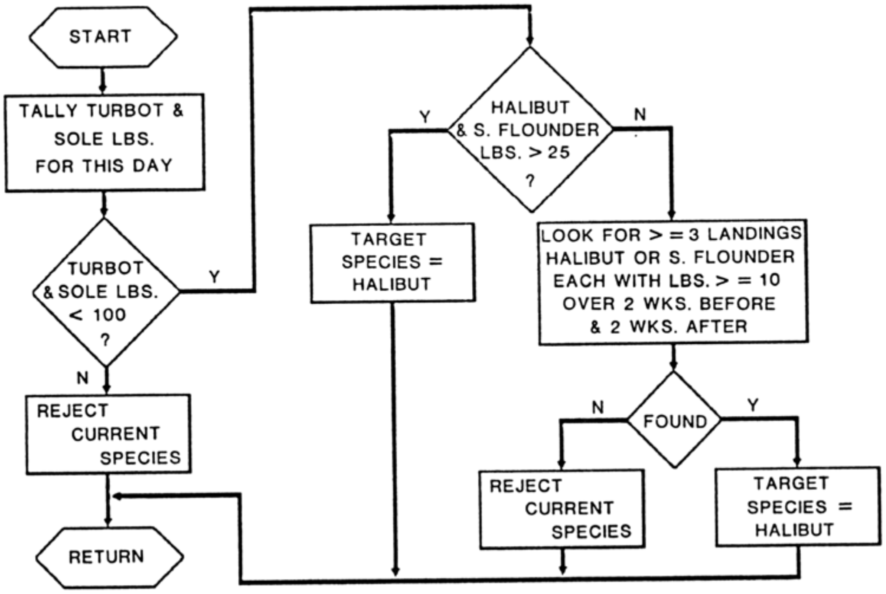

FIGURE 2. An example of the logic used by the computer to assign halibut as a target species if halibut or starry flounder were landed. Halibut could be a target species even if no halibut was landed that day, depending on the pounds landed of other species associated with halibut, and how consistently halibut was landed by that vessel.

FIGURE 2. An example of the logic used by the computer to assign halibut as a target species if halibut or starry flounder were landed. Halibut could be a target species even if no halibut was landed that day, depending on the pounds landed of other species associated with halibut, and how consistently halibut was landed by that vessel

Observations. By the start of the 1983 fishing year, observations of fishing activity were underway in all four areas. Observers recorded data such as date, location, target species, net length, mesh size, and the number by species of animals caught. Fisherman participation in the observation programs was voluntary; i.e. fishermen could refuse without reprisal to be observed.

Observations were of two basic types: those made at sea (at-sea observations), and those made from shore using Questar spotting scopes (shore-based observations). At-sea observations were usually arranged with as little advanced notice as possible, to minimize the chance that fishing activities might change due to an observer's presence. Shore-based observations were only used when fishermen in an area did not participate in the program, or when fishing took place in locations near the coast but far from port. Observers recorded the same kind of data as that gathered at sea; however, data on net length, soak time, and mesh size could not be obtained.

Total Number of Days Fished (D_a)

To obtain the total number of days fished, the three sources of halibut set net data were merged by boat number, date, and area using the method described by Wendell et al. (1986). A day of fishing was indicated by the presence of a log. If no log was submitted, a day of fishing was inferred by the presence of either a landing receipt or an observation.

Average Number of Nets Fished Daily (N_a)

Fishermen were asked to record on their logs the number of nets set daily. However, differences in interpretation and variation in the accuracy and completeness of logs submitted made log data inadequate for determining N_a. Therefore, observations were used with the logs as follows:

$$N_a = (\sum_i \sum_j n_{ij} / \sum_i F_i) / (L / b)$$

TABLE

where: N_a = average number of nets fished daily per vessel in area a; n_{ij} = cumulative length of all nets reported on fishing logs by boat i on day j; F_i = number of days fished reported on logs by boat i; L = sum of net lengths of all nets observed (excluding shore-based observations); and b = number of nets observed (excluding shore-based observations.

In summary, the average cumulative length of net fished daily per vessel as reported on logs was divided by the average length per net from at-sea observations. This was accomplished using a bootstrapping procedure in which randomly chosen values from the distribution of the numerator were divided by randomly chosen values from the distribution of the denominator (Efron 1979). The procedure was repeated at least 500 times, creating a new data set from the stored quotients. The average quotient, N_a, and its standard deviation were obtained from the new data set.

For the bootstrap procedure, the numerator and denominator were assumed to be normally distributed. Shore-based observations were not used because net length information could not be obtained. If an area lacked at-sea observations during the year, the average from the previous year was used.

To provide for a range in the estimated total number of nets, N_a was expressed as a low, mean, and high value for each area and year. Low and high values equaled the mean, minus and plus the standard deviation, respectively; however, low values of N_a could not be less than one, because a vessel must deploy at least one net for fishing to have occurred that day.

1980–1982 Halibut Fishing Effort

Data Used to Estimate TE_y

of the three data sources available for 1983–86 estimates, only landing receipts were consistently available for estimating total effort for 1980–82. The method of calculating effort for 1980–82 therefore relied on making receipt data comparable to the merged data from later years.

As with the 1983–86 method, landing receipts were examined to determine gear type and target species. Receipts with set nets as the recorded gear were considered set net receipts, as well as those that lacked an identified gear. The latter were included because most halibut were caught with gill and entangling nets. Halibut was the assigned target species whenever halibut was landed with set nets because halibut was not caught consistently in any other gill and entangling net fishery prior to 1983.

Total Number of Days Fished **(D_a)**

D_a for 1980–1982 was calculated by area using a linear regression between the annual number of halibut set net landings in 1983–86 and the yearly estimates of D_a obtained from merging the fishing logs, landing receipts, and observations for 1983–86 (Sokal and Rohlf 1973). Knowing the number of halibut set net landings in 1980–82, it was then possible to estimate D_a. Correlation coefficients between landings and estimates of D_a ranged from 0.84 in the Morro Bay area to 0.99 in the Monterey Bay area (Table 1).

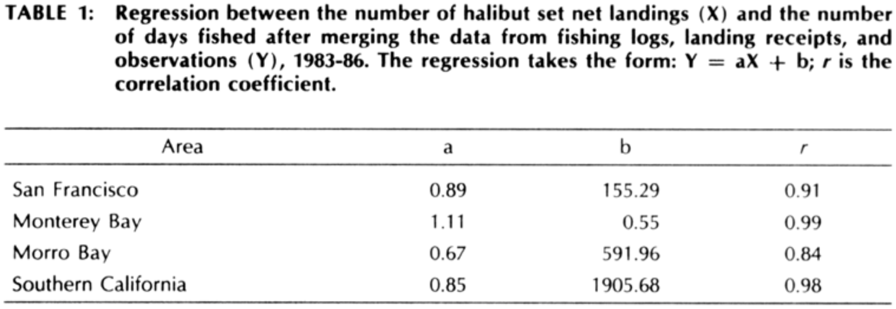

TABLE 1: Regression between the number of halibut set net landings (X) and the number of days fished after merging the data from fishing logs, landing receipts, and observations (Y), 1983-86. The regression takes the form: Y = aX + b; *r* is the correlation coefficient.

Area	a	b	*r*
San Francisco	0.89	155.29	0.91
Monterey Bay	1.11	0.55	0.99
Morro Bay	0.67	591.96	0.84
Southern California	0.85	1905.68	0.98

TABLE 1: ***Regression between the number of halibut set net landings (X) and the number of days fished after merging the data from fishing logs, landing receipts, and observations (Y), 1983–86. The regression takes the form: Y = aX + b; r is the correlation coefficient.***

Average Number of Nets Fished Daily **(N_a)**

Fishing logs and observations were not available for 1980–82. N_a was therefore estimated for these three years using one net fished daily per vessel as the low value, the 1983 mean as the mean value, and the 1983 mean plus the standard deviation as the high value.

RESULTS

The mean number of halibut set nets fished in California increased from about 16,500 in 1980 to approximately 21,000 in 1981, then remained steady through 1983. In 1984, mean fishing effort increased to approximately 31,000 nets, and then continued at that level through 1986 (Figure 3; Tables 2 and 3).

Distinct patterns of fishing effort were noted in each area. In the San Francisco area, fishing effort peaked at approximately 4500 nets in 1983, then declined. By 1986, effort had decreased to 2500 nets, which was below the 1981 level (Figure 4A; Tables 2 and 3). Similarly, the total number of days fished (D_a) peaked in 1983 and then declined (Figure 4B; Tables 2 and 3), while the average number of nets fished daily per vessel (N_a) remained constant (Figure 4B; Tables 2 and 3).

FIGURE 3. Total halibut set net fishing effort (●) in California. Error bars represent the standard deviation.

FIGURE 3. Total halibut set net fishing effort ([.]) in California. Error bars represent the standard deviation

In the Monterey Bay area, fishing effort decreased by approximately 30–40% annually between 1980 and 1983, then nearly quadrupled from 1983 to 1984 (Figure 5A; Tables 2 and 3). Although D_a was larger in 1984 than 1985, total effort peaked in 1985 at about 1600 nets, reflecting the unusually large N_a in that year (Figures 5A and B; Tables 2 and 3).

Fishing effort in the Morro Bay area was greatest during 1986 when an estimated 4600 nets were fished (Figure 6A; Tables 2 and 3). Although more days were fished in 1984, N_a was highest in 1986 with over four nets set daily per boat (Figure 6B; Tables 2 and 3).

Fishing effort in Southern California increased from about 11,000 nets fished in 1980 to 14,000 nets in 1981, then remained constant for 3 years. Fishing effort increased to about 22,000 nets in 1984, then stayed at that level through 1986 (Figure 7A, Tables 2 and 3). D_a showed a similar pattern, while N_a increased slightly from 1983 to 1984, then remained steady through 1986 (Figure 7B, Tables 2 and 3).

DISCUSSION

Fluctuations in fishing effort can be attributed to a variety of factors. In the San Francisco area, the increase in effort before 1983 was probably caused by the increasing number of participants in the fishery, and the influx of fishermen moving north to avoid closures in Monterey Bay. Local area and depth closures enacted to reduce the incidental take of marine mammals and seabirds may have caused the decrease in effort after 1983 (Marine Resources Division 1987).

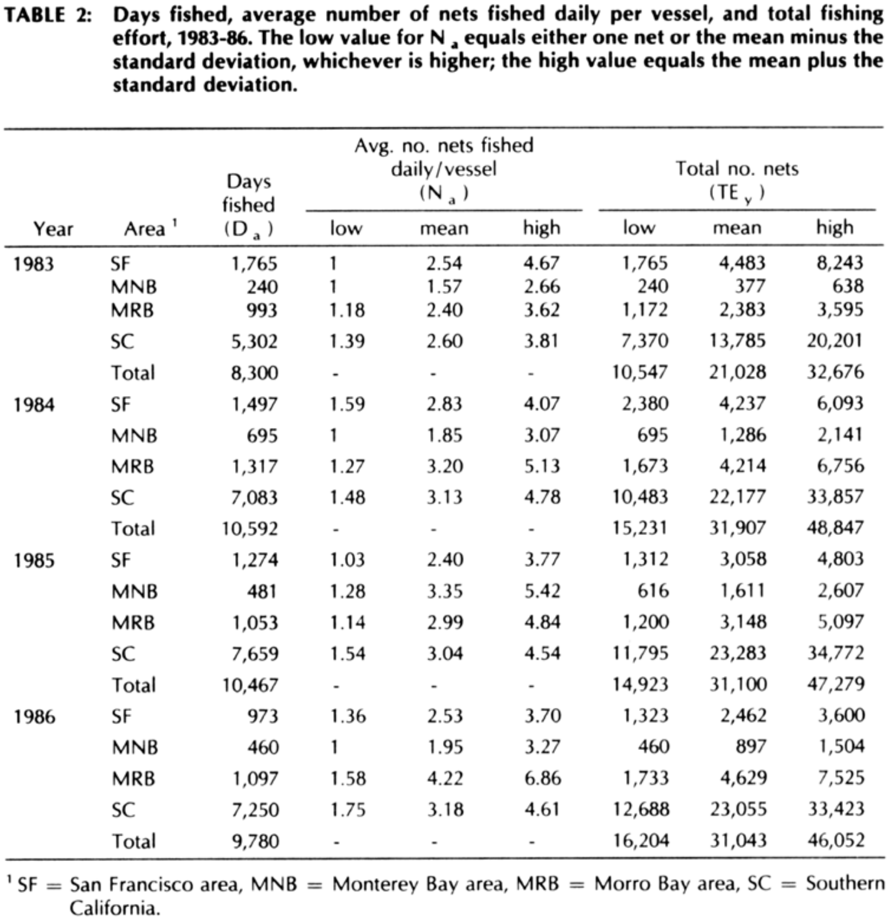

TABLE 2: Days fished, average number of nets fished daily per vessel, and total fishing effort, 1983-86. The low value for N_a equals either one net or the mean minus the standard deviation, whichever is higher; the high value equals the mean plus the standard deviation.

Year	Area[1]	Days fished (D_a)	Avg. no. nets fished daily/vessel (N_a)			Total no. nets (TE_y)		
			low	mean	high	low	mean	high
1983	SF	1,765	1	2.54	4.67	1,765	4,483	8,243
	MNB	240	1	1.57	2.66	240	377	638
	MRB	993	1.18	2.40	3.62	1,172	2,383	3,595
	SC	5,302	1.39	2.60	3.81	7,370	13,785	20,201
	Total	8,300	-	-	-	10,547	21,028	32,676
1984	SF	1,497	1.59	2.83	4.07	2,380	4,237	6,093
	MNB	695	1	1.85	3.07	695	1,286	2,141
	MRB	1,317	1.27	3.20	5.13	1,673	4,214	6,756
	SC	7,083	1.48	3.13	4.78	10,483	22,177	33,857
	Total	10,592	-	-	-	15,231	31,907	48,847
1985	SF	1,274	1.03	2.40	3.77	1,312	3,058	4,803
	MNB	481	1.28	3.35	5.42	616	1,611	2,607
	MRB	1,053	1.14	2.99	4.84	1,200	3,148	5,097
	SC	7,659	1.54	3.04	4.54	11,795	23,283	34,772
	Total	10,467	-	-	-	14,923	31,100	47,279
1986	SF	973	1.36	2.53	3.70	1,323	2,462	3,600
	MNB	460	1	1.95	3.27	460	897	1,504
	MRB	1,097	1.58	4.22	6.86	1,733	4,629	7,525
	SC	7,250	1.75	3.18	4.61	12,688	23,055	33,423
	Total	9,780	-	-	-	16,204	31,043	46,052

[1] SF = San Francisco area, MNB = Monterey Bay area, MRB = Morro Bay area, SC = Southern California.

TABLE 2: ***Days fished, average number of nets fished daily per vessel, and total fishing effort, 1983–86. The low value for N_a equals either one net or the mean minus the standard deviation, whichever is higher; the high value equals the mean plus the standard deviation.***

The decrease in effort in the Monterey Bay area from 1980 to 1983 was probably due to the area and depth restrictions that began in Monterey Bay in June 1982, and to the exodus of Vietnamese halibut fishermen to the developing rockfish, Sebastes spp., and white croaker, Genyonemus lineatus, fisheries. Specific causes of the fluctuations in fishing effort after 1983 in the Monterey Bay area and between 1980 and 1986 in the Morro Bay area are difficult to identify, but probably include changes in the number of licensed fishermen, shifts in the halibut population due to El Niño, and displacement of fishermen from closed areas. In addition, high levels of fishing effort in the Monterey Bay area in 1985 and the Morro Bay area in 1986 were the result of increases in the average number of nets fished daily. The increased value for N_a in the Monterey Bay area may not have been valid because the increase was not maintained the following year.

In Southern California, an increase in the number of halibut fishermen was possibly the cause of the increase in fishing effort between 1983 and 1984. The consistent level of fishing effort between 1984 and 1986 most likely resulted

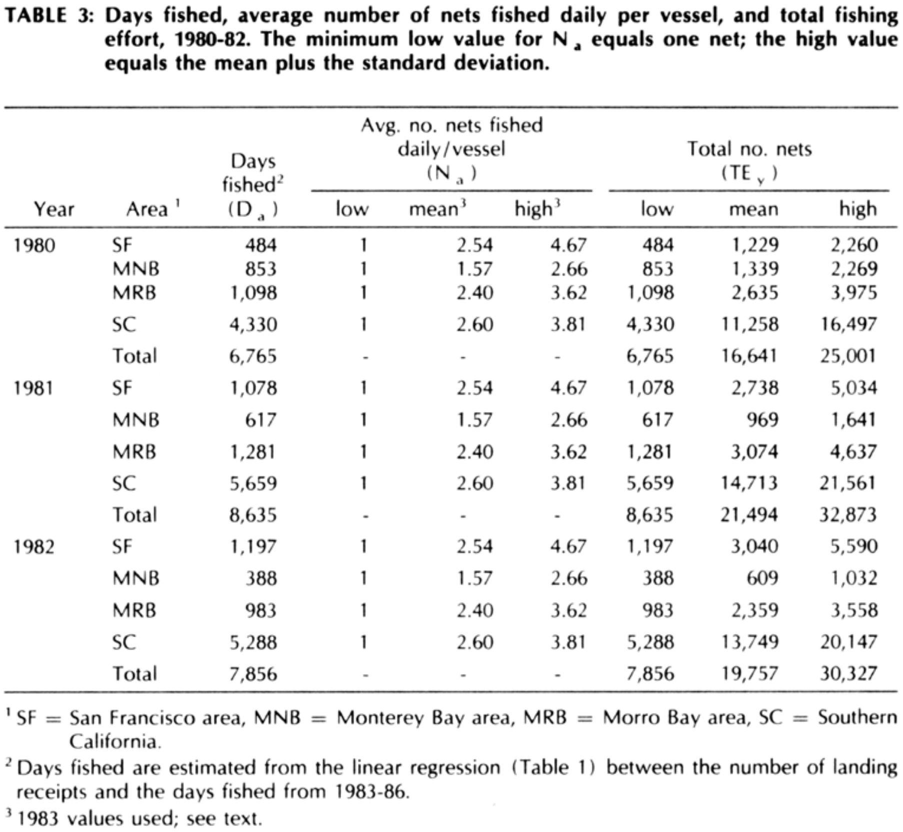

TABLE 3: Days fished, average number of nets fished daily per vessel, and total fishing effort, 1980-82. The minimum low value for N_a equals one net; the high value equals the mean plus the standard deviation.

Year	Area[1]	Days fished[2] (D_a)	Avg. no. nets fished daily/vessel (N_a)			Total no. nets (TE_y)		
			low	mean[3]	high[3]	low	mean	high
1980	SF	484	1	2.54	4.67	484	1,229	2,260
	MNB	853	1	1.57	2.66	853	1,339	2,269
	MRB	1,098	1	2.40	3.62	1,098	2,635	3,975
	SC	4,330	1	2.60	3.81	4,330	11,258	16,497
	Total	6,765	-	-	-	6,765	16,641	25,001
1981	SF	1,078	1	2.54	4.67	1,078	2,738	5,034
	MNB	617	1	1.57	2.66	617	969	1,641
	MRB	1,281	1	2.40	3.62	1,281	3,074	4,637
	SC	5,659	1	2.60	3.81	5,659	14,713	21,561
	Total	8,635	-	-	-	8,635	21,494	32,873
1982	SF	1,197	1	2.54	4.67	1,197	3,040	5,590
	MNB	388	1	1.57	2.66	388	609	1,032
	MRB	983	1	2.40	3.62	983	2,359	3,558
	SC	5,288	1	2.60	3.81	5,288	13,749	20,147
	Total	7,856	-	-	-	7,856	19,757	30,327

[1] SF = San Francisco area, MNB = Monterey Bay area, MRB = Morro Bay area, SC = Southern California.

[2] Days fished are estimated from the linear regression (Table 1) between the number of landing receipts and the days fished from 1983-86.

[3] 1983 values used; see text.

TABLE 3: ***Days fished, average number of nets fished daily per vessel, and total fishing effort, 1980–82. The minimum low value for N_a equals one net; the high value equals the mean plus the standard deviation.***

from two compensating factors: new market demands for species such as Pacific angel shark which reduced halibut fishing effort; and closures in other gill net fisheries, such as the shark-swordfish fishery, which increased halibut fishing effort.

Combining the three data sources provided better estimates of total fishing effort than using any individual source. Fishing logs alone were inadequate for estimating fishing effort due to problems with the quality and quantity of the data. For example, in a test comparison between logs and observations in Southern California for April 1985, 27% of the observed nets could not be matched to a log, and only 13% matched exactly by boat number, date, net length, and water depth. Likewise, based on days fished, between 9% and 45% of the fishing effort in each area during 1983–86 would not have been counted if logs alone were used.

Similarly, landing receipts were not used as the sole measure of effort because receipts were submitted by the fish buyers, not the fishermen; thus the accuracy of the information was uncertain. In addition, landing receipts only documented successful fishing effort. CDFG observations, although considered to be accurate, were not used alone as an effort estimator, due to the small percentage of fishing days that were observed.

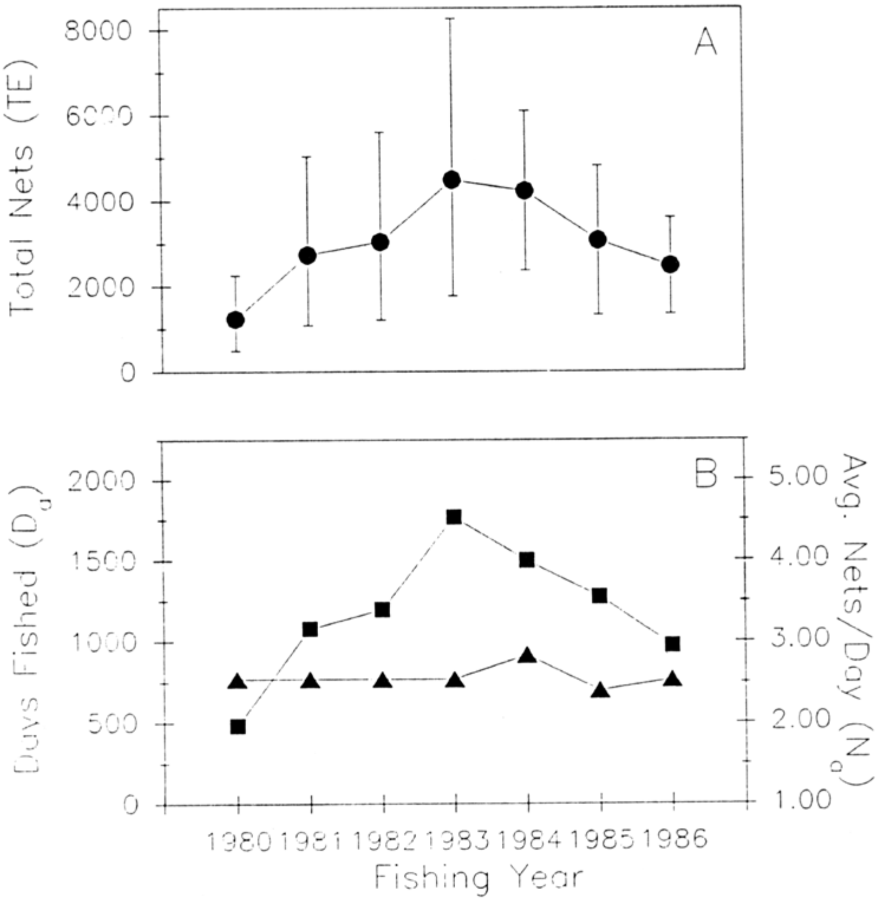

FIGURE 4. Halibut set net fishing effort in the San Francisco area. A. Total effort (●). Error bars represent the standard deviation. B. The number of days fished (■), and the average number of nets fished daily (▲).

FIGURE 4. Halibut set net fishing effort in the San Francisco area. A. Total effort (•). Error bars represent the standard deviation. B. The number of days fished (#), and the average number of nets fished daily (#)

Even using the three data sources, total fishing effort was underestimated by an unknown amount for three reasons. First, it was possible to fish without submitting a log, to buy or sell fish without a landing receipt, and to avoid being observed by the CDFG. This undocumented fishing effort was impossible to quantify. Second, each landing receipt or observation not associated with a log was considered only 1 day fished, although fishing trips often continued for several days. Third, N_a was underestimated because some fishermen underreported the length of net fished, due to apprehension about future restrictions on gear. The magnitude of this bias could not be assessed.

The greatest difficulty in estimating fishing effort was identifying the target species of the landing receipts and logs. Prior to the computerized system, target species assignments were often subjective and always labor intensive. The automated procedure used for the 1986 landing receipts overcame most of

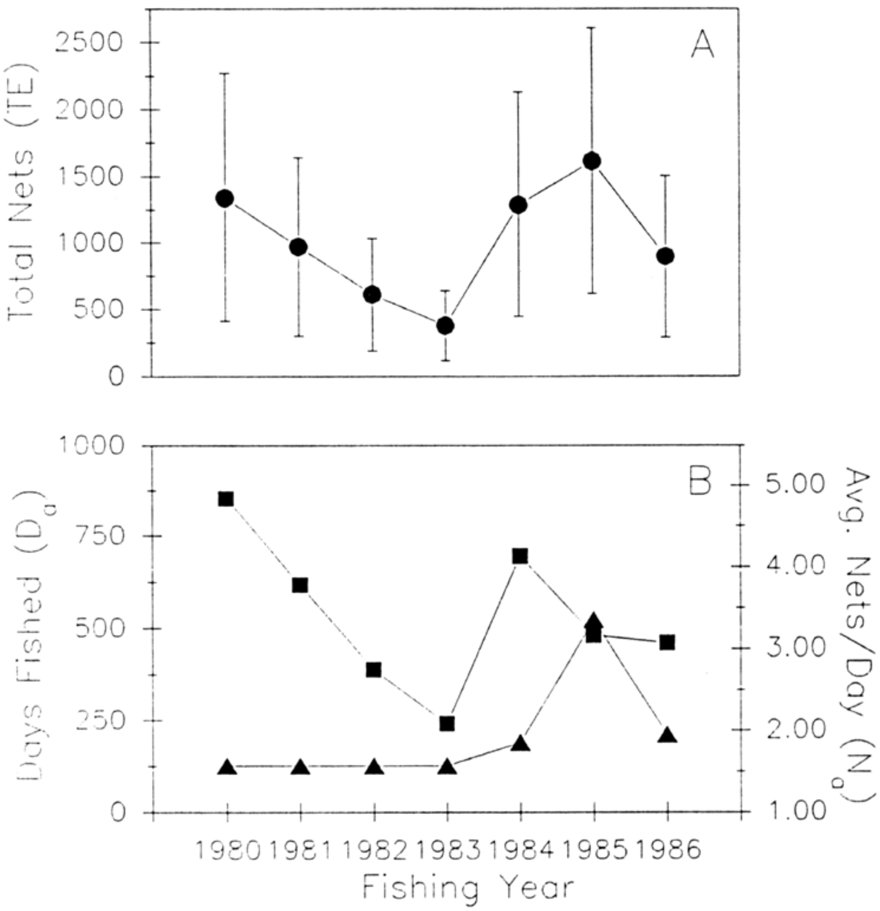

FIGURE 5. Halibut set net fishing effort in the Monterey Bay area. A. Total effort (●). Error bars represent the standard deviation. B. The number of days fished (■), and the average number of nets fished daily (▲).

FIGURE 5. Halibut set net fishing effort in the Monterey Bay area. A. Total effort (•). Error bars represent the standard deviation. B. The number of days fished (#), and the average number of nets fished daily (#)

these problems, but due to variations in data integrity, some computer generated target species assignments were unreconcilable or absent. These "problem" receipts were processed manually. Thus, a biologist was still needed to make the final decision.

Presently, target species assignments for logs are made manually using a strict set of criteria; however, the same problems mentioned above exist for this system. Creation of a computer program to assign target species to the logs is the next step in improving the estimates of fishing effort.

Direct observation of every fishing trip is the only method of obtaining accurate effort figures. This method is not an option in the entangling net fishery because of the size of the fishery itself, logistics, and monetary contraints. However, improving the quality of the available data is an option. The logs

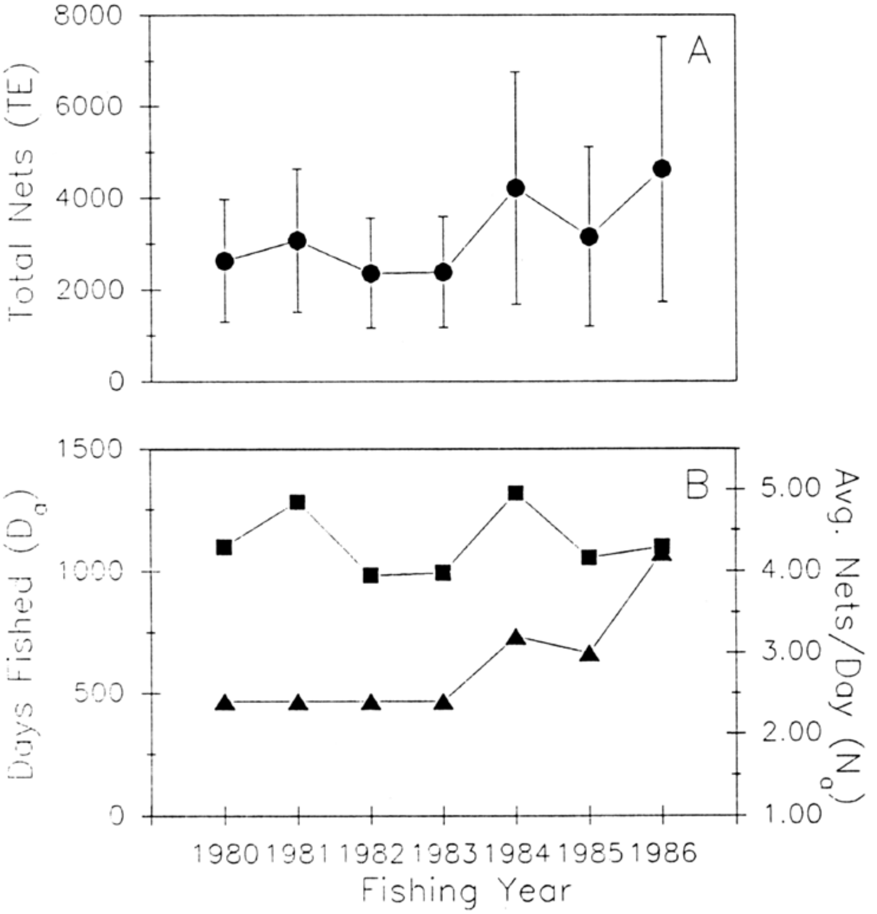

FIGURE 6. Halibut set net fishing effort in the Morro Bay area. A. Total effort (●). Error bars represent the standard deviation. B. The number of days fished (■), and the average number of nets fished daily (▲).

FIGURE 6. Halibut set net fishing effort in the Morro Bay area. A. Total effort (•). Error bars represent the standard deviation. B. The number of days fished (#), and the average number of nets fished daily (#)

alone could provide the most complete set of information for effort estimations. Suggestions for improvements to the data include better training of fishermen on log requirements, increased feedback about partially or incorrectly completed logs, and stricter enforcement of penalties for inaccuate or unsubmitted logs. The most difficult problem to overcome in improving log data is that many fishermen perceive restrictions on fishing operations as a direct result of the information submitted on logs. Unfortunately, this perception is often reality.

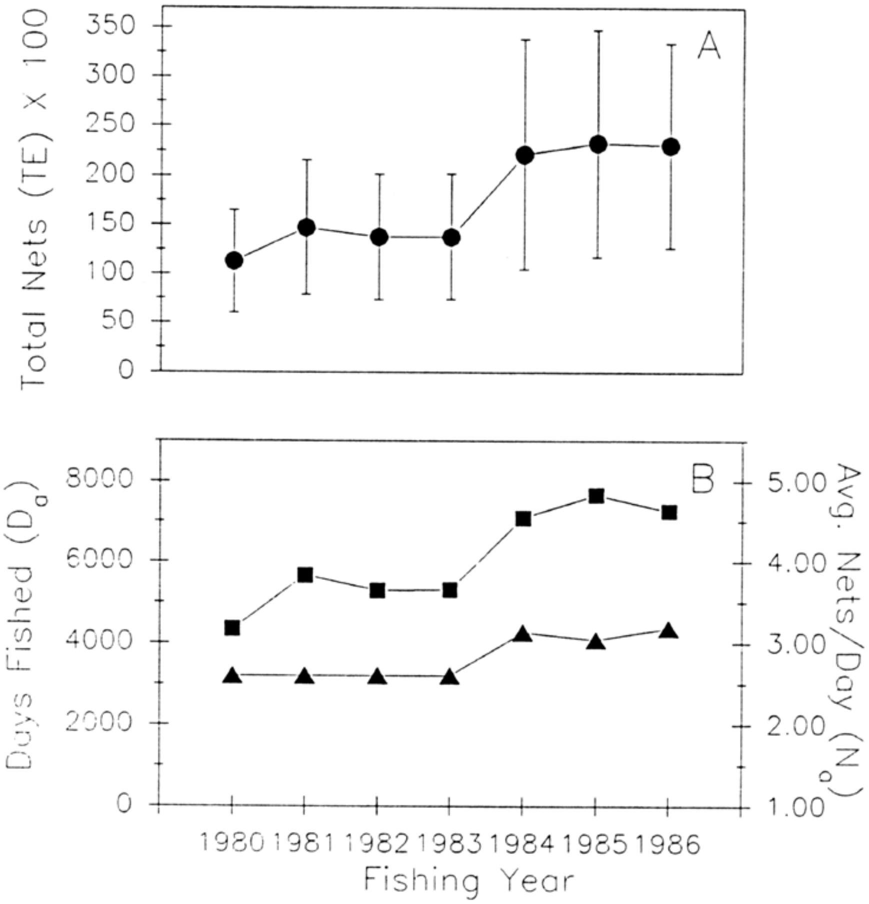

FIGURE 7. Halibut set net fishing effort in the Southern California area. A. Total effort (●). Error bars represent the standard deviation. B. The number of days fished (■), and the average number of nets fished daily (▲).

FIGURE 7. Halibut set net fishing effort in the Southern California area. A. Total effort (•). Error bars represent the standard deviation. B. The number of days fished (#), and the average number of nets fished daily (#)

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A COMPARISON OF CALIFORNIA HALIBUT CATCHES BY 8- AND 8.5-INCH MESH GILL AND TRAMMEL NETS OFF SOUTHERN CALIFORNIA

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ABSTRACT

An allocation conflict exists between recreational anglers and commercial gill and trammel net fishermen over the California halibut, Paralichthys californicus, resource off southern California. In 1986 legislation was enacted to increase the minimum mesh size from 8 to 8.5 inches for gill and trammel nets used to take halibut from Point Dume, Los Angeles County, to Ragged Point, San Luis Obispo County. The management objectives of this legislation were to (i) increase the size of halibut caught by gill and trammel nets; and thus, (ii) increase the number of small, legal-size halibut available to anglers; but at the same time (iii) maintain the total weight of halibut landings from the gill and trammel net fishery.

At-sea observations of the southern California gill and trammel net fishery for halibut were made from 1983 through 1988. Total length and catch per unit of effort (CPUE) of halibut observed caught by 8-inch mesh gill and trammel nets during the 6 years were summarized in a broad baseline analysis. Based on annual and areal variations within the baseline analysis, a more restrictive period (generally 1986–88) and areas (Los Angeles, Point Dume, and the Channel Islands) were then used in comparisons of catch by the 8- and 8.5- inch mesh nets to evaluate the effectiveness of meeting the management objectives.

Significant interannual and areal differences occurred in both length and CPUE within the baseline analysis of halibut catches from 8-inch mesh nets. Average lengths of halibut from observed catches were 24.8 inches from 1983 to 1985, but high recruitment in 1986 and 1988 reduced this to 23.4 inches for 1986 to 1988. Halibut caught at the Channel Islands averaged 28.3 inches, about 4 inches larger than fish caught along the mainland coast. Annual CPUE increased from 1983 to 1987; CPUE in numbers of halibut (total CPUE) was highest off the southern mainland, but salable weight CPUE was highest off the Channel Islands.

Comparisons between catches of 8- and 8.5-inch mesh nets made to evaluate success in meeting the above management objectives gave the following results:

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(i) length of halibut caught in 8.5-inch mesh nets was significantly greater than in 8-inch mesh nets at Point Dume and the Channel Islands, but not at Los Angeles;

(ii) total CPUE from 8.5-inch mesh nets was significantly lower at Los Angeles, significantly higher at the Channel Islands, and not significantly different at Point Dume;

(iii) salable weight CPUE from 8.5-inch nets was significantly lower at Los Angeles, significantly higher at the Channel Islands, and not significantly different at Point Dume. These results suggest that objectives (i) and (iii) are

more likely to be met. Objective (ii), availability to the angler of additional numbers of halibut, is less likely.

INTRODUCTION

California halibut, Paralichthys californicus, inhabit coastal waters, to a depth of 600 ft (183 m), from Baja California Sur, Mexico to Quillayute River, Washington (Eschmeyer et al. 1983). An allocation conflict has arisen between the recreational anglers and the commercial gill and trammel net fishermen in the intense southern California fishery. A recent management strategy attempting to mitigate this conflict has consisted of a California Department of Fish and Game (CDFG) sponsored gear modification requiring an increase in the minimum mesh size from 8 to 8.5 inches (203 to 216 mm) stretch measurement for gill and trammel nets used to take halibut. This paper compares the catches made by nets constructed of these two mesh sizes and discusses the potential effectiveness of using mesh size regulations to resolve the allocation conflict.

Southern California Halibut Fisheries

Halibut was the most sought after species among southern California marine sportfishes in 1986. Fishermen aboard privately owned and small rental boats took 80% of a total estimated catch of 1,339,000 halibut. However, since more than 90% of the catch was below the minimum size limit of 22 inches (559 mm) total length, and was released alive; the portion landed was estimated at 114,000 fish, weighing 619,500 lb (281 metric tons), and averaging 5.4 lb (2.5 kg) per fish (NMFS 1987).

Also, during 1986, halibut was the most valuable species to southern California nearshore set gill and trammel net fishermen. Commercial fishery landing receipts documented total landings of 293 mt, valued at about $1.4 million, in southern California ports that year. of this, 214 mt were landed from gill and trammel nets, 24 mt from trawl nets, and 52 mt from unrecorded gear types. Thus, gill and trammel nets took almost 89% of landings from known commercial origins.

Gill and trammel nets targeting halibut are constructed of monofilament mesh and anchored to the ocean bottom (set gill nets). A widely used modification to the standard gill net involves the use of "suspender" lines, constricting lines running from the float line to the lead line, that produce vertical slack in the mesh creating a type of trammel net. Gill nets and, to a lesser degree, trammel nets are highly selective for size of fish (Lagler 1971). The fish netted are largely restricted to sizes having a smaller head girth but a larger maximum girth than the perimeter of the net mesh (Hamley 1975). This is especially true for a smooth bodied species such as halibut. Overall, the size of fish captured increases as mesh size increases.

Minimum Mesh-Size Management

Based on a halibut catch of relatively small fish by the nonselective (by size) hook-and-line methods of the recreational fishery and a commercial fishery that primarily uses size-selective gill and trammel nets, the CDFG supported legislation to increase the minimum mesh size in gill and trammel nets. The objective was to increase the differential in the size of halibut caught by recreational and commercial fisherman, and thereby increase availability to the angler of fish growing past the 22-inch minimum size limit before they recruited to the size selectivity of the mandated larger mesh size.

In recent years gill and trammel net fisherman have used two alternative mesh sizes when targeting halibut. Before 1986 a minimum legal mesh size of 8 inches stretch measurement was in effect for trammel nets in southern California. Since 15 August 1986, a minimum mesh size of 8.5 inches has been in effect for both gill and trammel nets used to take halibut in an area extending from Point Dume, Los Angeles County, north to Ragged Point, San Luis Obispo County (Fish and Game Code, Section 8624). Fish and Game Code, Section 8625 expanded the 8.5-inch minimum mesh size requirement statewide beginning 15 August 1989; thus discontinuing the use of 8-inch mesh off southern California south of Point Dume.

METHODS

Field Sampling

The southern California gill and trammel net fishery was observed from May 1983 through December 1988. Observations took place at sea during 1-day fishing trips departing ports and marinas from San Diego to Santa Barbara. Beginning in 1985, 3- to 5-day cruises were made aboard a vessel chartered to taxi observers to distant fishing areas inaccessible to port-based samplers but frequented by fishermen during multiple-day fishing trips. Cruise-based observations were made at Santa Cruz Island, Santa Rosa Island, Point Dume, and the remote coastal areas as far north as Point Arguello (Figure 1).

Observers rode aboard the gill net boats with permission of the vessel operator; fishermen supplied information on gill net length and mesh size. As the nets were retrieved, observers counted the halibut, measured total length, and determined the sex by examining the gonads if the fish were cleaned. The final disposition of each halibut was recorded as released alive, discarded dead, kept for personal use, or kept for sale.

Data Analysis

Halibut catches are compared by their length compositions and catch-per-unit-effort (CPUE) levels.

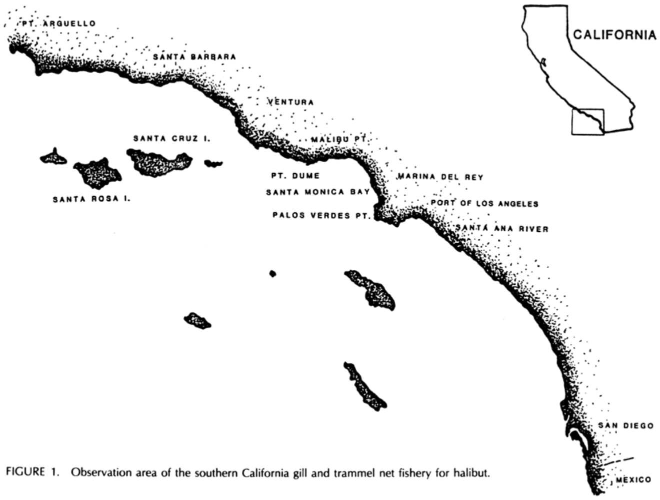

FIGURE 1. Observation area of the southern California gill and trammel net fishery for halibut.

FIGURE 1. Observation area of the southern California gill and trammel net fishery for halibut

Length Comparisons

Halibut catches are divided into three size ranges: sublegal fish < 22 inches, "selected" size fish 22–34 inches (864mm), and "large" fish > 34 inches. The selected size range is inferred from a comparison of mesh perimeter to head girth and maximum girth regressed on length (Hamley 1975); for 8- and 8.5-inch mesh this is approximately 22–34 inches for halibut (unpublished data).

CPUE Comparisons

CPUE is calculated by dividing the number or weight of halibut caught in each net by the length of the net (float line). No attempt is made to quantify the numerous other intrinsic and extrinsic variables (e.g. soak time, twine size, hanging ratio, net depth, weather, scavenger removal of entangled fishes) that affect the CPUE level of a gill net. It is assumed that fishing strategy attempted to maximize catch but was primarily limited by the amount of gear (net length) that could be deployed by a vessel.

Three measures of CPUE are used. Total CPUE includes all halibut observed in a net. Salable CPUE is the portion of total CPUE kept for sale. Generally, salable CPUE is equivalent to the CPUE of legal-size fish less a small amount damaged by scavengers making them unmarketable. The third measure, salable weight CPUE, is calculated by converting the measured lengths of salable fish to weights using a length-weight conversion (J.W. Schott, CDFG, unpublished data described by Reed and MacCall 1988), calculating an average weight, and then multiplying by the number of salable fish. Length-weight conversions differ for male and female halibut, so sex specific weight conversions are calculated when sex is known; otherwise, a weight conversion for combined sexes (about # female) is used.

The three CPUE measures are sensitive to different aspects of the gill net catch. Total CPUE describes the entire catch and is sensitive to young fish recruitment. High survivorship of a year class will initially show up as the entangled sublegal (i.e. nonsalable) portion of the catch. Salable CPUE includes only legal-size fish and is more sensitive to changes in catch due to mesh-size selectivity. Both of these measures are reported as numbers of halibut per unit of net. In evaluating angler versus gill net fisherman allocation-conflict mitigation, the assumption is made that, given constant effort and recruitment, a reduced gill net CPUE in numbers will increase the numbers of halibut available to the angler. Salable weight CPUE takes into account the size of the fish in the catch. Catch weight is the "bottom line" to a gill net fisherman intent on making a living. In evaluating the allocation-conflict mitigation the assumption is made that maintaining the salable weight CPUE maintains the economic return to the fisherman.

Since nets typically varied in length from 200 to 300 fm (366 to 549 m), total CPUE and salable CPUE are reported as halibut/100 fm and salable weight as pounds/100 fm (0.25 kg/100 m).

Statistical Tests

Nonparametric statistics were used in halibut length and CPUE comparisons. Multimodal distributions of length-frequency histograms and a high incidence of nets observed without halibut catches (CPUE skewed to the right) violated assumptions of normality. A statistical test of a null hypothesis is considered "significantly different" (null hypothesis rejected) at a probability (P) < 0.05.

Preliminary Baseline Analysis

Nets of 8-inch mesh were used almost exclusively by halibut fisherman during 1983–85 and continued to be the dominant gear in the fishery south of Point Dume during 1986–88. Catches from 8- inch mesh during this 6-year observation period along the mainland coast are presented in the "Baseline Catch Description" section where annual and areal differences in length of fish caught and CPUE can be referenced. The three divisions (and periods of sampling) for 8-inch mesh baseline areal comparisons are: (i) a southern mainland area extending from the Mexico border to Palos Verdes Point (1983–88), (ii) a northern mainland area extending from Malibu Point to Point Arguello (1983–86), and (iii) a Channel Islands area consisting of Santa Cruz and Santa Rosa Islands (1985–86; Figure 1).

Mesh-Size Analysis

In the "Mesh-Size Related Catch Differences" section, the years 1986–88 are selected for analysis in order to synchronize catches with the implementation of 8.5-inch mesh, and because baseline comparisons indicated high interannual recruitment variations with those of 1983–85. Because of persistent areal variability in the baseline catch analysis, three smaller but diverse geographical areas are chosen to analyze potential mesh- size-induced changes in catch. The three areas selected are: (i) Los Angeles Port Vicinity. This includes approximately 25 mi (46 km) of the coast from Palos Verdes Point to the Santa Ana River, and involves some of the most intensely gillnetted area off southern California (Vojkovich et al. 1988). (ii) Point Dume. This includes approximately 5 mi (9 km) of coast between Point Dume and Malibu Point, and is adjacent to the northern border of the area closed to commercial fishing in Santa Monica Bay. Also, approximately 30 mi (56 km) from the gill net fleet ports of Los Angeles and Ventura, and 16 mi (30 km) from the nearest recreational fleet at Marina Del Rey, this area is assumed to receive considerably less fishing effort than the Los Angeles Port Vicinity. (iii) Channel Islands. Santa Cruz and Santa Rosa Islands are separated from the mainland by about 20 mi (37 km). The baseline catch analysis indicated the halibut catch here was very different from that from the mainland. Unlike the two coastal mainland areas the catch from 1985 is included in the analysis. For this area only, an asynchrony in the mesh-size comparison exists in which 8-inch mesh was observed from 1985 to 1986, but only 8.5-inch mesh was observed during 1987 to 1988.

RESULTS

Baseline Catch Description

Length Comparisons

A total of 5,648 fish was measured ranging from 9.0 inches (229 mm) to 49.4 inches (1255 mm), and averaging 24.2 inches (615 mm). Annual length-frequency histograms display a primary mode near 24 inches (610 mm; Figure 2). However, proportions of sublegal fish were significantly different in the 6 years ($x^2 = 93.2$, 5 df, $P < 0.0001$). High recruitment of young fish in 1986 resulted in the largest annual sublegal catch proportion of 33%. In the following year, small, legal-size fish, 22–24.4 inches (559–620mm), constituted 43% of the total catch. Sublegal recruitment was high again in 1988, constituting 27% of the catch.

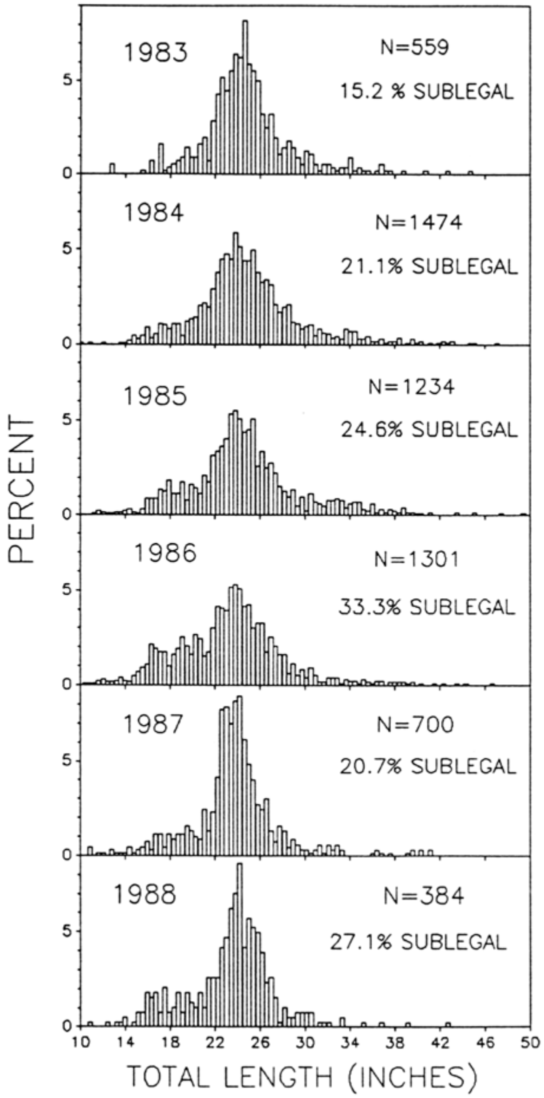

FIGURE 2. Annual length frequencies of halibut caught by 8-inch mesh gill and trammel nets in coastal waters off the southern California mainland (1983–88).

FIGURE 2. Annual length frequencies of halibut caught by 8-inch mesh gill and trammel nets in coastal waters off the southern California mainland (1983–88)

A combination of lower recruitment of sublegal and small legal-size fish, and somewhat higher levels of large fish >34 inches during 1983–85, resulted in halibut catches of larger fish averaging 24.8 inches (630 mm; Table 1). The annual average size of fish from 1986–88 was 23.4 inches (594 mm). A Kruskal-Wallis test (test statistic, H) of the null hypothesis that the size of halibut caught was the same in all six years was rejected (H=121.4, 5 df, $P < 0.0001$).

TABLE 1. Variations in the total lengths of halibut caught by 8- inch mesh gill and trammel nets: A. Annual variations off the entire southern California mainland coast, 1983-88. B. Areal variations from the southern mainland (1983-88), northern mainland (1983-86), and Channel Islands (1985-86) areas of southern California.

A. Annual variations

	Year					
Comparison	1983	1984	1985	1986	1987	1988
No. of sets	250	508	351	297	150	79
No. fish measured	559	1474	1234	1301	700	384
% < 22 inches	15.2	21.1	24.6	33.3	20.7	27.1
% 22–34 inches	81.4	74.2	69.5	64.0	77.4	71.9
% > 34 inches	3.4	4.7	5.9	2.7	1.9	1.0
Mean length of all fish (inches)	24.9	24.8	24.7	23.3	23.6	23.3

B. Areal variations

	Area		
Comparison	South mainland	North mainland	Channel Islands
No. of sets	1107	528	93
No. fish measured	4104	1522	265
% < 22 inches	26.9	18.0	9.8
% 22–34 inches	69.1	78.6	70.6
% > 34 inches	4.0	3.4	19.6
Mean length of all fish (inches)	24.0	24.7	28.3

TABLE 1. ***Variations in the total lengths of halibut caught by 8- inch mesh gill and trammel nets: A. Annual variations off the entire southern California mainland coast, 1983–88. B. Areal variations from the southern mainland (1983–88), northern mainland (1983–86), and Channel Islands (1985–86) areas of southern California.***

Length-frequency histograms of the catches show a primary mode between 22 and 26 inches (660 mm) for the three areas (Figure 3). Proportions of sublegal fish were significantly different by area (X^2=78.6, 2 df, $P < 0.0001$). The southern mainland had the highest sublegal component (26.9%), declining to 18% in the northern mainland area, and to only 9.8% in the Channel Islands area. Nearly 20% by number of the catch at the islands consisted of large fish > 34 inches compared to a 3 to 4% level along the mainland coast (Table 1). Mean length was lowest for fish from the southern mainland at 24.0 inches, moderately higher at 24.7 inches (627 mm) for fish from the northern mainland, and considerably larger at 28.3 inches (719 mm) for fish from the Channel

Islands. A Kruskal-Wallis test of the null hypothesis that the size of halibut in the catches was the same for all three areas was rejected (H=166.6, 2 df, $P < 0.0001$).

CPUE Comparisons

A total of 1635 nets with 8-inch mesh was observed along the mainland coast from 1983 to 1988. A trend of increased annual CPUE in total numbers of halibut, salable numbers, and salable weight is observed, with only a slight drop in the salable CPUE occurring in 1988 (Figure 4). Over 25% of the nets observed from 1983–84 did not catch halibut. From 1984 to 1987 median CPUE levels increased 72% in total number, 100% in salable number, and 112% in salable weight. Kruskal-Wallis tests indicated significant differences in total number and salable number (H=45.5, H=45.9, 5 df, $P < 0.0001$), and in salable weight (H=38.0; 55 df, P=0.0016) CPUE.

The outcome of the 8-inch mesh baseline CPUE comparisons between areas depended on the CPUE measure used. Median total CPUE off the southern mainland was 25% higher than the level off the northern mainland and Channel Islands (Figure 5); the Kruskal-Wallis comparison was significant (H=10.9, 2 df, P= 0.0043). No significant difference was observed in the salable number CPUE, but in terms of salable weight, the 7.2 lb/100 fm median CPUE at the Channel Islands was considerably higher than the 4.8 lb/100 fm and 3.8 lb/100 fm levels observed from the southern and northern mainland areas, respectively. The Kruskal-Wallis test comparing salable weight between the areas was significant (H=7.7, 2 df, P=0.02). These results are consistent with the areal differences in the lengths of halibut in the catch. High recruitment along the southern mainland yielded a high total CPUE, and a high proportion of large fish > 34 inches at the Channel Islands yielded a high salable weight CPUE.

Mesh-Size Related Catch Differences

Length Comparisons

Los Angeles Port Vicinity. A total of 913 halibut from 350 nets was measured with 78% of the fish from 8-inch mesh (Table 2). This was the area of origin of the smallest individuals, with sublegal halibut proportions of over 30% from both 8- and 8.5- inch meshes, not significantly different from each other. Catch proportions for the other two size groupings were also similar for the two meshes, about two-thirds of the fish in the 22–34 inch range of mesh selectivity, and less than 2% > 34 inches. The null hypotheses that no differences occurred in the size of halibut caught by 8- and 8.5-inch mesh nets was accepted for all fish, and for fish within the 22–34 inch size range.

Point Dume. A total of 491 halibut from 126 nets was measured with 63% from 8-inch mesh (Table 2). This area had intermediate-size fish in the catches. No significant difference occurred in the 19% and 20% proportions of sublegals taken by 8- and 8.5-inch mesh, respectively. The proportions of catch in the other two size groupings were also similar between mesh sizes, just over three-quarters in the 22–34 inch size range, and about 3% > 34 inches.

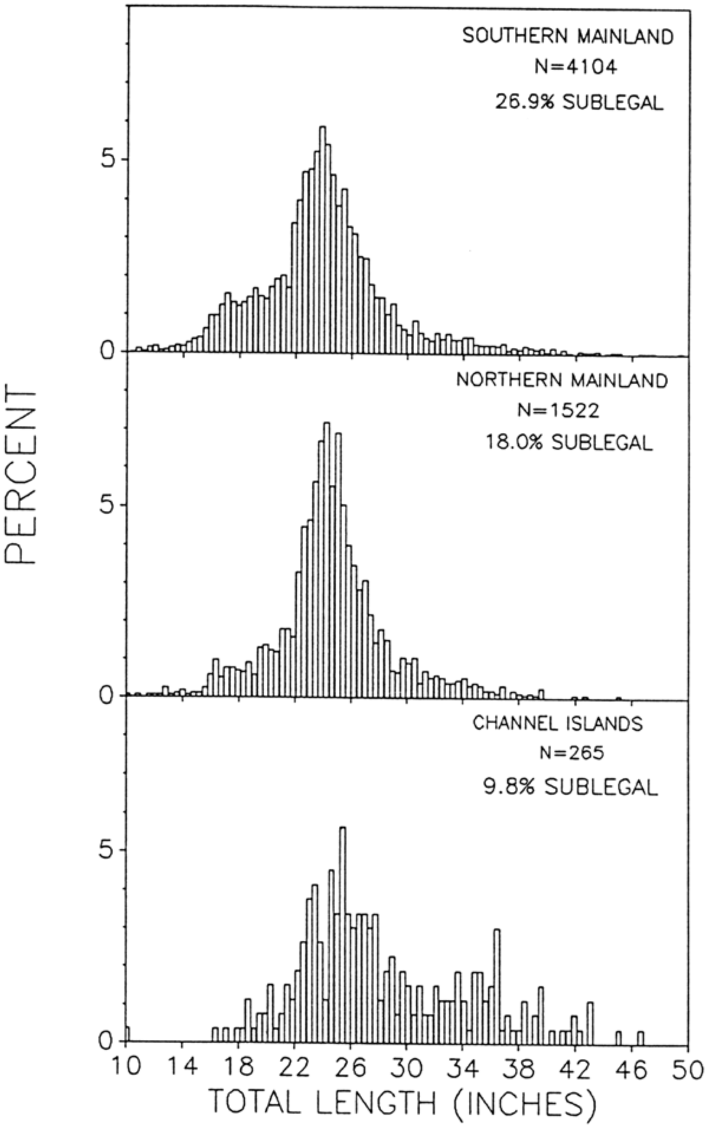

FIGURE 3. Length frequencies of halibut catches observed in 8-inch mesh gill and trammel nets from the southern mainland (1983–88), northern mainland (1983–86), and Channel Islands (1985–86) areas off southern California.

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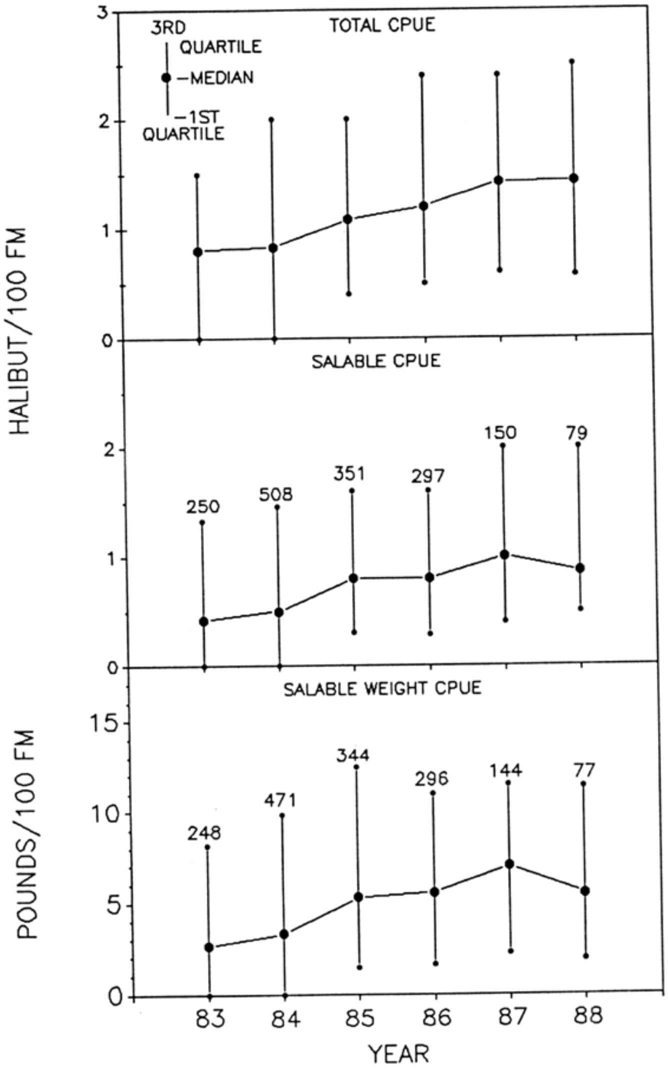

FIGURE 4. Annual CPUE levels in total number, salable number, and salable weight of halibut caught by 8-inch mesh gill and trammel nets in coastal waters off the southern California mainland (1983–88). Numbers atop salable CPUE quartile range bars are numbers of nets observed; numbers atop salable weight CPUE quartile range bars are numbers of nets in which length measurements were taken, or no catch was made.

FIGURE 4. Annual CPUE levels in total number, salable number, and salable weight of halibut caught by 8-inch mesh gill and trammel nets in coastal waters off the southern California mainland (1983–88). Numbers atop salable CPUE quartile range bars are numbers of nets observed; numbers atop salable weight CPUE quartile range bars are numbers of nets in which length measurements were taken, or no catch was made

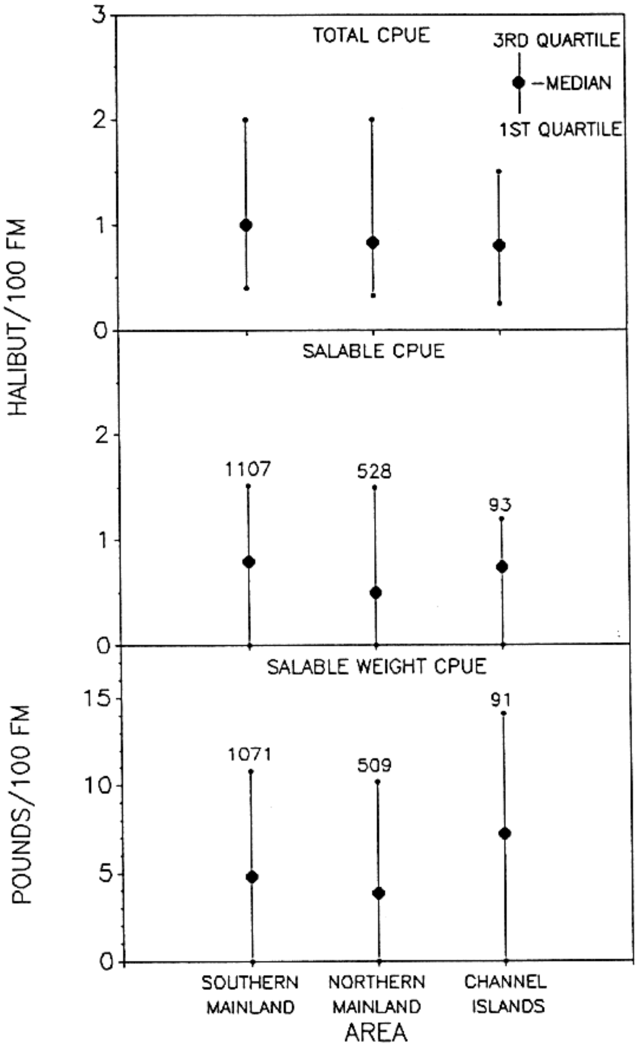

FIGURE 5. CPUE levels in total number, salable number, and salable weight of halibut caught by 8-inch mesh gill and trammel nets at the southern mainland (1983–88), northern mainland (1983–86) and Channel Islands (1985–86) areas off southern California. Numbers atop salable CPUE quartile range bars are numbers of nets observed; numbers atop salable weight CPUE quartile range bars are numbers of nets in which length measurements were taken, or no catch was made.

FIGURE 5. CPUE levels in total number, salable number, and salable weight of halibut caught by 8-inch mesh gill and trammel nets at the southern mainland (1983–88), northern mainland (1983–86) and Channel Islands (1985–86) areas off southern California. Numbers atop salable CPUE quartile range bars are numbers of nets observed; numbers atop salable weight CPUE quartile range bars are numbers of nets in which length measurements were taken, or no catch was made

TABLE 2. Length comparisons of halibut catches made by 8- and 8.5-inch mesh gill and trammel nets off three southern California areas.

Los Angeles Port Vicinity (1986-88)

Comparison	Mesh size 8-inch	Mesh size 8.5-inch	Mann-Whitney test Value	Mann-Whitney test Two-sided P
No. of sets	253	97		
No. fish measured	716	197		
% < 22 inches	31.6	32.5		
% 22–34 inches	67.0	66.0		
% > 34 inches	1.4	1.5		
Mean length of all fish (inches)	23.1	23.2	0.35	0.7
Mean length of 22–34 inch fish	24.9	25.1	0.89	0.4

Point Dume (1986-88)

Comparison	Mesh size 8-inch	Mesh size 8.5-inch	Mann-Whitney test Value	Mann-Whitney test Two-sided P
No. of sets	76	50		
No. fish measured	309	182		
% < 22 inches	19.1	20.3		
% 22–34 inches	78.3	76.9		
% > 34 inches	2.6	2.8		
Mean length of all fish (inches)	24.1	25.4	3.7	0.003
Mean length of 22–34 inch fish	25.1	26.8	5.6	< 0.0001

Channel Islands
(1985-86/8-inch mesh)
(1987-88/8.5-inch mesh)

Comparison	Mesh size 8-inch	Mesh size 8.5-inch	Mann-Whitney test Value	Mann-Whitney test Two-sided P
No. of sets	93	132		
No. fish measured	265	431		
% < 22 inches	9.8	2.6		
% 22—34 inches	70.6	85.6		
% > 34 inches	19.6	11.8		
Mean length of all fish (inches)	28.3	28.8	2.1	0.03
Mean length of 22–34 inch fish	26.8	27.6	3.3	0.001

TABLE 2. ***Length comparisons of halibut catches made by 8- and 8.5-inch mesh gill and trammel nets off three southern California areas.***

However, unlike the Los Angeles Port Vicinity comparisons, the mean sizes of fish from 8.5-inch mesh nets were 1.3 inches (33 mm) larger for the fish of all sizes, and 1.7 inches (43 mm) larger for the selectivity-influenced 22- to 34-inch size range. Mann-Whitney tests indicated significantly larger halibut were caught by 8.5-inch mesh nets (Table 2).

Channel Islands. A total of 696 halibut from 225 nets was measured with 62% from 8.5-inch mesh (Table 2). Halibut from the islands were 4–5 inches (100–125 mm) larger on average than fish from either mainland area, and the proportion of sublegal fish was much lower. Comparing between mesh sizes, the 2.6% proportion of sublegals in 8.5-inch mesh nets was significantly less (x^2 = , 1 df, $P < 0.0001$) than the 9.8% from 8-inch mesh nets. Large fish > 34 inches also occurred in a lower proportion in the 8.5-inch mesh nets. The mean sizes of halibut from 8.5-inch mesh nets were 0.5 inch (13 mm) larger for fish of all sizes, and 0.8 inch (20 mm) larger for the 22–34 inch size range, than fish caught by nets constructed of 8-inch mesh. As at Point Dume, Mann-Whitney tests indicated significantly larger fish were caught by the larger mesh nets.

CPUE Comparisons

Los Angeles Port Vicinity. For the three areas summarized, lowest CPUE levels occurred here, especially in nets with 8.5- inch mesh (Figure 6). Within the area, total, salable, and salable weight CPUE levels of 8.5-inch mesh nets were below the level of 8-inch mesh nets by 36%, 43%, and 40%, repectively; Mann-Whitney tests were significant for all three comparisons (Tables 3 4 5).

Point Dume. In contrast to the Los Angeles Port Vicinity median levels of total number and salable weight CPUE were slightly higher in the 8.5-inch mesh nets (Figure 6), but Mann-Whitney tests yielded no significant differences in the three CPUE measures (Tables 3–5).

Channel Islands. Median levels of total, salable and salable weight CPUE were 25%, 43%, and 25% higher, respectively, in the 8.5-inch mesh nets (Figure 6). Mann-Whitney tests of the null hypotheses of no difference in CPUE between mesh sizes were rejected for total number and salable number measures, but were accepted for the salable weight measure (Tables 3–5).

DISCUSSION

Baseline Variation

The six year baseline analysis describes a major change in the availability of halibut to the mainland coastal fishermen. Annual size distributions have a persistent primary mode at about 24 inches (Figure 2), probably reflecting the optimum size selectivity of 8-inch mesh. The catch observed in 1986 included 33% sublegal fish, suggesting a large cohort that became fully recruited into optimum selectivity during 1987. The size frequency histogram in 1987 is tightly distributed around the 24-inch mode, and this year fishermen had the highest annual CPUE of the study. Southern California commercial fishery landings of halibut in the 22- to 24-inch size range were largely composed of 4- to 6-year-old females during 1985–88 (Pattison and McAllister 1990). This corresponds to year classes spawned in 1983 and 1982. During these years a pronounced El Niño event of elevated temperatures occurred off southern

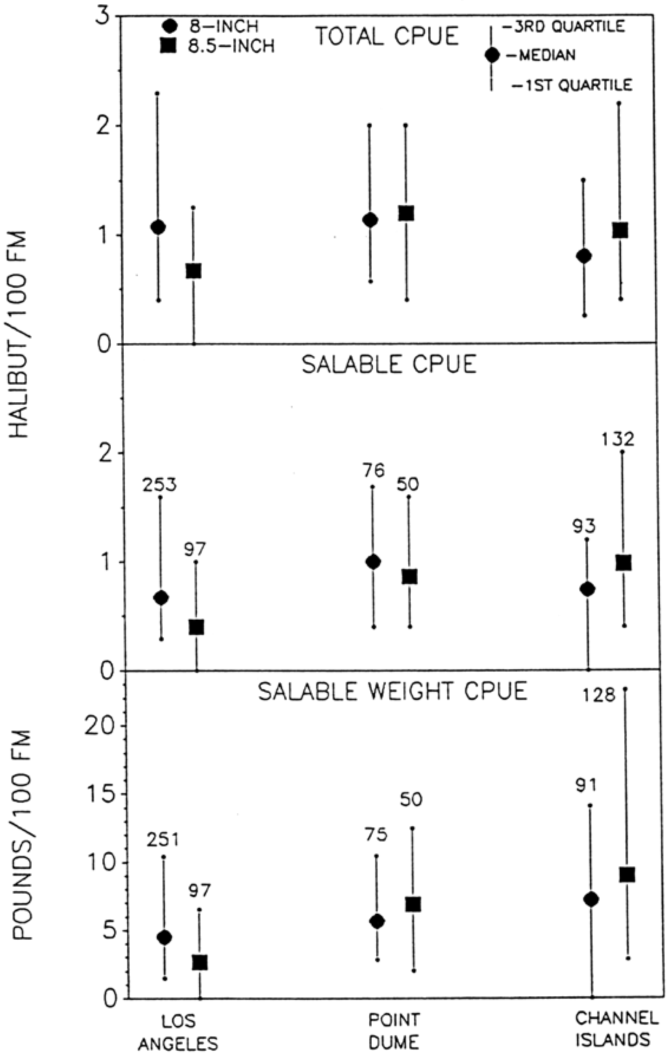

FIGURE 6. Comparison of CPUE levels of 8- and 8.5-inch mesh gill and trammel nets at Los Angeles Port Vicinity (1986–88), Point Dume (1986–88), and the Channel Islands (1985–86, 8-inch; 1987–88, 8.5 inch) areas of the southern California coast. Numbers atop salable CPUE quartile range bars represent numbers of observed nets; numbers above salable weight CPUE bars are numbers of nets in which length measurements were taken, or no catch was made.

FIGURE 6. Comparison of CPUE levels of 8- and 8.5-inch mesh gill and trammel nets at Los Angeles Port Vicinity (1986–88), Point Dume (1986–88), and the Channel Islands (1985–86, 8-inch; 1987–88, 8.5 inch) areas of the southern California coast. Numbers atop salable CPUE quartile range bars represent numbers of observed nets; numbers above salable weight CPUE bars are numbers of nets in which length measurements were taken, or no catch was made

California (McGowan 1984). Relatively high temperatures enhance juvenile halibut survival (Gadomski and Caddell 1991), perhaps accounting for the surge of recruitment to the fishery in 1986–87.

Although oceanic events may influence widespread interannual variations in the size composition of halibut from gill net catches, persistent areal differences in the 8-inch mesh baseline catch analysis suggest that size composition is also strongly influenced on a smaller scale by local habitat. Highest sublegal recruitment occurred off the southern mainland area (27%), declined to 18% off the northern mainland, and comprised less than 10% of the Channel Islands catch. Shallow embayments are the optimum nursery areas for halibut (Kramer 1990); an absence of appropriate nursery habitat in the northern mainland area and at the Channel Islands may limit recruitment there. Concomitant with a lack of sublegal recruitment at the Channel Islands is a secondary mode of halibut at about 34 inches (Figure 3), resulting in an average catch length about 4 inches (100 mm) larger than at the mainland. The presence of very large fish at Santa Cruz and Santa Rosa Islands may be a result of lower fishing pressure or of size-selective foraging concentrations of larger fish adjacent to market squid, Loligo opalescens, spawning areas at those islands. Fishermen at Santa Rosa Island commonly set their nets near echo-sounded targets believed to be squid aggregations, and the retrieved nets frequently have squid egg casings attached to or entangled in the netting.

Allocation-Conflict Mitigation

In attempting to mitigate the allocation conflict between recreational and commercial fisheries by a legislated mesh-size increase, three objectives were considered: (i) increasing the size of halibut caught in the gill and trammel net catches; and thus, (ii) increasing the number of small, legal-size halibut available to anglers; but at the same time (iii) maintaining the total weight of halibut landings of the gill and trammel net fishery. The evidence for achieving these three objectives is discussed in this section.

Increased Size

For halibut in the 22 to 34-inch size range, fish caught by nets with 8.5-inch mesh averaged 0.2 to 1.8 inches (0.5 to 46 mm) larger than those in the 8-inch mesh nets for the three areas tested (Table 2). At Point Dume and the Channel Islands the size differences were significant, and the objective of increasing the size of halibut caught was achieved. However, the average size of halibut caught in the Los Angeles Port Vicinity is the smallest of the three observation areas, with the size of fish in the catch essentially unaffected by the mesh size used in the nets. The high fishing effort in this area may be responsible for the absence of this shift to larger fish. Halibut recruit to the size-selectivity range of the 8-inch mesh before they grow large enough to become optimally selected by the larger 8.5-inch mesh. Under simultaneous intensive fishing pressure by both mesh sizes, the smaller mesh may outcompete the larger mesh, hence the absence of a size shift and the reduced CPUE in the 8.5-inch mesh.

In the absence of 8-inch mesh, what amount of a size shift in the halibut catch can be expected from conversion to 8.5-inch mesh gill nets? At Point Dume the halibut from 8.5-inch mesh nets averaged 25.4 inches (645 mm; Table 2), a difference of +1.3 inches (33 mm) from the 8-inch mesh catch. The difference at the Channel Islands was only +0.5 inches (13 mm), but this may have been due to high availability of large (>34 inch) halibut taken by the 8-inch mesh nets in 1985–86 prior to the use of the 8.5-inch mesh (Figure 7). The halibut length frequency histograms from the Channel Islands show a +1.2-inch (30-mm) shift in the modal length of the catch following the implementation of 8.5-inch mesh. The 1.2- and 1.3-inch observed increases in length are probably a reasonable approximation to the change that can be expected in the average size of halibut from southern California gill net landings south of Point Dume after the 15 August 1989 conversion to 8.5-inch mesh statewide.

As a corollary to increased average size, it might be expected that the larger mesh would also catch a lower proportion of sublegal halibut. Comparisons at the three locations do not support that expectation. At the Los Angeles Port Vicinity and Point Dume areas, sublegal proportions from 8.5-inch mesh nets were somewhat, but nonsignificantly, higher. A significantly lower catch proportion of sublegals did occur in 8.5-inch mesh at the Channel Islands area, but this may have resulted from the sampling asynchrony, rather than mesh-size selectivity, caused by higher availability of sublegal fish during the 1985–86 period of 8-inch mesh use. Sublegal halibut may be too small to be influenced by the size-selectivity properties of either 8- or 8.5-inch mesh, with resultant catches due to random entanglements independent of mesh size. The slackness of netting material may more directly determine sublegal capture levels. The sublegal catch of halibut in gill and trammel nets will not be significantly altered by converting to the 8.5-inch minimum mesh size.

Increased Availability to the Angler

Total CPUE changes in the gill and trammel net fishery are assumed to be inversely proportional to the number of halibut available to the angler. At constant effort, a reduction in the CPUE of the nets presumably affords the angler increased opportunities to catch the fish not harvested by the nets. The changes in both total CPUE and salable CPUE have a similar area- related pattern (Tables 3, 4).

The objective of increased numbers of halibut available to anglers (i.e. reduced CPUE in 8.5-inch mesh nets) has not occurred at Point Dume (CPUE unchanged), and availability of halibut to the anglers may be reduced (i.e. significantly higher CPUE in 8.5-inch mesh nets) at the Channel Islands.

At the Los Angeles Port vicinity area significantly lower total and salable CPUE levels occur in the 8.5-inch mesh nets, and the objective of increased availability of halibut to the angler could be argued. However, unlike Point Dume and the Channel Islands area, the initial objective of an increase in the size of halibut in the catch from 8.5-inch mesh nets has not occurred. As described above, in the absence of this size shift, I think reduced CPUE in 8.5-inch mesh nets is more likely due to competition with the 8-inch mesh nets in the intensely fished Los Angeles area, rather than an accomplishment of the increased availability objective.

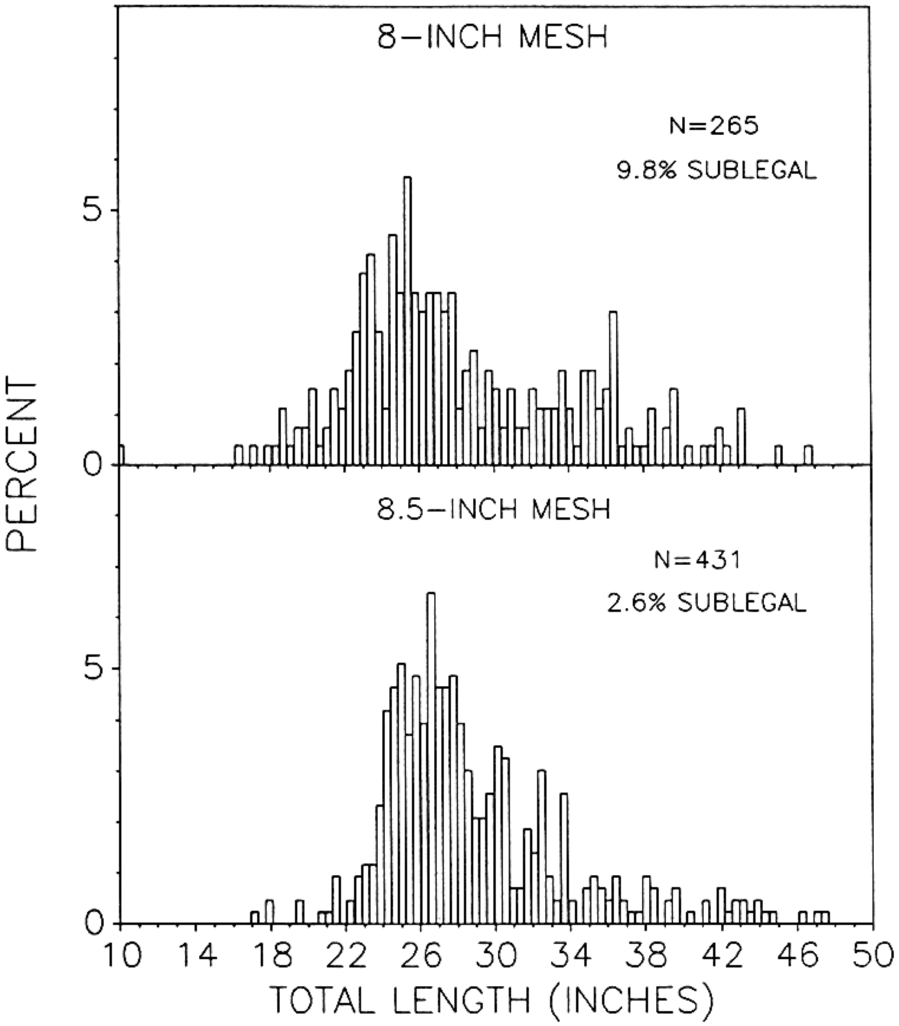

FIGURE 7. Comparison of length frequencies of halibut caught by 8-inch and 8.5-inch mesh gill and trammel nets at the Channel Islands. Catches were made in the 8-inch mesh during 1985–86 and in the 8.5-inch mesh during 1987–88.

FIGURE 7. Comparison of length frequencies of halibut caught by 8-inch and 8.5-inch mesh gill and trammel nets at the Channel Islands. Catches were made in the 8-inch mesh during 1985–86 and in the 8.5-inch mesh during 1987–88

Although admittedly confusing variation by area occurs in the changes to total and salable number CPUE associated with gill net mesh-size comparisons, as an overall interpretation no change in CPUE numbers is likely. As a result, no change in the availability of numbers of halibut to the angler is predicted to occur as a result of the 15 August 1989 statewide conversion to 8.5-in mesh.

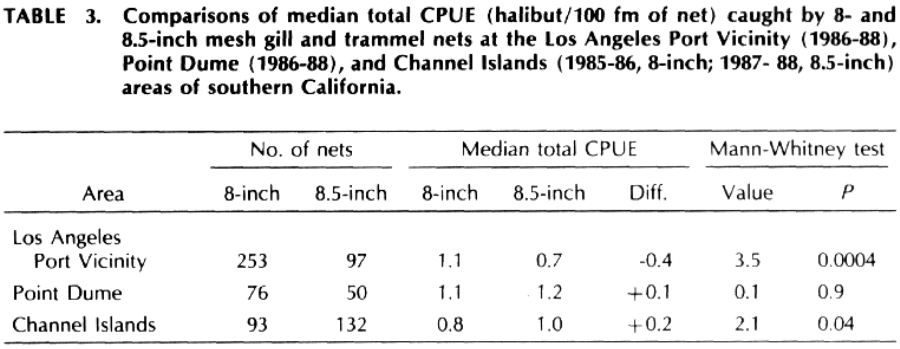

TABLE 3. **Comparisons of median total CPUE (halibut/100 fm of net) caught by 8- and 8.5-inch mesh gill and trammel nets at the Los Angeles Port Vicinity (1986-88), Point Dume (1986-88), and Channel Islands (1985-86, 8-inch; 1987- 88, 8.5-inch) areas of southern California.**

	No. of nets		Median total CPUE			Mann-Whitney test	
Area	8-inch	8.5-inch	8-inch	8.5-inch	Diff.	Value	*P*
Los Angeles Port Vicinity	253	97	1.1	0.7	-0.4	3.5	0.0004
Point Dume	76	50	1.1	1.2	+0.1	0.1	0.9
Channel Islands	93	132	0.8	1.0	+0.2	2.1	0.04

TABLE 3. ***Comparisons of median total CPUE (halibut/100 fm of net) caught by 8- and 8.5-inch mesh gill and trammel nets at the Los Angeles Port Vicinity (1986–88), Point Dume (1986–88), and Channel Islands (1985–86, 8-inch; 1987–88, 8.5-inch) areas of southern California.***

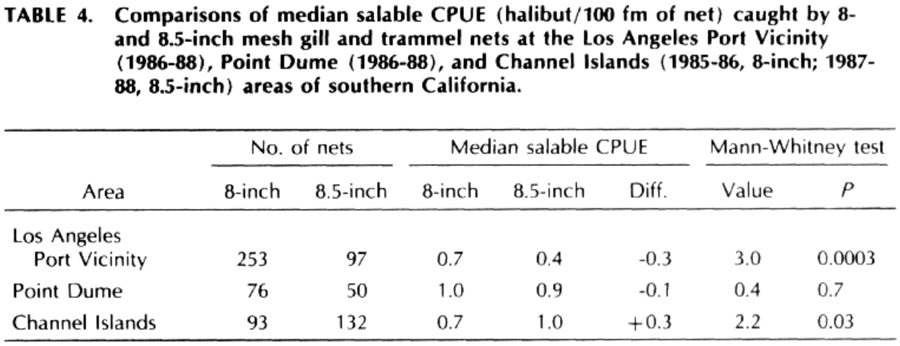

TABLE 4. **Comparisons of median salable CPUE (halibut/100 fm of net) caught by 8- and 8.5-inch mesh gill and trammel nets at the Los Angeles Port Vicinity (1986-88), Point Dume (1986-88), and Channel Islands (1985-86, 8-inch; 1987-88, 8.5-inch) areas of southern California.**

	No. of nets		Median salable CPUE			Mann-Whitney test	
Area	8-inch	8.5-inch	8-inch	8.5-inch	Diff.	Value	*P*
Los Angeles Port Vicinity	253	97	0.7	0.4	-0.3	3.0	0.0003
Point Dume	76	50	1.0	0.9	-0.1	0.4	0.7
Channel Islands	93	132	0.7	1.0	+0.3	2.2	0.03

TABLE 4. ***Comparisons of median salable CPUE (halibut/100 fm of net) caught by 8- and 8.5-inch mesh gill and trammel nets at the Los Angeles Port Vicinity (1986–88), Point Dume (1986–88), and Channel Islands (1985–86, 8-inch; 1987–88, 8.5-inch) areas of southern California.***

Maintenance of Gill and Trammel Net Catches

Fish and Game Code Section 8626 empowers the CDFG director to reduce the minimum mesh size to 8 inches south of the Los Angeles-Ventura county line if it is determined that following a one year period (1 September 1989 to 31 August 1990), commercial halibut landings have declined 10% from the previous year as a direct result of the 8.5-inch mesh requirement. Is their evidence that such a decline is likely?

Salable weight CPUE, the most correlative CPUE indicator of commercial landings, varied regionally (Table 5). As with the other CPUE measures, salable weight from 8.5-inch mesh nets was significantly lower than that in 8-inch mesh at the Los Angeles Port Vicinity, perhaps as a result of the lower availability of large fish in this area. At Point Dume and the Channel Islands median salable weight CPUE was 20% higher in the 8.5-inch mesh, but was not significantly different from the CPUE of 8-inch mesh.

With the possible exception of areas of very high angling intensities, salable weight CPUE (and landings) of 8.5-inch mesh gill and trammel nets may be equal to or slightly higher at equilibrium than in a fishery based on 8-inch mesh. However, a period of adjustment may take place in the heavily fished Los Angeles Port Vicinity, and possibly other populous areas of southern California. As the size structure of the available population responds to the phasing out of the 8-inch mesh nets, a preliminary decline in landings may be expected until

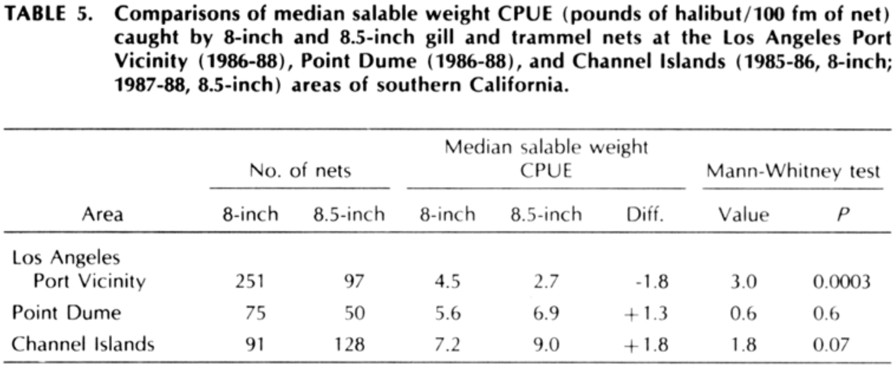

TABLE 5. Comparisons of median salable weight CPUE (pounds of halibut/100 fm of net) caught by 8-inch and 8.5-inch gill and trammel nets at the Los Angeles Port Vicinity (1986-88), Point Dume (1986-88), and Channel Islands (1985-86, 8-inch; 1987-88, 8.5-inch) areas of southern California.

	No. of nets		Median salable weight CPUE			Mann-Whitney test	
Area	8-inch	8.5-inch	8-inch	8.5-inch	Diff.	Value	*P*
Los Angeles Port Vicinity	251	97	4.5	2.7	-1.8	3.0	0.0003
Point Dume	75	50	5.6	6.9	+1.3	0.6	0.6
Channel Islands	91	128	7.2	9.0	+1.8	1.8	0.07

TABLE 5. ***Comparisons of median salable weight CPUE (pounds of halibut/100 fm of net) caught by 8-inch and 8.5-inch gill and trammel nets at the Los Angeles Port Vicinity (1986–88), Point Dume (1986–88), and Channel Islands (1985–86, 8-inch; 1987–88, 8.5-inch) areas of southern California.***

fish grow into the approximately +1.2-inch shift of the optimum size selectivity of 8.5-inch mesh. A simultaneous environmentally induced decrease in the recruitment of young, legal fish could exacerbate this decline in landings. On the other hand, high recruitment during that year would mask over even a preliminary decline in landings. From 1983 to 1988, annual variations in the median salable weight CPUE of 8-inch mesh nets was +61% to -22% (Figure 4). Considering the magnitude of this variation, it may be difficult to statistically demonstrate that a 10% decline in landings was a direct result of the conversion to 8.5-inch mesh.

ACKNOWLEDGMENT

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AGE, SIZE, AND SEX COMPOSITION OF CALIFORNIA HALIBUT FROM SOUTHERN CALIFORNIA COMMERCIAL FISHERY LANDINGS, 1983–1988

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ABSTRACT

California halibut, Paralichthys californicus, were sampled from 1983 to 1988 for length and sex; otoliths were collected from 1985 to 1988. Age composition was dominated by three age groups (5-, 6-, and 7-year olds) during three of the 4 years sampled. Median size ranged from 588 mm total length in 1983 to 647 mm in 1988. Larger fish were taken by gill nets than by trawls, while inshore-caught halibut were smaller than those taken offshore. Females outnumbered males by a 4.3:1 ratio; this ratio was higher inshore than offshore.

INTRODUCTION

The California halibut, Paralichthys californicus, is a popular sport and commercial species in southern and central California. Annual commercial landings of halibut have averaged over 1 million pounds over the past 8 years. Halibut has been the focus of numerous scientific studies by the California Department of Fish and Game (CDFG). Clark (1930) published one of the earliest papers on this species dealing with catch rates of commercial fishing boats. Holmberg (1949) and Frey (1971) presented historical overviews of the commercial fishery while Young (1969) reviewed the recreational partyboat fishery. Haaker (1975) described the life history of halibut in Anaheim Bay, and Pattison and McAllister (1990) studied the length at age of halibut from central and southern California. Schott (1975) and Karpov (1981) reported on the effectiveness of gear changes in the commercial fisheries.

Data such as size, age, and sex composition of the commercial catch have not been compiled, and such information is essential in formulating and designing population models needed in making management decisions. This study was initiated to collect such data and to determine if there were significant differences in size, age, and sex compositions by geographical areas, by offshore and inshore areas, by gear type, and between years.

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METHODS

Beginning in 1983, a sampling program was initiated to collect data on size, age, and sex composition of halibut taken by commercial fishermen and landed at four main ports in southern California: Santa Barbara, Ventura, San Pedro, and San Diego (Figure 1). Samples were taken daily from landings at certain fish processors. Halibut were selected randomly from holding bins and a maximum of 40 fish were sexed and measured to nearest millimeter total length. The percentage of landings sampled from each port averaged above 5%. Other data, including catch location and gear type, were collected by reviewing fish landing receipts and fishermen's logs. Fishing gears used were gill nets with mesh sizes ranging from 8 inches (203 mm) to 8.5 inches (216 mm) and trawl nets with a minimum mesh size of 7.5 inches (190 mm) at the cod end, used primarily in the Santa Barbara Channel.

Otoliths were extracted by cutting through the otic capsule just behind the operculum and removing the sagittal otoliths. Otoliths of fish less than 750 mm were surface aged, while those from fish greater than 750 mm were broken or cut and burned with an alcohol flame, using methods described by Chilton and Beamish (1982). Otoliths were viewed under a stereo microscope with reflected fiber optic lighting.

For aging purposes, otoliths were collected beginning in 1985 from the Santa Barbara-Ventura and San Diego areas and from San Pedro beginning in 1986. Additional otoliths were extracted from subadult fish taken by trawl gear during research cruises conducted by the F/V KAREN MARIE in 1985. These data were used for calculating length at age. Age data from all years were pooled by area due to insufficient data during certain years, and Santa Barbara and Ventura were combined as one port for analysis purposes. Length at age was determined by using the Von Bertalanffy growth equation.

Length data were compiled on an annual basis and combined for all ports. Length data were also compiled by gear type, and by inshore and offshore areas. Inshore and offshore areas were selected by designating all Fish and Game block areas (10 min of latitude by 10 min of longitude) adjacent to the coast as inshore areas and all blocks beyond the coastline as offshore areas (Figure 1).

Median lengths of length distributions were calculated as well as mean lengths because of the skewed nature of the distributions. Chi-square tests were conducted on length frequencies and age distributions to test homogeneity of the data, using methods described in Sokal and Rohlf (1969).

Sex was determined by visually examining gonads. Sex ratios were developed for fish captured in offshore and inshore areas, taken by gill net and trawl net, and landed by port complex.

RESULTS

Age Composition of Catch

Aging was done using 1334 pairs of otoliths. of this total, 193 pairs were from males, 994 from females, and 147 from fish of unknown sex. Three age groups (5-, 6-, and 7-year olds) dominated the sampled catch in three of the 4 years

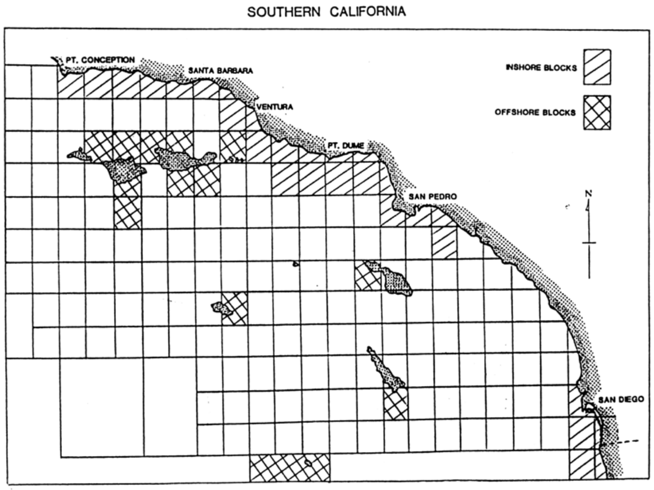
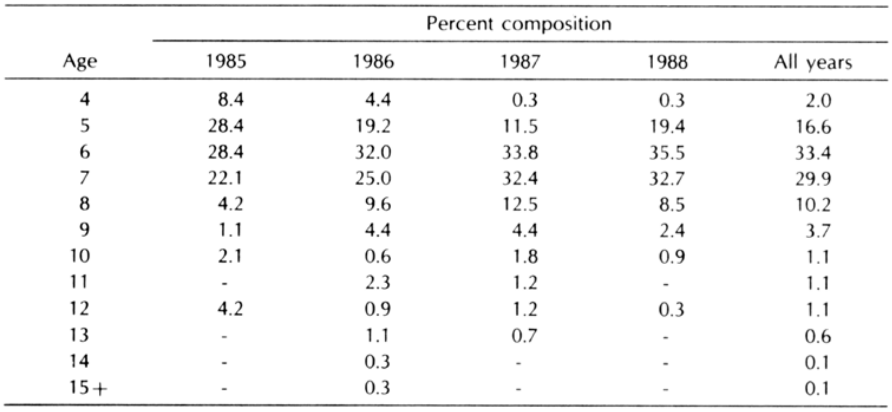


FIGURE 1. Major ports of southern California and major inshore and offshore fishing areas for California halibut.

FIGURE 1. Major ports of southern California and major inshore and offshore fishing areas for California halibut

(Figure 2). The 4-year average indicates that ages 5, 6, and 7 comprised nearly 80% of the catch, while fish 8 years and older averaged 18% over the same period (Figure 3). The major age group for all 4 years was the 6-year olds, which increased from 28% in 1985 to 35% in 1988 (Table 1). Fish 8 years and older increased from 12% in 1985 to 22% in 1987, but declined to 12% by 1988.

Table 1. Age composition of California halibut by year from the southern California commercial fishery landings, 1985-88.



	Percent composition				
Age	1985	1986	1987	1988	All years
4	8.4	4.4	0.3	0.3	2.0
5	28.4	19.2	11.5	19.4	16.6
6	28.4	32.0	33.8	35.5	33.4
7	22.1	25.0	32.4	32.7	29.9
8	4.2	9.6	12.5	8.5	10.2
9	1.1	4.4	4.4	2.4	3.7
10	2.1	0.6	1.8	0.9	1.1
11	-	2.3	1.2	-	1.1
12	4.2	0.9	1.2	0.3	1.1
13	-	1.1	0.7	-	0.6
14	-	0.3	-	-	0.1
15+	-	0.3	-	-	0.1

TABLE 1. ***Age composition of California halibut by year from the southern California commercial fishery landings, 1985–88.***

A chi-square test was used to compare for homogeneity of the age distribution between all four years and the distributions were significantly different (X^2 = 10.51 to 24.61, 4 df, *P* > .05). The differences were due primarily to changes in the younger and older age groups between years.

Geographically, the same three age groups (5-, 6-, and 7-year olds) comprised a major portion of the samples in all three areas. A chi-square test for homogeneity of age groups between areas resulted in a significant difference (X2 = 43.8, 6 df, *P* < .05). The San Diego area included more older and larger fish (fish 8 years and older totaled 25% of samples); conversely, younger fish (5 years and younger) were more abundant in the Santa Barbara-Ventura area (Figure 4).

The most abundant age group for both male and female halibut was the 6-year olds, which numbered 34% in both sexes (Figure 5). Males 8 years and older were more abundant in terms of relative percentage (27% to 17%), while females 5 years old and younger occurred in nearly three times the relative percentages of males (21% to 8%). More age groups were present among females (13 age groups) than males (8 age groups; Figure 5).

Length at Age

Halibut length-at-age results indicated that there were significant differences in size between sexes. Males averaged 244 mm at age 1; the oldest male aged at 12 years was 963 mm. The smallest female aged was 1 year with a length of 274 mm and the largest was 15 years, totaling 1103 mm (Table 2). A growth

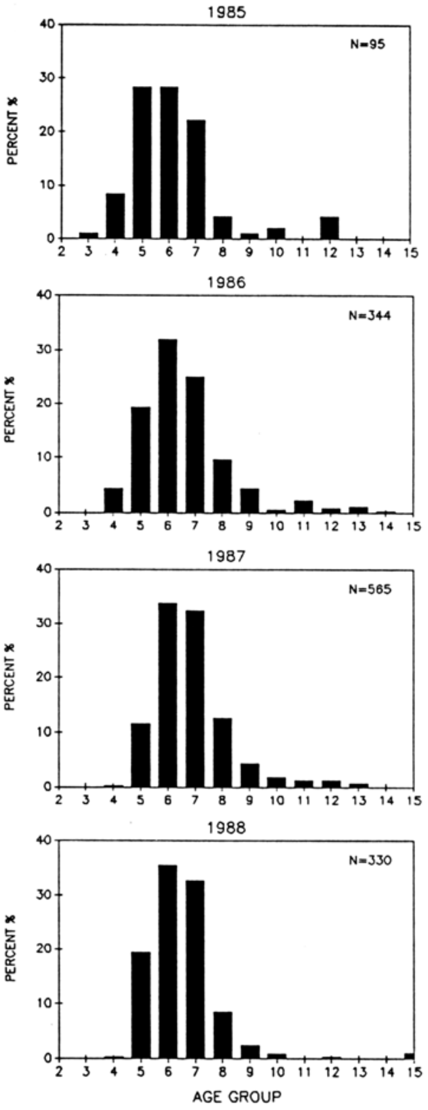


FIGURE 2. Age composition of California halibut by year from southern California commercial landings, 1985-88.

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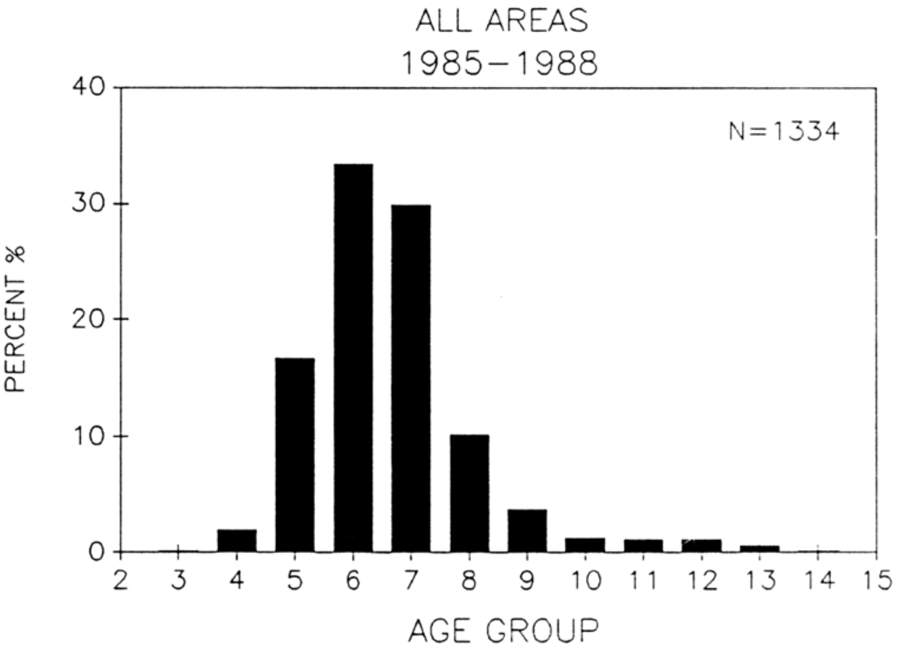

FIGURE 3. Age composition of California halibut from southern California commercial landings, 1985-88.

FIGURE 3. Age composition of California halibut from southern California commercial landings, 1985–88

curve based on the Von Bertalanffy growth equation resulted in a maximum length of 1445 mm for females, and 909 mm for males (R.D. McAllister, CDFG, pers. comm.). Current gear regulations restrict the taking of halibut to a size greater than 22 inches (559 mm). Based on the growth curve and calculations (R.D. McAllister, pers. comm.), female halibut become fully recruited into the fishery at age 6 with an average length of 618 mm; the males also become available to the fishery at age 6, averaging 576 mm.

Size Composition of Catch

Lengths from 20,643 halibut sampled ranged from 500 mm to over 1200 mm. The combined size distribution of all halibut sampled indicated that two modes near 560 mm and 620 mm, were present in both 1983 and 1984 (Figure 6). However, from 1985 to 1988, only one major mode between 600 mm to 650 mm was apparent. The median size of halibut increased each year from 1983 at 588 mm to 651 mm in 1987. In 1988, the median length declined slightly to 647 mm.

Size frequencies and a comparison of median lengths of trawl- and gill net-caught fish demonstrated gear selectivity, as larger fish were taken by gill nets (Figure 7). The length-frequency distributions of trawl- and gill-net-caught halibut were statistically different, although median lengths of each increased over time.

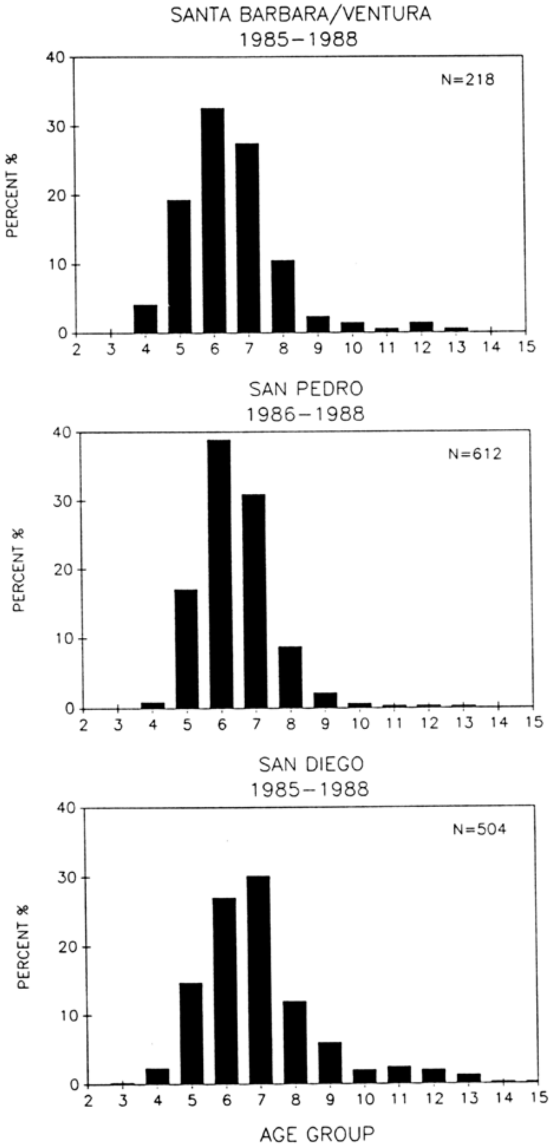

FIGURE 4. Age composition of California halibut by area from southern California commercial landings.

FIGURE 4. Age composition of California halibut by area from southern California commercial landings

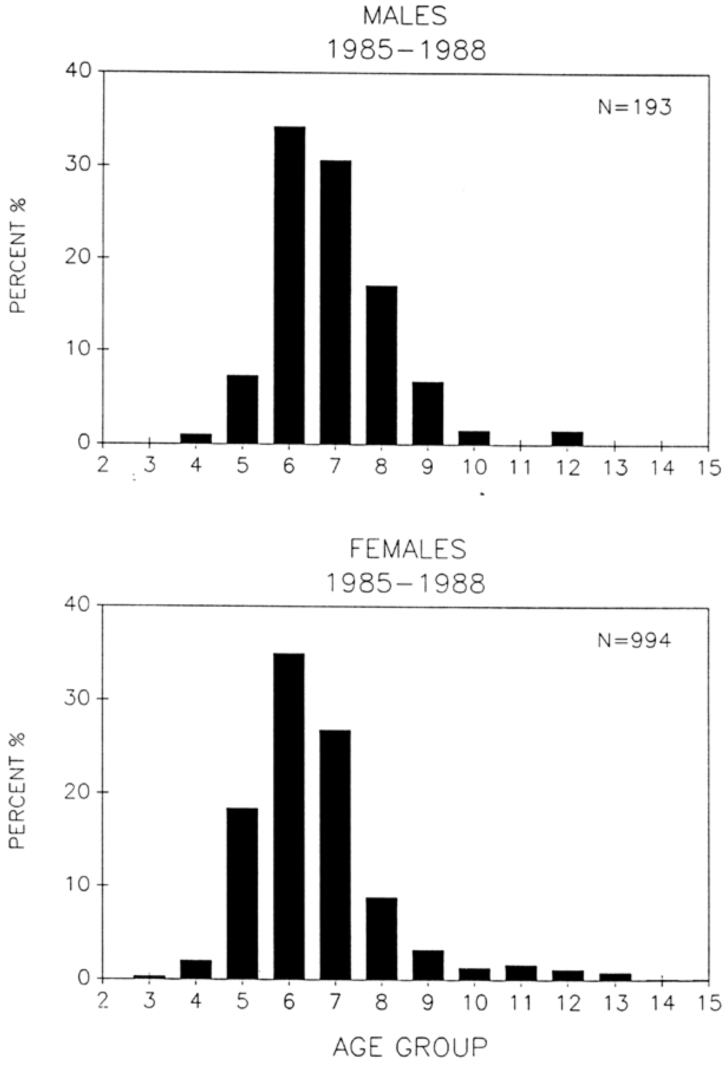

FIGURE 5. Age composition of California halibut by sex from southern California commercial landings.

FIGURE 5. Age composition of California halibut by sex from southern California commercial landings

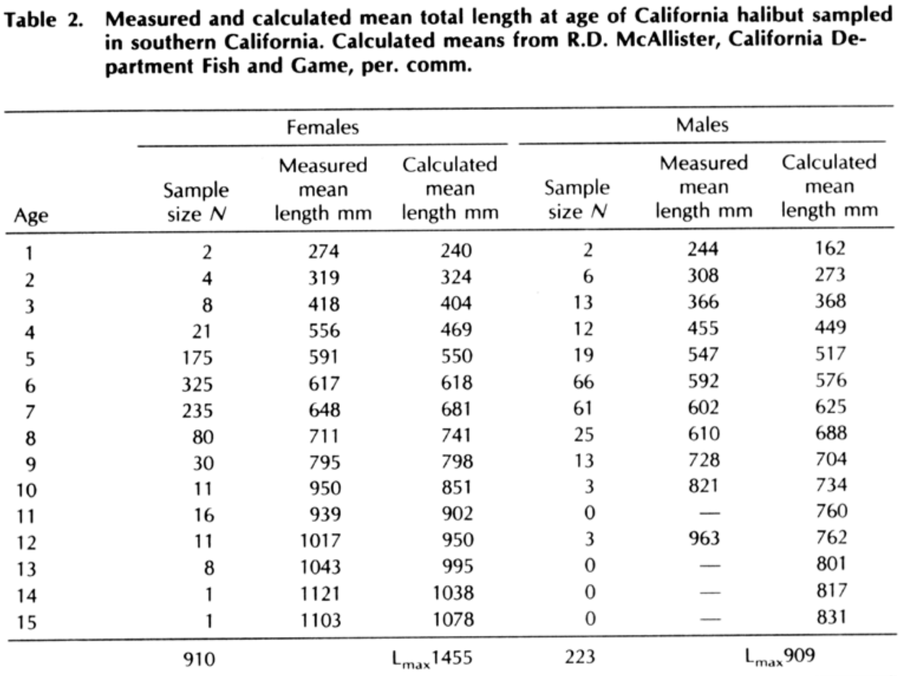

Table 2. Measured and calculated mean total length at age of California halibut sampled in southern California. Calculated means from R.D. McAllister, California Department Fish and Game, per. comm.

	Females			Males		
Age	Sample size N	Measured mean length mm	Calculated mean length mm	Sample size N	Measured mean length mm	Calculated mean length mm
1	2	274	240	2	244	162
2	4	319	324	6	308	273
3	8	418	404	13	366	368
4	21	556	469	12	455	449
5	175	591	550	19	547	517
6	325	617	618	66	592	576
7	235	648	681	61	602	625
8	80	711	741	25	610	688
9	30	795	798	13	728	704
10	11	950	851	3	821	734
11	16	939	902	0	—	760
12	11	1017	950	3	963	762
13	8	1043	995	0	—	801
14	1	1121	1038	0	—	817
15	1	1103	1078	0	—	831
	910		L_{max}1455	223		L_{max}909

TABLE 2. ***Measured and calculated mean total length at age of California halibut sampled in southern California. Calculated means from R.D. McAllister, California Department Fish and Game, per. comm.***

Annual size compositions of female halibut exhibited a pronounced mode between 600 and 650 mm, while male halibut size distributions were characterized by a major mode near 600 mm. Median lengths of females ranged from 635 mm in 1986 to 652 mm in 1987, while male median lengths fluctuated between 607 mm in 1986 and 635 mm in 1985 (Figure 8).

Inshore-caught halibut were much smaller than fish from offshore areas (Figure 9). Median sizes of offshore-caught fish during 1984 were as much as 129 mm larger than the inshore-caught fish. The size distributions were significantly different ($X^2 = 525$, df = 9, $P < .001$).

Sex Ratio of Catch

A total of 10,333 female and 2411 male halibut was sampled in southern California, resulting in a ratio of 4.3 females to 1 male. Sex ratios have increased every year from a 2.3 female to male ratio in 1985 to 5.4:1 by 1988 (Figure 10). Both trawls and gill nets have taken a disproportionate number of females. Gill nets captured females in the ratio of 2.4 per male in 1985, increasing to 5.5 females per male in 1988 (Figure 11). Trawl gear likewise took more females with ratios of 1.2 females per male in 1985 to 3.6 females per male by 1988.

Sex ratios of halibut for inshore areas greatly favored females as compared to offshore areas. Inshore areas had sex ratios ranging from 4.5 to 5.2 females per male whereas offshore areas had female to male ratios of nearly 1:1 in 1985 and 1987 (Figure 12).

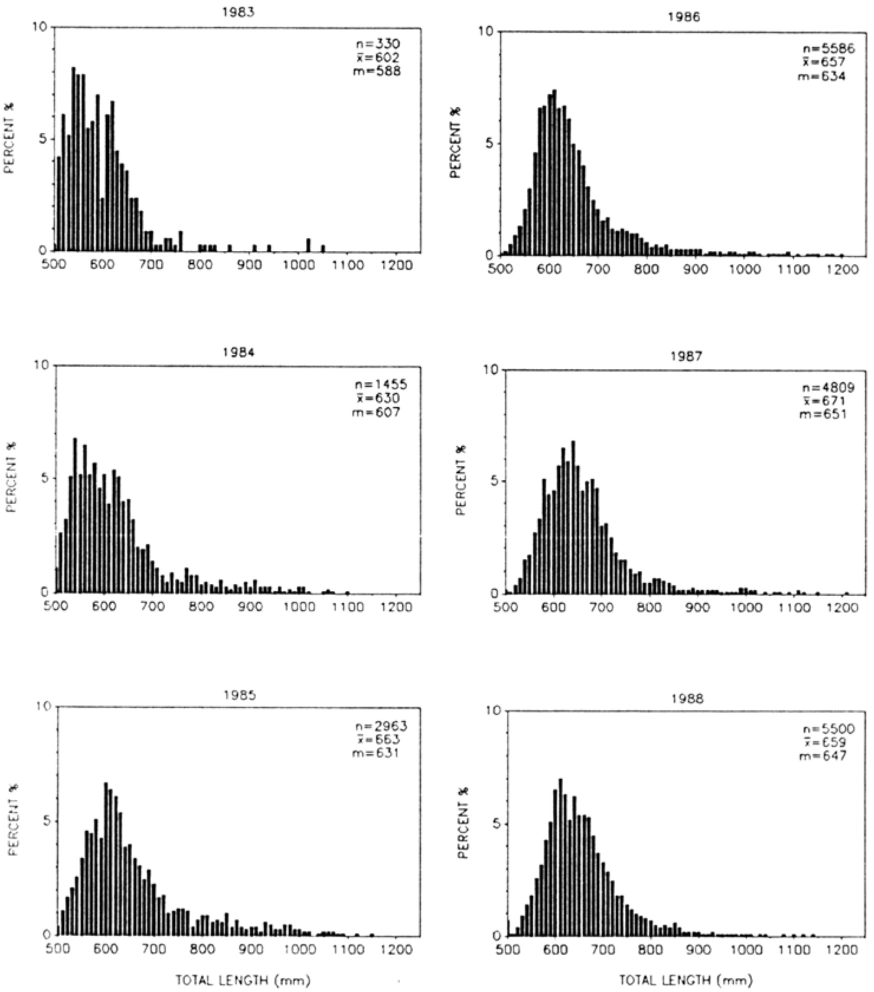

FIGURE 6. Length frequencies of California halibut of both sexes from southern California commercial landings, 1983-88.

FIGURE 6. Length frequencies of California halibut of both sexes from southern California commercial landings, 1983–88

The San Pedro area had female to male ratios ranging from 2.5:1 to 4.7:1, and overall there was a trend towards a higher ratio each year. The Ventura-Santa Barbara complex likewise had more females than males, with ratios ranging from 1.9:1 to 5.5:1 (Figure 13). The San Diego area had the highest female to male ratio for areas with a 10.6:1 value in 1987.

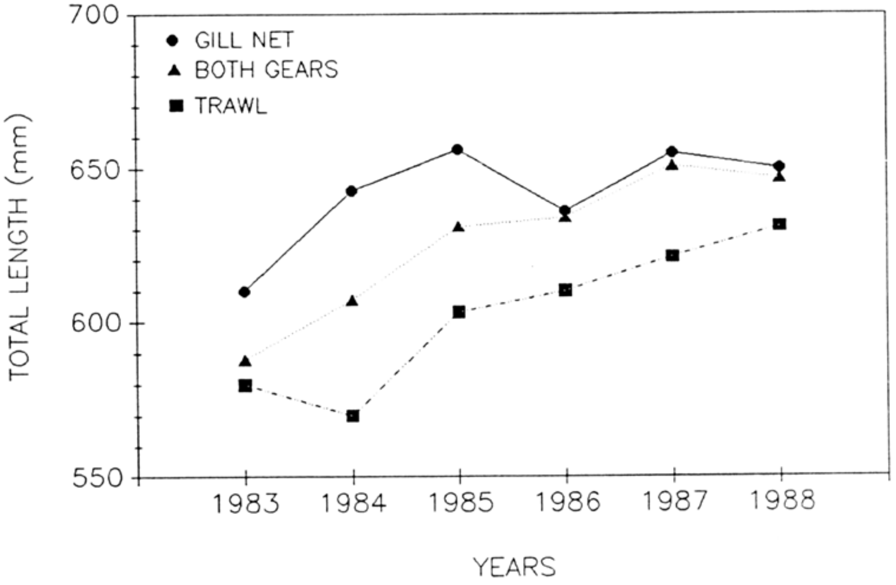

FIGURE 7. Median lengths of California halibut by gear type from southern California commercial landings, 1983-88.

FIGURE 7. Median lengths of California halibut by gear type from southern California commercial landings, 1983–88

FIGURE 8. Median lengths of California halibut by sex from southern California commercial landings, 1985-88.

FIGURE 8. Median lengths of California halibut by sex from southern California commercial landings, 1985–88

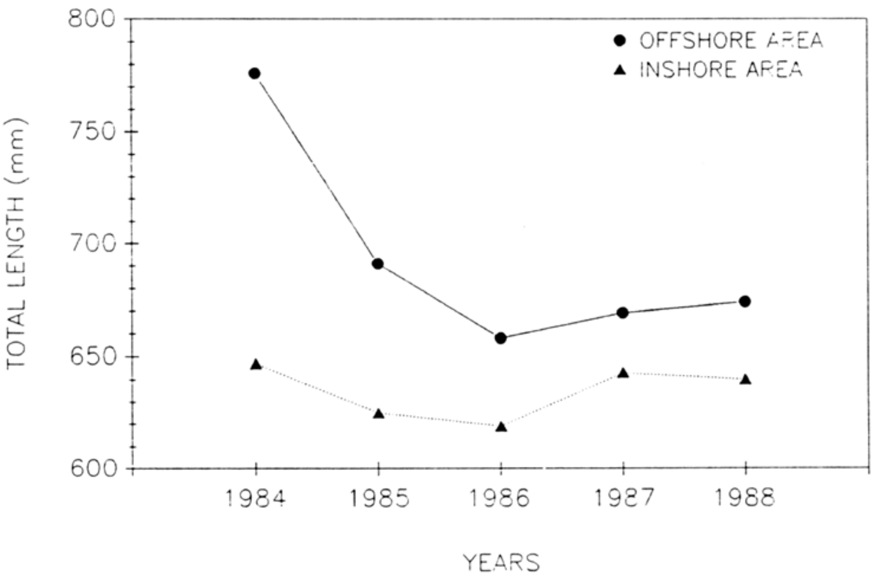

FIGURE 9. Median lengths of California halibut taken from inshore and offshore areas from southern California commercial landings, 1984-88.

FIGURE 9. Median lengths of California halibut taken from inshore and offshore areas from southern California commercial landings, 1984–88

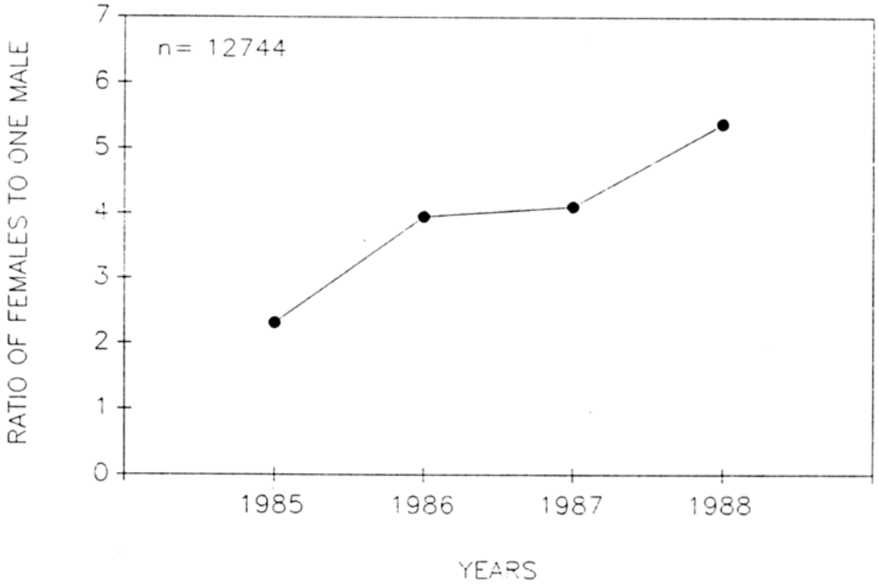

FIGURE 10. Sex ratios of California halibut from southern California commercial landings, 1985–88.

FIGURE 10. Sex ratios of California halibut from southern California commercial landings, 1985–88

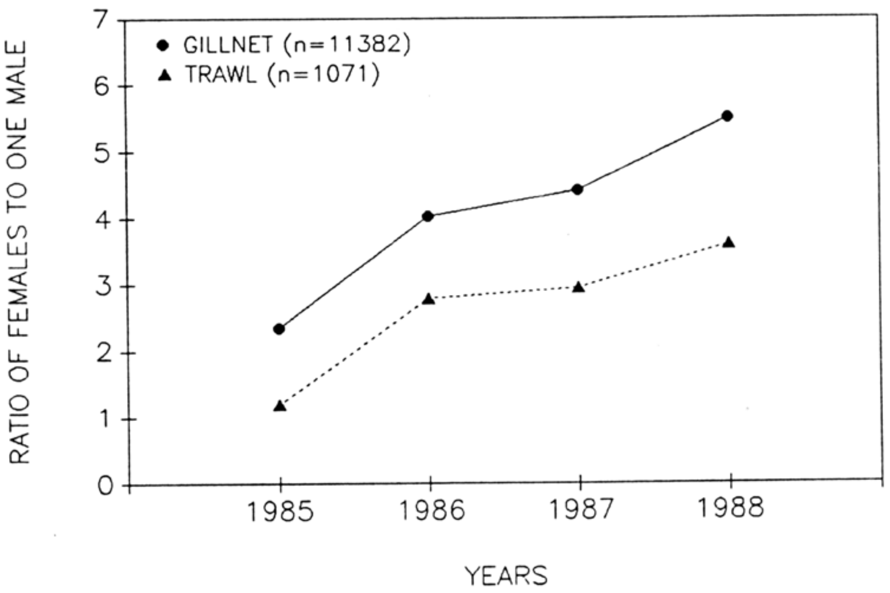

FIGURE 11. Sex ratios of California halibut by gear type from southern California commercial landings, 1985-88.

FIGURE 11. Sex ratios of California halibut by gear type from southern California commercial landings, 1985–88

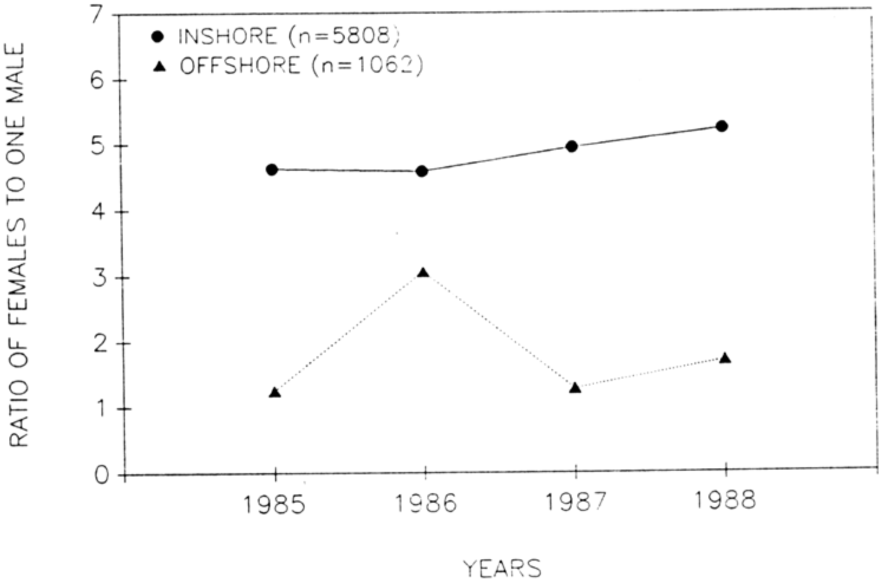

FIGURE 12. Sex ratios of California halibut by area from southern California commercial landings, 1985-88.

FIGURE 12. Sex ratios of California halibut by area from southern California commercial landings, 1985–88

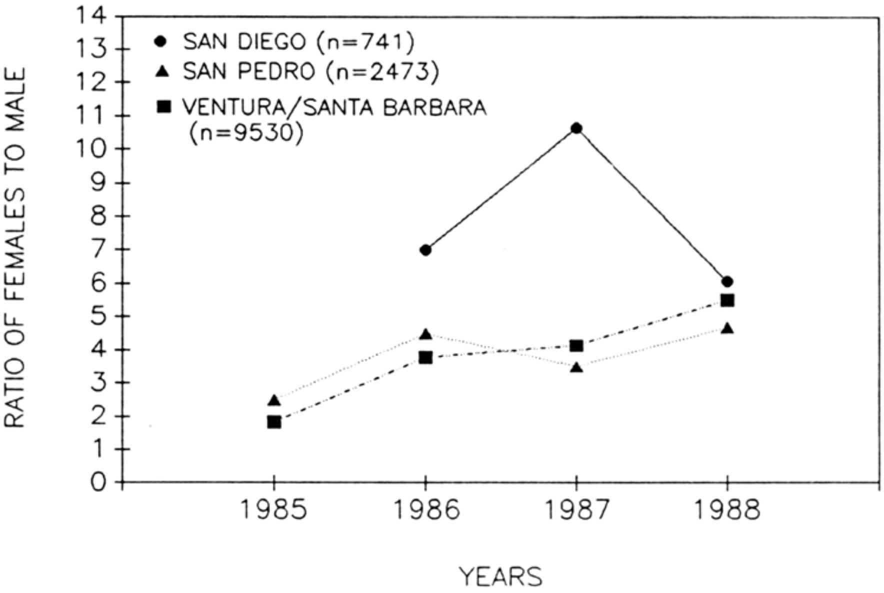

FIGURE 13. Sex ratios of California halibut by port from southern California commercial landings, 1985-88.

FIGURE 13. Sex ratios of California halibut by port from southern California commercial landings, 1985–88

DISCUSSION

Results of this study indicate the commercial harvest of halibut is dominated by at least two age groups (6- and 7-year- old fish), which contributed over 63% of the sampled catch during the 4-year period. The fish first appeared in the fishery at age 3 and were not fully recruited until age 6. Because of gear regulations on mesh size, fish less than 22 inches (559 mm) were infrequently landed. Fish 9 years and older were few in number (7%) during all the years sampled. Females occurred in increased proportions among older age groups, which was the case with other species such as northern anchovy, Engraulis mordax, (Sunada 1977) and summer flounder, Paralichthys dentatus, (Smith and Daiber 1977). Also, certain gear restrictions may limit the number of males in the landings because of their smaller length at age.

Annual length frequencies displayed pronounced modes near 650 mm in recent years and numbers of fish greater than 800 mm declined during the same period. These conditions indicate that the resource is being intensely harvested near the minimum legal size, while older, larger fish were unavailable to the fishery as they either moved offshore or were fished out. Length data revealed that median lengths of halibut from offshore areas were larger than those from inshore areas, indicating an offshore movement by larger fish, increased concentrations of smaller fish in the inshore areas, or a combination of both. Love (1982) and Innis (1982) both commented that subadult fish prefer nearshore areas, while Sunada (1985) and Wallace (1990) observed a greater abundance of large fish in offshore areas. Other species such as Greenland halibut, Reinhardtius hippoglossoides, have demonstrated this tendency to move to deeper waters as they mature (Alton et al. 1988).

Sex ratios demonstrated significant bias for females; they were never the expected 1:1 ratio. Females were more abundant in inshore areas (4.8:1 female:male ratio) than offshore areas (2:1). A potential explanation for this sex segregation could be spawning behavior. Clark (1931) mentioned that during April through May, halibut move inshore to spawn. The inshore habitat provides a better environment for females of species such as English sole, Parophrys vetulus, to spawn, as was noted by Becker (1988).

Another possibility for the high proportion of females in the catch could be related to gear vulnerability. During the sampled years, gill nets have been the main gear type in use, with sizeable gill net fishing occurring in nearshore areas. Since females are much larger than males at the same age and occur in greater numbers than males in nearshore areas, females are more vulnerable to this gill net fishery. Trawl nets captured relatively fewer females than did gill nets. Fishing by trawl gear is restricted to offshore areas during the spawning season and reflects the lower female:male ratios found offshore. Also females are larger than males at the same age and may be more capable of escaping a trawl net.

Another explanation for female dominance in the fishery samples could be sampling bias. Klingbeil (1978) working with northern anchovies documented that samplers had a tendency to select larger fish.

There is the possibility of increased mortality among males of older ages. This has been shown for several pleuronectid flatfishes (Rae 1965; Kovtsova 1982). Haaker (1975) reported that sex ratios of halibut were strongly skewed toward males at smaller sizes, but male dominance decreased rapidly with increasing length, and by 150 mm, ratios were 1:1. This indicates that males are found in equal numbers to females at sizes less than 350 mm. Beyond this size, females predominate. The available data indicate that a female dominant sex ratio exists, and if the highly disproportionate sex ratio is the normal or natural ratio, one need not be alarmed by these figures. Conversely, if the female dominant sex ratio is abnormal and the fishery is harvesting excessively high numbers of females, serious consequences could arise if this practice continues. Population modelers need to be aware of the anomaly and understand its significance.

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THE CENTRAL CALIFORNIA EXPERIENCE: A CASE HISTORY OF CALIFORNIA HALIBUT SET NET LAWS AND REGULATIONS

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ABSTRACT

Laws and regulations for California halibut, Paralichthys californicus, set net fishing in central California changed rapidly in the 1980s. These changes resulted from concerns about impacts of set net fisheries upon seabirds, marine mammals, and other nontarget species taken in the nets. Events, actions, and the resultant changes in laws and regulations during 1980–89 are reviewed chronologically. Effectiveness of the changes and continuing actions are discussed.

INTRODUCTION

In central California, from the late 1970s to 1990, the gill and trammel set net fishery for California halibut, Paralichthys californicus, and the laws regulating this fishery underwent rapid and dramatic changes. During this period, at least 21 state legislative bills were enacted regulating gill and trammel net fishing in California; 12 of these affected halibut set net fishing in central California. This case history reviews events leading to and resulting from these changes, actions taken in response to the events, and the resulting changes in laws and regulations.

Events affecting the halibut set net fishery were closely interwoven with those affecting the white croaker, Genyonemus lineatus, set net fishery in central California. Thus, information for the latter fishery is included where appropriate.

The Area

The ocean area focused upon in this report extends from Yankee Point on the south to the Sonoma-Mendocino County line (Figure 1), north of which set net fishing has not been allowed in California since at least 1915. Within the focal area, set net boats have operated from ports at Bodega Bay, Bolinas Bay, San Francisco Bay, Half Moon Bay, and Monterey Bay. This area includes state Fish and Game Districts 10, 15, 16, and 17. (In 1988, District 15 was eliminated and this area was incorporated into District 17.)

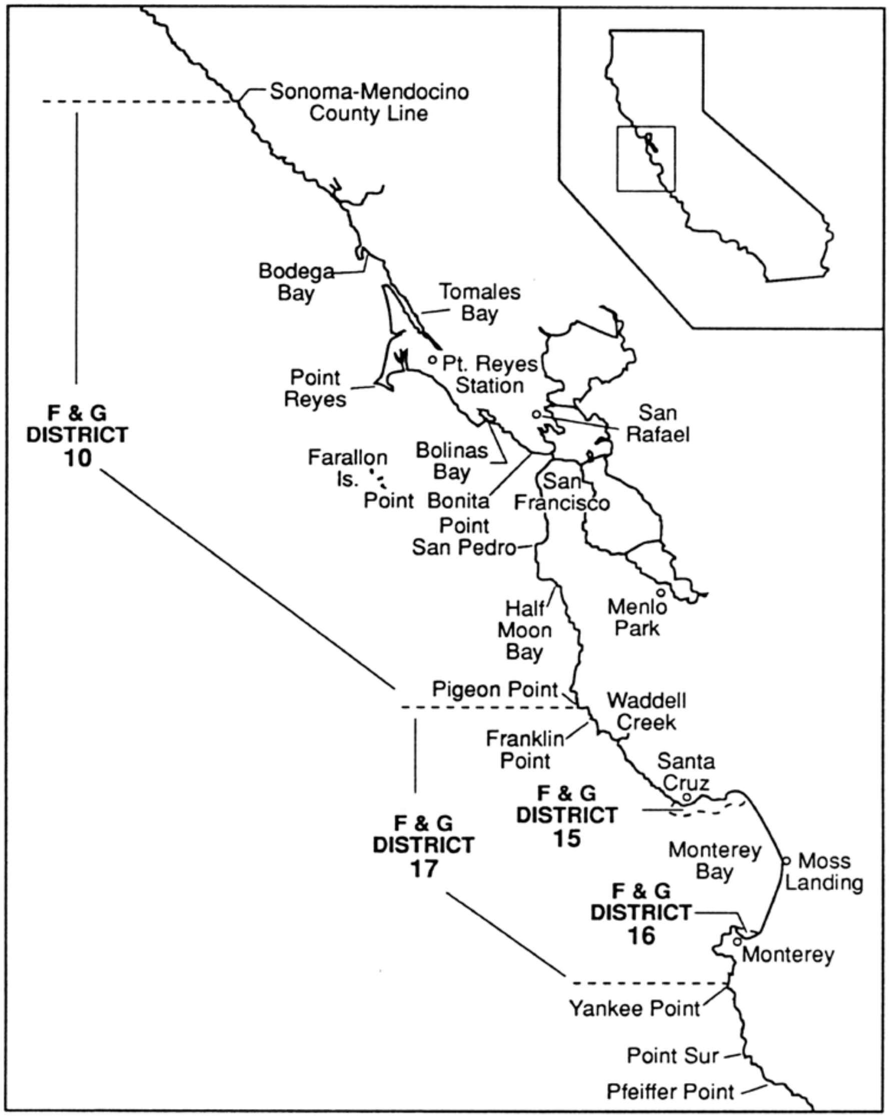

FIGURE 1. Focal area of halibut set net regulation changes.

FIGURE 1. Focal area of halibut set net regulation changes

The Set Net Fishery

Three types of set nets are fished for halibut. These are conventional gill nets, suspendered gill nets, and trammel nets.

Conventional gill nets and suspendered gill nets are constructed of a single wall of webbing. Suspendered gill nets have lines (suspenders) from the float line to the lead line at about 6- to 10-ft (1.8- to 3.0-m) intervals along the net, causing slack in the webbing.

Traditional trammel nets have two or three walls of webbing between the float line and lead line. One wall (the middle one in three-wall nets) is very slack and the other wall(s) is (are) taut. The mesh of the taut walls usually is three to four times larger than that of the slack wall. Suspendered gill nets are considered trammel nets in the California Fish and Game Code. Since 15 August 1989, all trammel nets in California must have 8.5-inch (21.6 cm) mesh (stretched-mesh measurement) or larger. Prior to this, minimum mesh size for trammel nets was 8 inches (20.3 cm).

Halibut set nets typically are 10 to 12 ft (3.0 to 3.7 m) high and 100 to 300 fm (1 fm = 6 ft [1.8 m]) long. They usually are fished overnight, pulled, and reset, although, at times, sets are for 2 or more days. One to several nets are fished at a time. In central California, halibut set nets have been observed to catch a variety of fishes, invertebrates, seabirds, and marine mammals.

Croaker gill net mesh ranges from 2 to 3 inches (5.1 to 7.6 cm). Croaker nets generally are much longer than halibut nets (500–1500 fm), but usually are fished only one net at a time and for shorter periods (a few hours versus 24–48 h for halibut nets). Croaker nets catch primarily white croakers as well as many other species caught in halibut nets, but rarely have been observed to catch marine mammals.

Regulations for set net fishing for halibut in the focal area in 1980 included the following:

1. Set net fishing was allowed in Fish and Game Districts 10, 16, and 17. Trammel nets were not allowed in District 16, and only trammel nets were allowed north of Point Reyes in District 10.

2. No set net fishing was allowed in District 15.

3. The minimum commercial size limit for halibut was 22 inches (55.9 cm), or by weight, 4 lb (1 lb = 0.45 kg) in the round, 3 ½ lb dressed with the head on, or 3 lb dressed with the head off. Each fisherman was allowed up to 30 lb of sublegal halibut per day for personal use.

4. Species not allowed to be possessed by gill and trammel net fishermen included salmon, Oncorhynchus spp.; sturgeon, Acipenser spp.; striped bass, Morone saxatilis; seabirds; and marine mammals.

Beginning in 1981, Senate Bill (SB) 2564 (Statutes 1980, Chapter 886) required commercial gill and trammel net fishermen to obtain a permit from the California Department of Fish and Game (CDFG) to use gill and trammel nets and to maintain and submit to the CDFG a log of fishing activities.

THE ONSET OF CONCERNS AND CONFLICTS

During the late 1970s and early 1980s, several concerns developed over impacts of set net fishing in central California. Initially, these concerns focused upon accidental catches of seabirds and marine mammals and, eventually, included the take of other nontarget species such as salmon, sturgeon, and striped bass. Major factors in the development of these concerns included i) increasing public access to and use of the the coast, accompanied by increased environmental awareness; ii) increases in set net fishing effort; and iii) increases in seabird and marine mammal populations.

Diamond and Vojkovich (1990) calculated estimates of set net fishing effort for halibut fisheries during 1980–86. Fluctuations in set net fishing effort are reflected in halibut and croaker landings (Figure 2). Dramatic increases in croaker landings in the 1980s were almost entirely due to new gill net fisheries which developed in some of the same areas that were being fished for halibut.

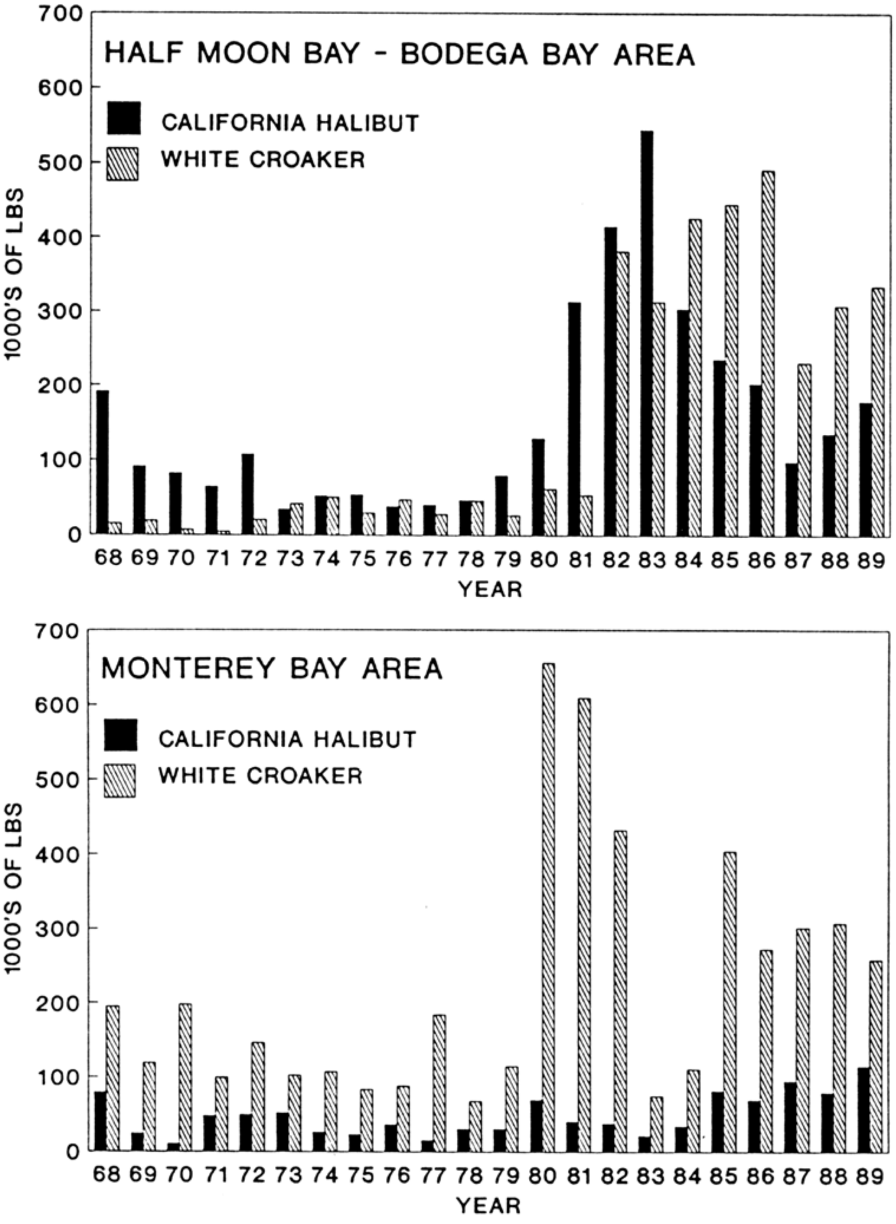

FIGURE 2. Commercial fishery landings of halibut and croaker by all gear types for Monterey Bay and Half Moon Bay-Bodega Bay areas, 1968-89.

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Among concerns over set net fisheries, the catch of seabirds, especially common murres, Uria aalge, became a major problem in central California in the 1980s. Prior to the mid-1800s, up to 400,000 common murres may have bred on the Farallon Islands (Ainley and Lewis 1974). A severe decline in murre numbers at the islands began in the mid-1800s and continued until the late 1960s. This was due to intense commercial murre egg gathering to feed a booming San Francisco gold rush market in the mid-1800s, oil flushed from ships' bilges outside the Golden Gate in murre feeding areas in the early 1900s, later larger oil spills, and a strong El Niño Southern Oscillation (ENSO) during 1957–59. In 1959, the murre population on the south Farallon Islands was estimated at only 6000 (Ainley and Lewis 1974).

In 1969, the U.S. Fish and Wildlife Service expanded the Farallon National Wildlife Refuge (established in 1909) to include Southeast Farallon Island and nearby islets. With this added protection from human disturbance and a period of favorable environmental conditions, a dramatic recovery of murres occurred. By 1982, the Farallon Islands population was estimated at 153,560 breeding common murres (Takekawa et al. 1990). However, following intensive set net fishing effort in the early to mid-1980s, a strong ENSO in 1982–83, and oil spills in the Gulf of the Farallons in 1984 and 1986, murre numbers declined sharply (Takekawa et al. 1990). In 1989, breeding murres at the islands were estimated at 68, 168 (Carter et al. 1990).

By the early 1980s, several marine mammal populations in California were increasing (Bonnell et. al 1983; D.A. Hanan, CDFG, pers. comm.). By 1982, the California sea lion, Zalophus californianus, population was approaching an estimated 80,000 animals. Harbor seals, Phoca vitulina, were estimated at about 17,000 with substantial numbers in central California. About 4000 northern elephant seals, Mirounga angirostris, occupied rookeries in central California and the population was increasing rapidly (B.L. Le Boeuf, Univ. Calif. Santa Cruz, pers. comm.). Harbor porpoise, Phocoena phocoena, were estimated at about 10,000, most of which were in central and northern California (D.A. Hanan, pers. comm.). Sea otters, Enhydra lutris, though still probably below 2000 in number, had extended their range northward along the length of Monterey Bay (Riedman 1989). The federal government, under provisions of the Endangered Species Act of 1977, placed sea otters in California on a list of threatened species for which no take is allowed. Thus, any accidental take of sea otters in set nets is a serious concern.

Observations by the CDFG and others of set net fishing activities in central California have documented the take of various nontarget species in the nets (Table 1).

Against this background and mounting concerns about effects of set net fishing, a scenario of events and actions developed which resulted in numerous changes in set net laws and regulations that were designed to protect some marine populations while attempting to provide a reasonable harvest of commercially-sought species.

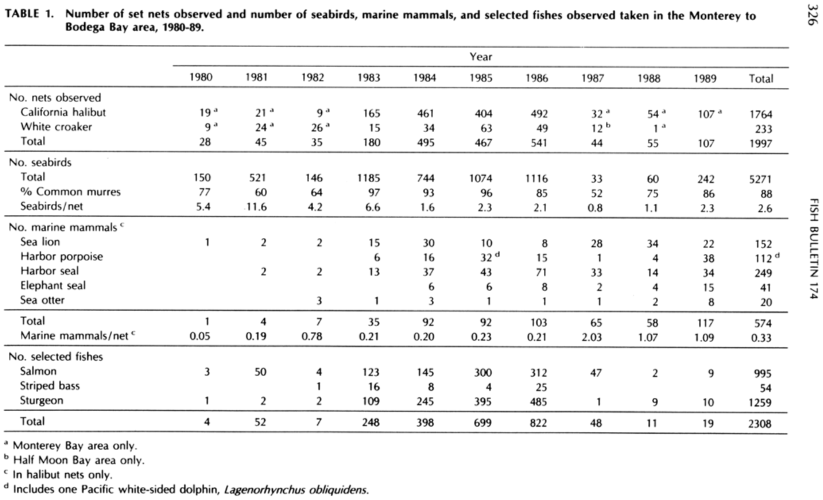

TABLE 1. **Number of set nets observed and number of seabirds, marine mammals, and selected fishes observed taken in the Monterey to Bodega Bay area, 1980-89.**

	Year										
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Total
No. nets observed											
California halibut	19 [a]	21 [a]	9 [a]	165	461	404	492	32 [a]	54 [a]	107 [a]	1764
White croaker	9 [a]	24 [a]	26 [a]	15	34	63	49	12 [b]	1 [a]		233
Total	28	45	35	180	495	467	541	44	55	107	1997
No. seabirds											
Total	150	521	146	1185	744	1074	1116	33	60	242	5271
% Common murres	77	60	64	97	93	96	85	52	75	86	88
Seabirds/net	5.4	11.6	4.2	6.6	1.6	2.3	2.1	0.8	1.1	2.3	2.6
No. marine mammals [c]											
Sea lion	1	2	2	15	30	10	8	28	34	22	152
Harbor porpoise				6	16	32 [d]	15	1	4	38	112 [d]
Harbor seal		2	2	13	37	43	71	33	14	34	249
Elephant seal					6	6	8	2	4	15	41
Sea otter			3	1	3	1	1	1	2	8	20
Total	1	4	7	35	92	92	103	65	58	117	574
Marine mammals/net [c]	0.05	0.19	0.78	0.21	0.20	0.23	0.21	2.03	1.07	1.09	0.33
No. selected fishes											
Salmon	3	50	4	123	145	300	312	47	2	9	995
Striped bass			1	16	8	4	25				54
Sturgeon	1	2	2	109	245	395	485	1	9	10	1259
Total	4	52	7	248	398	699	822	48	11	19	2308

[a] Monterey Bay area only.

[b] Half Moon Bay area only.

[c] In halibut nets only.

[d] Includes one Pacific white-sided dolphin, *Lagenorhynchus obliquidens.*

TABLE 1. ***Number of set nets observed and number of seabirds, marine mammals, and selected fishes observed taken in the Monterey to Bodega Bay area, 1980–89.***

CHRONOLOGY OF EVENTS, ACTIONS, AND CHANGES IN LAWS AND REGULATIONS

1980

In 1980, halibut landings in Monterey Bay were the highest since 1968 (Figure 2). Halibut set net fishing effort that year was higher than for several subsequent years (Diamond and Vojkovich 1990). Croaker landings increased dramatically in 1980 (Figure 2), due primarily to substantial increases in set net fishing for croakers.

During 1980, the CDFG received reports of larger than usual numbers of dead seabirds washing ashore on Monterey Bay beaches. Concerns also were raised about occasional dead marine mammals on the beaches, some of which were found with set net webbing entangled about their heads and necks (J.A. Ames, CDFG, pers. comm.).

In response to these concerns, in June 1980, CDFG researchers studying fishery-marine mammal interactions began at-sea observations of set net fishing from a skiff maneuvered close to fishing boats as the nets were being retrieved. These observations documented the take of seabirds and other species of concern in set nets in Monterey Bay (Table 1). In October 1980, the CDFG began making bi-weekly counts of dead seabirds and marine mammals on eight 1-mile (1.6 km) sections of Monterey Bay beaches; these counts were made through August 1981.

1981

Halibut fishing effort and landings were down from 1981 (Diamond and Vojkovich 1990) (Figure 2) while croaker landings remained high.

At-sea observations of set net fishing in 1981 were conducted by students from Moss Landing Marine Laboratories (MLML). Seabird mortality in observed nets was very high (Table 1). Included were common murres; sooty shearwaters, Puffinus griseus; cormorants, Phalacrocorax spp.; pigeon guillemots, Cepphus columba; grebes (Podicipedidae); and loons, Gavia spp. Murres, cormorants, and shearwaters comprised 98% of the total.

Nearly 3800 dead diving seabirds were counted on beaches during October 1980 through August 1981; 42% were common murres and 39% were sooty shearwaters. The remainder included all of the species seen in set nets plus a few others such as gulls, auklets, etc. Seabird mortality on beaches and in set nets was highest during the months of July and August when halibut set net fishing and seabird abundance peak in nearshore waters. An estimated 20,000 seabirds drowned in set nets during a 14-month period from June 1980 through August 1981 (MRR and MRB Staff, 1981).

A few marine mammals were observed drowned in halibut nets in both 1980 and 1981 (Table 1). Dead marine mammals on beaches during the 14 months of observations included 19 sea lions, 3 harbor propoise, 6 harbor seals, and 6 sea otters.

In response to these problems, SB 1475 (Statutes 1981, Chapter 316) was enacted and took effect on 28 June 1982. This legislation closed Monterey Bay to set net fishing in waters 10 fm (18.3 m) or less in depth, gave the CDFG director emergency power to prohibit set net use in Districts 10 and 17 for specified periods to protect seabirds and marine mammals, and closed District 16 to the use of gill nets.

1982

Set net fishing effort and landings for halibut and croaker in Monterey Bay were down from 1980 and 1981 (Diamond and Vojkovich 1990; Figure 2), presumably due, in part, to the 10-fm closure to set nets beginning in June 1982.

At-sea observations of set net fishing in Monterey Bay were continued during 1982 by MLML students from a skiff maneuvered near fishing boats. Observed seabird mortality was lower than in the previous 2 years (Table 1). Murre mortality remained high with cormorants and pigeon guillemots comprising most of the remainder. Among observed marine mammals were three sea otters, the first recorded drownings of this species in California's set net fisheries. All were taken in June before the 10-fm closure took effect.

In the area from Half Moon Bay to Bodega Bay, halibut set net fishing effort and landings were increasing (Diamond and Vojkovich 1990; Figure 2). In addition, croaker set net fisheries began in 1982 near Half Moon and Bolinas Bays (Figure 2). In June, the CDFG received reports of large numbers of dead seabirds washing ashore on beaches north of San Francisco.

On 28 June 1982, the CDFG held a public hearing at Point Reyes Station to take testimony on the problem of seabirds and marine mammals drowning in set nets. On 9 July, the CDFG director closed nearshore ocean waters less than 10 fm to the use of gill and trammel nets from Point Reyes to Point Bonita until 1 September 1982.

In July, large numbers of seabirds began washing ashore on beaches south of Half Moon Bay. The CDFG surveyed 3.25 miles (5.2 km) of coast in this area and counted 659 dead seabirds. Approximately 90% were common murres; one was entangled with several meshes of halibut set net webbing.

The CDFG held another public hearing at Half Moon Bay on 10 August. Following the hearing, the CDFG director closed nearshore ocean waters less than 10 fm to the use of gill and trammel nets from Point Reyes to Pigeon Point from 10 August until 1 October 1982.

In response to mounting concerns about effects of set net fisheries, in late 1982, the CDFG established the Central California Gill and Trammel Net Investigations project to conduct a comprehensive program of observations of set net fishing activities throughout central California. In addition, legislation initiated in 1982 provided further protections for resources affected by set net fishing. Assembly Bill (AB) 2580 (Statutes 1982, Chapter 1477), authorized the CDFG director to restrict construction and use of set nets if a fishery resource was being adversely affected. It became effective 1 January 1983. Assembly Bill 153 (Statutes 1983, Chapter 131), authorized the CDFG director to restrict method of use, materials, and construction of set nets for periods up to 180 days to protect seabirds and marine mammals. It became effective 27 June, 1983.

1983

Set net fishing effort and landings for both halibut and croaker were very low in Monterey Bay in 1983 (Diamond and Vojkovich 1990; Figure 2), presumably due, in part, to the 10-fm closure in effect since June 1982. However, in the Half

Moon Bay to Bodega Bay area, halibut set net effort and landings increased substantially and croaker landings remained high (Diamond and Vojkovich 1990; Figure 2).

The CDFG's new gill and trammel net project began conducting observations in April 1983 when the halibut fishing season was getting underway. Observations were continued from a skiff in Monterey Bay but were conducted aboard set net fishing boats from Half Moon Bay to Bodega Bay. Overall, observations of set nets increased substantially that year (Table 1).

Observed seabird mortality in set nets was low in the Monterey Bay area. Most of the observed mortality was in the Half Moon Bay to Bodega Bay area. Two periods of high mortality occurred, one in late May and one in late July to early August. Murre mortality was especially high. The total estimated seabird mortality in set nets throughout the area in 1983 was 30,000 (Staff, Mar. Resour. Div. 1987). Overall, the level of mortality was of serious concern, but especially for local populations of common murres.

The overall rate of observed marine mammal mortality did not increase over previous years, but the harbor porpoise take was of additional concern (Table 1). Most of the porpoise (4) and harbor seals (12) were taken in the Half Moon Bay to Bodega Bay area; an otter was taken in Monterey Bay. Most of the harbor seals were young of the year, about 40 to 60 lb (18 to 27 kg) in weight.

The CDFG held two public hearings in 1983 to review concerns about impacts of set net fisheries. The first was held in San Francisco on 1 June. The CDFG concluded that no emergency action was justified at that time. The second was held in San Rafael on 5 August. The CDFG director closed the nearshore ocean area from Pigeon Point to Point Reyes to gill and trammel net fishing from 15 August through 16 October. The closures ranged in depth from 10 to 15 fm (27.4 m). The area from Half Moon Bay to just north of Point San Pedro, where observed seabird mortality was the highest, was closed in 15 fm or less.

In late 1983, the CDFG held a series of meetings with set net fishermen, representatives of federal agencies responsible for seabirds and marine mammals, and private conservation and preservation organizations to seek permanent solutions to set net caused mortality of seabirds and marine mammals. Concerns also were raised about effects of set nets on salmon, striped bass, and sturgeon. The observed rate of take for these species had increased when set net observations included the Half Moon Bay to Bodega Bay area (Table 1). Although the catch levels were not detrimental to these populations, these species are important to sport fisheries and commercial salmon troll fisheries. Thus, a reduction of their set net take was desirable, especially the large numbers of small salmon (mostly 12–18 inches [30–45 cm] in length) in croaker nets.

As a result of the meetings, SB 2266 (Statutes 1984, Chapter 206), was enacted and became effective on 20 June 1984. This bill established a complex set of zonal closures in nearshore ocean waters from Pigeon Point to Point Reyes (Figure 3) and extended the 10-fm closure in Monterey Bay to waters 15 fm or less to provide additional protection for sea otters. The bill also required fishermen to obtain from the CDFG a special permit, in addition to the required general gill and trammel net permit, to fish set nets in state waters between the Sonoma-Mendicino County line and Pfeiffer Point.

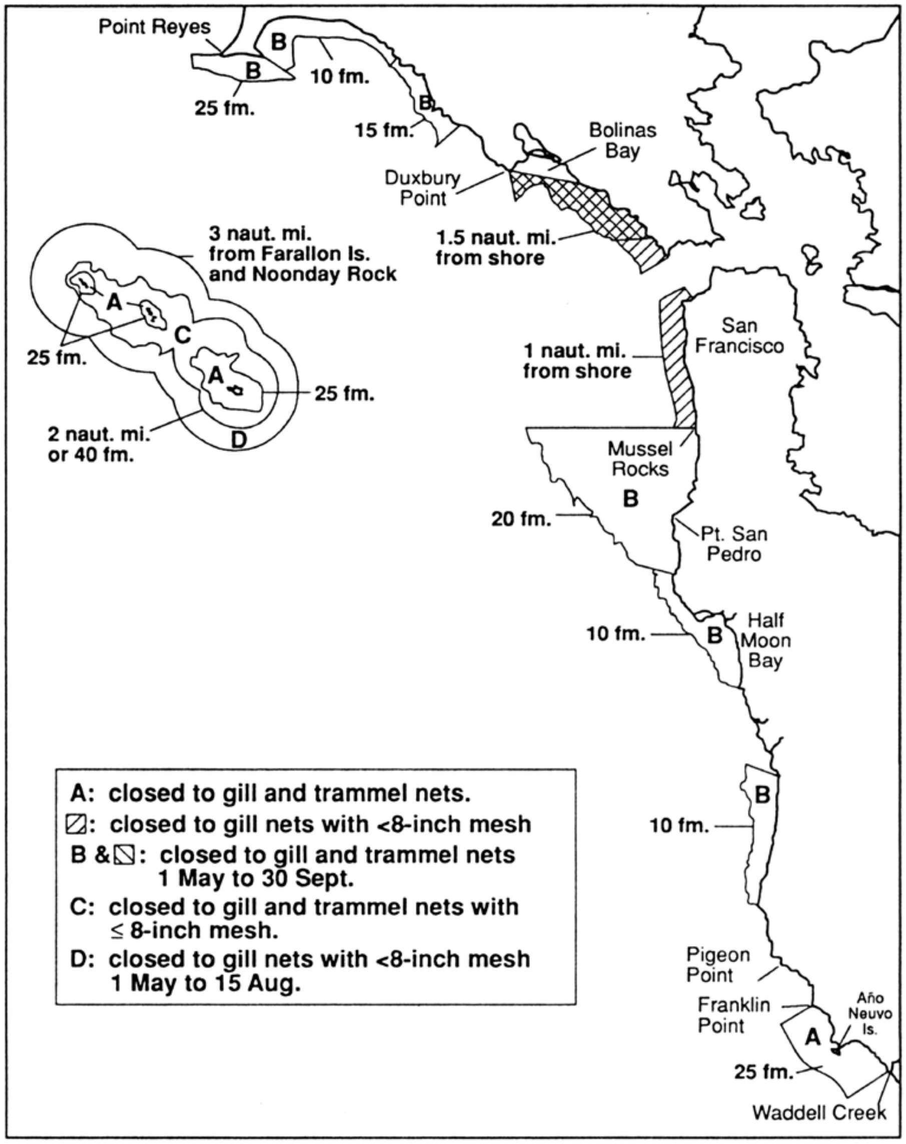

FIGURE 3. Areas closed to gill and trammel net fishing by SB 2266, 1984, beginning 20 June 1984.

FIGURE 3. Areas closed to gill and trammel net fishing by SB 2266, 1984, beginning 20 June 1984

1984

In 1984, set net fishing effort for halibut in Monterey Bay was up markedly over 1983 but was down slightly in the area from Half Moon Bay to Bodega Bay (Diamond and Vojkovich 1990). Halibut landings increased in Monterey Bay over 1983 but were down substantially in the Half Moon Bay to Bodega Bay area (Figure 2). Croaker set net fishing effort and landings were up over 1983 in both areas (Figure 2).

Set net observations increased substantially over previous years (Table 1). The rate of observed seabird mortality was much lower than for previous years (Table 1), presumably due primarily to increased closures to gill and trammel net use. Total estimated seabird mortality in 1984 was 7000 (Staff, Mar. Res. Div. 1987), down markedly from 1983; 93% of the observed mortality in set nets was murres. However, because of continuing declines in local murre populations, further reductions in mortality were necessary.

Observed marine mammal mortality continued at a similar rate to 1983 (Table 1). Most harbor seals and all elephant seals were young of the year. Three sea otters were taken in set nets in Monterey Bay in June before the closure was extended to 15 fm. Observed catch rates of salmon, striped bass, and sturgeon in 1984 were lower than in 1983 (Table 1). The actions taken through 1984 appeared to be having beneficial effects on reducing catches of several nontarget species. Nevertheless, interest was increasing for further limiting gill and trammel net fishing effort and for encouraging these fishermen to try other methods for catching target species.

Two legislative bills directed at these interests were initiated in 1984 and enacted in 1985. Senate Bill 89 (Statutes 1985, Chapter 50) became effective 30 May 1985. This bill extended the 15-fm closure in Monterey Bay north to Waddell Creek and south to Yankee Point (Figure 1). It also directed the CDFG to explore alternatives to gill and trammel net fishing between Waddell Creek and Point Sal (Santa Barbara County). Senate Bill 346 (Statutes 1985, Chapter 436) limited the number of special gill and trammel net permits that the CDFG could issue annually to a maximum of 135.

1985

Halibut set net effort was up slightly from 1984 in Monterey Bay but was down about 28% from Half Moon Bay to Bodega Bay (Diamond and Vojkovich 1990). Halibut landings in Monterey Bay increased substantially but continued to decline from Half Moon Bay to Bodega Bay (Figure 2). There were rumors of illegal set net fishing for halibut in 1985 in Monterey Bay where nets reportedly were being fished in shallow water and pulled and reset at night (C.W. Haugen, CDFG, pers. comm.). No violators were apprehended that year, but illegal fishing may have contributed to the increased landings.

Croaker set net landings were up markedly from 1984 in Monterey Bay and were similar to 1984 in the Half Moon Bay to Bolinas Bay area (Figure 2).

Set net observations continued at a pace similar to 1984 (Table 1). The overall rate of observed seabird mortality was higher than in 1984 (Table 1), even though it was very low in Monterey Bay (0.20 per net) in 1985. Estimated total seabird mortality in set nets in 1985 was 8000, which, even with reduced fishing effort, was about 12% higher than in 1984 (Staff, Mar. Res. Div. 1987). Ninety-six percent of the observed mortality was murres (Table 1). Because of continuing declines in local breeding populations of murres, the continuing set net mortality of seabirds remained a serious concern.

Marine mammal mortality during 1985 continued at about the same rate as in 1983 and 1984 (Table 1). The porpoise take was especially high in the Bodega Bay area where 25 were taken, most in April and May. The harbor seal take continued to be high in Half Moon Bay and Bodega Bay areas where 20 and 14, respectively, were taken; again, most were young of the year.

Catch rates of salmon, striped bass, and sturgeon were about double those of 1984 (Table 1). However, these catches still did not pose threats to these resources. For example, the total estimated set net catch of salmon in 1985 was 2170 fish and the total estimated sport and commercial catch was 547,000 fish (Staff, Mar. Resour. Div. 1987). Nevertheless, the CDFG still considered it desirable to reduce the set net catch and wastage of these fishes.

The CDFG continued meetings with various interest groups to seek permanent solutions to continuing concerns over set net fishing. Two legislative bills initiated in 1985, addressing these concerns, took effect 1 January 1986. Assembly Bill 307 (Statutes 1985, Chapter 1002) established a statewide moratorium on the issuance of general gill and trammel net permits until 1990. This bill also modified the amount of sublegal California halibut a commercial fisherman was allowed to keep for personal use from 30 lb (13.5 kg) to four fish (about 10 to 15 lb [4.5 to 6.8 kg]). Assembly Bill 2915 (Statutes 1985, Chapter 910) provided additional closures to gill and trammel net use south of Monterey Bay for further protection for sea otters. It also provided funds for low interest loans for gear modifications to qualified fishermen selected to participate in experimental alternative gear fisheries.

Additionally, the CDFG issued the first two experimental gear permits for alternative gear fisheries for halibut in November 1985, pursuant to SB 89 (1985; Haseltine and Thornton 1990).

1986

Set net fishing effort and landings for halibut declined from 1985 throughout the focal area (Diamond and Vojkovich 1990; Figure 2). In Monterey Bay, considerable illegal halibut set net fishing occurred in the summer and fall in closed areas (C.W. Haugen, pers. comm.) and, again, may have contributed substantially to that area's landings. From Half Moon Bay to Bodega Bay, halibut landings continued a declining trend from peak landings of 1983 (Figure 2).

Croaker landings were down about a third from 1985 in Monterey Bay but were up slightly from Half Moon Bay to Bolinas Bay (Figure 2). By late 1986, this fishery ceased off Bolinas Bay because of poor catches outside the area closed pursuant to SB 2266 (1984) (Figure 3).

Overall, set net observations increased over previous years (Table 1). The observed seabird mortality rate was down slightly from 1985, but was still higher than in 1984 (Table 1). More than 99% of the observed mortality was in the Half Moon Bay to Bodega Bay area; the highest localized mortality that year was near San Francisco. Only 10 seabirds (0.20 per net) were observed in set nets in Monterey Bay. Murres comprised 85% of the total seabird mortality (Table 1); 8% were pigeon guillemots and 5% were cormorants.

Estimated total seabird mortality in set nets in 1986 was 5000, the lowest since observations began in 1980. However, this was due to reduced fishing effort, not reduced catch rates. Seabird mortality in set nets continued to be a serious concern, especially because of continued declines in local populations of common murres and continuing set net mortality of other seabirds. Furthermore, the center of highest localized mortality shifted from year to year, making it impractical to manage by zonal closures.

Illegal set net fishing in Monterey Bay in shallow water (<15 fm) in the summer and fall probably caused some additional mortality of seabirds and marine mammals. This activity ceased when CDFG wardens aboard a patrol boat arrested a violater who was retrieving a halibut set net at night in water 6-fm (11.0-m) deep.

Overall, observed marine mammal mortality continued at a rate similar to the previous 3 years (Table 1), although the harbor seal take was the highest yet observed. The take of harbor seals, porpoise, and otters continued to be of concern, and catches of salmon, striped bass, and sturgeon continued at unwanted levels (Table 1).

The CDFG continued to hold meetings with interest groups to review results of actions taken and regulations enacted to reduce the take of nontarget species in set nets. One issue of concern was the Migratory Bird Treaty Act of 1917 which covers the seabird species that were being taken in set nets. This treaty does not permit the take of these seabirds by fisheries. This concern became a major consideration in seeking permanent solutions to this problem.

Legislation initiated in 1986 resulted in SB 40 (Statutes 1987, Chapter 1298) which took effect on 28 September 1987. This bill prohibited the use of gill and trammel nets north of Point Reyes, within waters 40 fm or less from Point Reyes to Waddell Creek, and within 3 naut mi around the Farallon Islands and Noonday Rock Buoy. The 40-fm closure was phased in by prohibiting gill and trammel net use in waters 20 fm or less from Duxbury Buoy to Franklin Point and within a 5-naut-mi radius of Point San Pedro until 31 March 1988, after which the 40-fm closure took effect (Figure 4). The bill deleted the requirement for special permits for use of gill and trammel nets. It established a Nearshore Research Advisory Committee to review applications for experimental alternative gear permits and provided funds for low interest loans for gear modifications for experimental gear permittees.

1987

In anticipation of enactment of SB 40 (1987), and the need to take expedient action prior to its passage, the CDFG held a public hearing in Menlo Park on 1 April 1987. On that date, the CDFG director closed nearshore ocean waters to the use of gill and trammel nets from the Sonoma-Mendicino County line to Franklin Point in 20 fm (36.6 m) or less, except that from Point Reyes to Duxbury Point, waters 40 fm (73.2 m) or less were closed, as was the area within 5 naut mi of Point San Pedro. Also, waters within 3 naut mi of the Farallon Islands and Noonday Rock Buoy were closed to the use of gill and trammel nets. This emergency closure remained in effect until SB 40 was implemented on 28 September 1987.

No estimates of set net fishing effort were available for 1987 in the focal area. The emergency and subsequent permenant closures drastically reduced set net fishing from Half Moon Bay to Bodega Bay. Landings of both halibut and croaker were down markedly from preceeding years (Figure 2). The halibut set net fishery virtually ceased north of Waddell Creek with these closures and most of the halibut landed were caught by other gear.

In Monterey Bay, set net fishing effort probably was not greatly different from that in 1986. Landings of halibut in Monterey Bay in 1987 were the highest in more than 20 years (Figure 2), but 44% of these landings were made by the two experimental gear permittees using trawls (Haseltine and Thornton 1990).

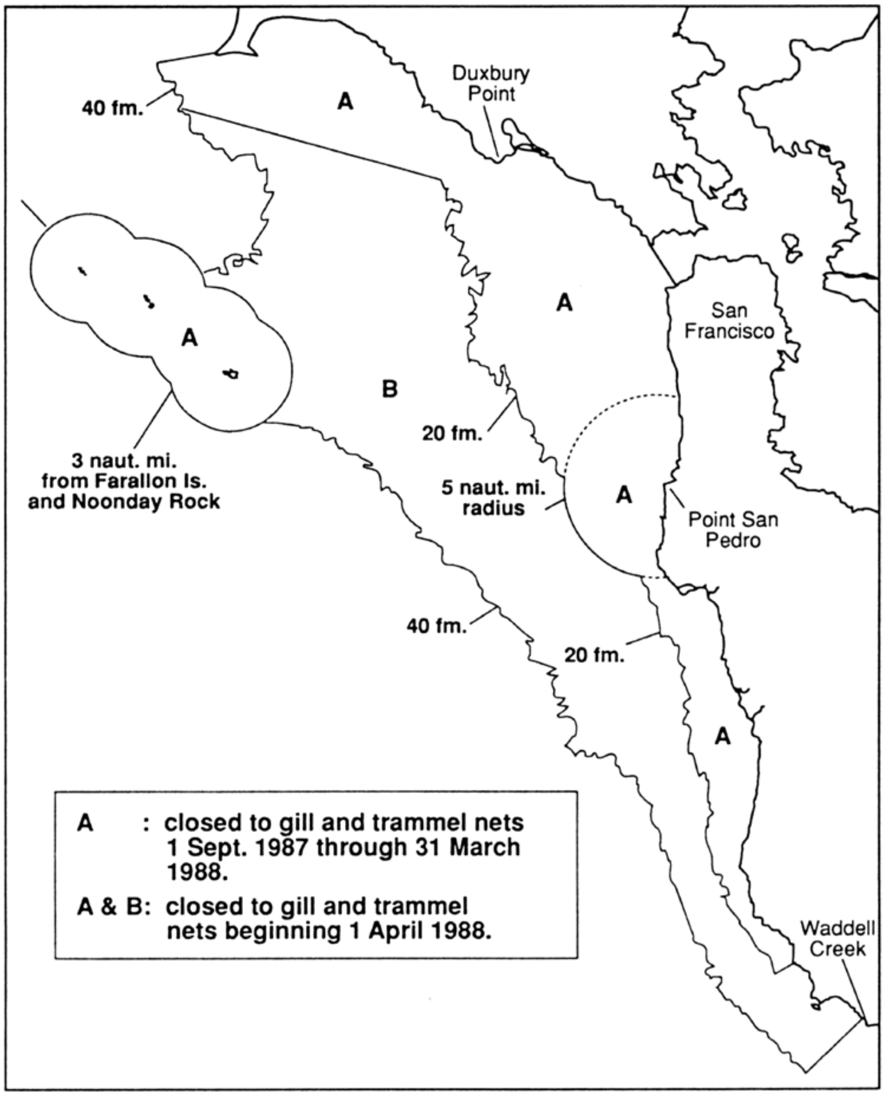

FIGURE 4. Areas closed to gill and trammel net fishing by SB 40, 1987, beginning 28 September 1987.

FIGURE 4. Areas closed to gill and trammel net fishing by SB 40, 1987, beginning 28 September 1987

Much of their catches were made in waters 5- to 10-fm deep. In 319 trawl sets observed, no seabirds, salmon, or striped bass were caught; two sea lions were drowned and one sturgeon was caught. Croaker landings in Monterey Bay were similar to those in 1986 (Figure 2).

Halibut set nets continued to be observed in Monterey Bay in 1987 but none were observed in the Half Moon Bay to Bodega Bay area. Twelve croaker nets were observed near Half Moon Bay (Table 1) from January through August.

The seabird mortality rate was the lowest recorded (Table 1). Near Half Moon Bay, seven seabirds, all common murres, were observed in croaker nets; all were taken during January and February, before the emergency closure that year took effect. Seabirds observed in set nets in Monterey Bay included 10 common murres, 10 cormorants, 4 loons, and 2 pigeon guillemots. No total seabird mortality estimate was available, but apparently it was the lowest since observations began in 1980.

The observed marine mammal mortality rate was the highest recorded (Table 2). However, because total halibut set net effort was markedly lower in 1987, total marine mammal mortality also probably was lower. Nevertheless, marine mammal drownings in set nets continued to be of serious concern.

Catches of nontarget fishes of concern were markedly lower in 1987 than those of preceeding years (Table 1).

When closures pursuant to SB 40 (1987) took effect, set net observations north of Waddell Creek were discontinued.

Legislation initiated in 1987 resulted in two bills affecting set net regulations in the focal area. Assembly Bill 3197 (Statutes 1988, Chapter 1031) requires a minimum mesh size of 8.5 inches to take halibut. This bill also limits the total length of halibut nets fished from any vessel in the focal area to 1500 fm (2.7 km). Senate Bill 2782 (Statutes 1988, Chapter 1511) revised regulations in SB 40 (1897) to allow a maximum of four permits to use gill and trammel nets in Tomales Bay and excluded Drakes Estero and Estero de Limantour (both near Point Reyes) to the use of gill nets.

1988

No estimates of set net fishing effort were available for 1988. Halibut landings in Monterey Bay were down about 23% from 1987 (Figure 2). However, experimental trawls contributed 52% of these landings (Haseltine and Thornton 1990). Croaker landings in Monterey Bay were similar to those in 1987.

From Half Moon Bay to Bodega Bay, halibut landings were up slightly from 1987 (Figure 2); experimental gear fisheries beginning in that area (Haseltine and Thornton 1990) largely accounted for the increase in landings. Croaker landings were up substantially near Half Moon Bay as this deeper-water (>40 fm) set net fishery apparently improved in that area.

Set net observations continued in Monterey Bay in 1988 (Table 1). The observed nets were all fished in water ranging in depth from about 15 to 20 fm. The rate of observed seabird mortality was up slightly from 1987, and murres continued to comprise a majority of the catch (Table 1). However, because set net effort was markedly reduced by recent closures to the north, total mortality apparently was much lower than in the mid-1980's.

The observed marine mammal catch rate, although only about half that of 1987, was still much higher than in earlier years (Table 1).

Observed catches of fishes of concern were markedly reduced from those in earlier years (Table 1).

No regulation changes or emergency closures were initiated in 1988, but continuing catches of seabirds and marine mammals in set nets, especially at the depths being fished, were disturbing.

1989

Set net fisheries for halibut and croaker continued in the Monterey Bay area in waters deeper than 15 fm. However, no estimates of set net fishing effort for 1989 were available. Halibut landings in Monterey Bay in 1989 were the highest in more than 20 years (Figure 2); set net landings accounted for 62% of the total. Croaker landings were down from 1988 (Figure 2).

The rate of seabird mortality in observed set nets was more than double those of the previous 2 years and the proportion of murres in the observed catch also increased (Table 1).

Observed marine mammal mortality continued at about the same rate as in 1987 (Table 1), but the high observed catches of porpoise and otters were of serious concern. During February through April, at least 25 porpoise carcasses, some with evidence of set net entanglement, washed ashore on Monterey Bay area beaches. Set net observations from a skiff in 1989 began in late March. Twenty porpoise were observed drowned in 34 set nets during March and April.

The high mortality of porpoise early in the year and continuing observed mortalities of other species prompted several actions during the year. On 15 April, the CDFG director closed nearshore ocean waters in 40 fm or less from Waddell Creek to the northern Fort Ord boundary (Figure 5) to gill and trammel net fishing. On 20 April, the CDFG held a public hearing at Moss Landing to take testimony on effects of the closure and to consider whether modifications were necessary. On 6 June, the area from the northern Fort Ord boundary to Yankee Point was closed to gill and trammel net fishing in 20 fm or less. On 1 September, the area from Fort Ord to Waddell Creek in waters deeper than 20 fm was opened to gill and trammel net fishing, leaving the entire area from Waddell Creek to Yankee Point closed in 20 fm or less.

Much of the mortality of seabirds and marine mammals observed in 1989 occurred after the 40-fm closure was reduced to 20 fm on 1 September. About one-half of the harbor seals (19), elephant seals (7), and sea lions (9), and 42% of the seabirds were taken between 1 September and 4 December in 32% of the set nets observed in 1989. The marine mammal mortality rate was 1.47 per net. Much of the mortality was in nets set between Santa Cruz and Waddell Creek.

By the end of 1989, legislation was being initiated to close the area from Waddell Creek to Yankee Point (and the entire south central coast) in 30 fm or less to gill and trammel net fishing.

DISCUSSION AND EPILOGUE

Set net fisheries in nearshore ocean waters of central California have adversly affected large numbers of nontarget species, especially seabirds and marine mammals. Emergency and permanent nearshore zonal closures during the mid-1980s reduced observed seabird mortality rates (Table 1) and total estimated mortality, although not to desired levels (i.e. approaching zero). Observed marine mammal mortality rates were not reduced by the closures and were highest after halibut set net fishing virtually ceased north of Waddell Creek in 1987. The rate remained high even after set nets were prohibited in less than 20 fm south of Waddell Creek on 1 September 1989. However, total marine mammal mortality fluctuated with set net fishing effort.

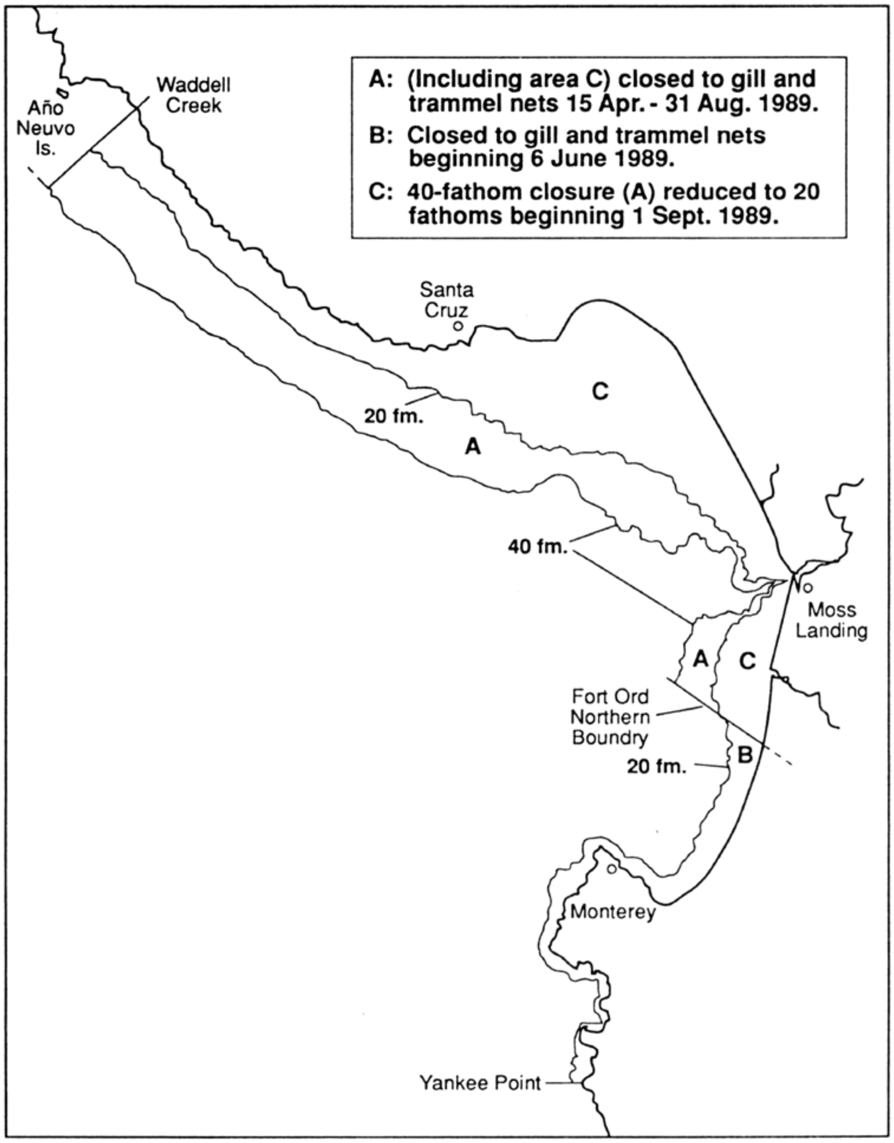

FIGURE 5. Emergency closures to gill and trammel net fishing in the Monterey Bay area in 1989.

FIGURE 5. Emergency closures to gill and trammel net fishing in the Monterey Bay area in 1989

The measures taken were not as effective as desired for several reasons. Diving seabirds that were affected by set nets forage upon anchovies, juvenile rockfishes, and other small fishes. Whether seabirds are attracted to set nets is unknown, but it seems likely that they are entangled while seeking or pursuing forage fishes. Schools of these fishes move considerably. It is not possible to predict their movements, nor to predict when or where seabirds will forage upon them. Localized areas of observed seabird mortality shifted seasonally and annually. Thus, zonal management efforts were thwarted and total estimated seabird mortalities continued at unacceptable levels.

Some marine mammals feed upon fishes entangled in set nets and probably are attracted to easy prey in the nets. Sea otters rarely eat fishes but could be attracted to crabs and other species entangled in the nets. Marine mammals also may encounter nets accidentally and become entangled. Whatever the reasons, rates of marine mammal mortalities in halibut set nets (Table 1) were not reduced by zonal closures. These mortalities continued to be a serious concern.

Continuing mortalities necessitated more stringent permanent closures. The total closure to set nets north of Point Reyes since 1987 and the 40-fm closure north of Waddell Creek since April 1988 have precluded set net fisheries for halibut in these areas. Thus, these measures eliminated this source of nontarget mortalities and virtually eliminated seabird mortalities in croaker nets, although some croaker set net fishing has continued in deeper water. Observed seabird mortality was virtually nil in nets set in water deeper than 40 fm.

In the Monterey Bay area, continuing seabird mortalities and high rates of marine mammal mortalities in nets set deeper than 20 fm in the late 1980's were disturbing. Legislation (SB 2563 1990, Chapter 884]) to restrict set net fishing in waters shallower than 30 fm throughout central California south of Waddell Creek was passed on 13 September 1990. This closure took effect on 1 January 1991. Effectiveness of a 30-fm closure will need to be evaluated.

Experimental nearshore alternative gear fisheries for halibut using modified otter trawls (Haseltine and Thornton 1990) were terminated in April 1990 when the California Fish and Game Commission denied renewal of these permits. The permits were reinstated by the Commission in August 1990 following court action brought by the permittees. Although these trawls are effective for catching halibut, and have reduced or eliminated mortalities of nontarget species of concern, some sportfishing groups and other commercial fishermen are opposed to nearshore trawling. They are concerned that nearshore trawling will leave fewer fish for them to catch. They have questions about effects of nearshore trawling on the the benthic environment. They have concerns about observed high catch and discard rates of elasmobranchs, especially skates and rays, in the trawls. The CDFG is continuing to evaluate management alternatives for halibut in nearshore waters throughout central California.

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ALTERNATIVE GEAR DEVELOPMENT OFF CENTRAL CALIFORNIA

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ABSTRACT

In the early 1980s, concern over seabird and marine mammal mortalities resulted in legislative closures of certain areas to the use of gill and trammel nets in central California nearshore waters. Consequently, an Alternative Gear Development Program (AGDP) was developed to investigate alternative gear types for the take of California halibut, Paralichthys californicus, and white croaker, Genyonemus lineatus. The program was established as a cooperative effort between the California Department of Fish and Game and the Coastal Resources Center. Testing was conducted during the years 1986 through 1988 in four central California areas: Morro Bay, Monterey Bay, San Francisco, and Bodega Bay. Gear tested for the take of halibut were: otter trawl, Scottish seine, pair trawl, beam trawl, traps, bottom longline, and troll gear. Most nets had 7.5-inch mesh throughout. One additional pair trawl was tested for the take of white croaker; mesh sizes varied between 3 and 5 inches.

Otter trawls were the most effective gear for catching legal-size halibut. The bycatch consisted mainly of flatfish and elasmobranchs; most elasmobranchs were returned to the ocean. The catch of sublegal halibut, protected fish species, and crabs generally was minimal. Over 1100 observed otter trawl tows were made during the test period; no seabirds were caught, and the only marine mammal mortalities were 11 California sea lions, Zalophus californianus. No other marine mammals were threatened by the nets.

The halibut pair trawl showed promising results in landing the target species; however, testing was minimal. Experiments with traps and troll gear suggest these gears have potential for landing limited quantities of halibut; further testing is encouraged. Scottish seine, beam trawl, and bottom longline were not found to be feasible alternatives to gill nets.

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The white croaker pair trawl showed increasing potential for landing the target species; however, results were still inconclusive. No seabirds or marine mammals were threatened during the white croaker experiments.

The high efficiency of otter trawls in landing halibut may preclude the use of this gear by most displaced gill and trammel net fishermen. The AGDP is scheduled to continue through 1989 (one additional year) before a permanent fishery is considered.

INTRODUCTION

In the early 1980s closures of certain areas to the use of gill and trammel nets were instituted in nearshore waters of central California (Wild 1990). These closures were legislatively mandated, and were enacted out of concerns over the incidental take of seabirds and marine mammals.

It was recognized these closures possibly would result in economic impacts on the fishing industry, especially gill and trammel net fishermen targeting California halibut, Paralichthys californicus, and white croaker, Genyonemus lineatus. Consequently, the Alternative Gear Development Program (AGDP) was established in 1985 with the passage of Senate Bill 89 (Chap. 50, Stats. 1985) which directed the California Department of Fish and Game (CDFG) to explore alternative fishing gear and methods to take California halibut in central California nearshore areas where gill and trammel nets were prohibited pursuant to that legislation.

In response to SB 89, the California Fish and Game Commission (CFGC) approved in 1985 the issuance of permits to test small, modified otter trawl nets for harvesting halibut. Senate Bill 89 was followed by two additional legislative acts, Assembly Bill 2915 (Chap. 910, Stats. 1986) and SB 40 (Chap. 1298, Stats. 1987), which further encouraged the development of alternative fishing gear for halibut and white croaker. Assembly Bill 2915 established a program to examine alternative fishing gear in the area from Point Conception (Santa Barbara County) to Monterey Bay. This bill also provided funding for low-interest loans to fishermen to purchase alternative gear and to help support at-sea monitoring of the gear.

Senate Bill 40 authorized the CDFG to issue up to seven experimental alternative gear permits which would operate in nearshore areas from Waddell Creek (Santa Cruz County) to the Sonoma-Mendocino County line. This bill also created a 12-member Nearshore Research Advisory Committee to advise the CDFG regarding issuance and monitoring of the permits.

A significant portion of the AGDP consisted of a cooperative effort between the CDFG and the Coastal Resources Center (CRC), a statewide, nonprofit organization established in 1985 to work for the protection of fisheries and fishery habitats. The CRC (originally the Coastal Fisheries Foundation) specializes in developing solutions to coastal problems identified by those interested in coastal resource protection. A more detailed description of the CRC's 1987 alternative gear activities is presented by Thornton (1988).

Criteria for evaluating alternative gear involved assessing effects on: i) protected species (seabirds and marine mammals), ii) targeted and nontargeted species, iii) prohibited fish species (sturgeon, Acipenser spp.; striped bass, Morone saxatilis; and salmon, Oncorhynchus spp.), and iv) other gear and user groups. Also, practicality of use and economic feasibility were taken into consideration in evaluating alternatives.

The information presented in this report covers testing that occurred during 1986, 1987, and 1988. Fishing techniques and onboard monitoring improved each year; consequently the 1988 data are the most complete and the most meaningfully compared (by gear type and by area). The 1988 data are, therefore, emphasized in this report. Data in this report are preliminary; the AGDP currently is scheduled to continue to the end of 1989 after which a comprehensive final report with recommendations as to the continued use of the tested gear will be prepared.

METHODS AND MATERIALS

The AGDP has evaluated gear in four central California areas: Morro Bay (Point Conception, Santa Barbara County to Point Sur, Monterey County), Monterey Bay (Fort Ord, Monterey County to Santa Cruz, Santa Cruz County), San Francisco (Pigeon Point, San Mateo County to Point Reyes, Marin County), and Bodega Bay (Point Reyes to Fort Ross, Sonoma County). Data from the San Francisco and Bodega Bay areas are combined in this report. Seven of the evaluated gear types targeted halibut. The CDFG was responsible for evaluating ten otter trawls, one Scottish seine, and one series of troll gear trials. The CRC assumed responsibility for evaluating one Scottish seine, one pair trawl, one beam trawl, one small otter trawl (working from a bowpicker), traps, bottom longline, and an additional series of troll gear trials. Also, one small-mesh "pair trawl" (actually a towed seine) was used for white croaker; this gear was tested and evaluated by the Vietnamese Fishermen's Association of America (VFAA). All fishing activity occurred within 3 miles from shore, in areas where trawl nets have been prohibited in the past. All participants using trawl or seine nets were issued experimental gear permits authorized by the CFGC. Testing of gear types other than nets (e.g. traps, bottom longline, and troll gear) did not require permits.

Catch statistics and evaluation of gear are based on reports from onboard observers, trawl logs (from fishermen), and fish receipts submitted to the CDFG. The CDFG monitored, with onboard observers, at least 25% of fishing effort (hours) of experimental trawls and seines. Also, frequent input was received from the fishermen participating in the program, as well as from other segments of the commercial fishing industry (halibut trollers, fish dealers), sportfishing interests (charterboat operators, skiff fishermen, scuba divers), environmental groups, and the general public.

Otter Trawl

Descriptions of otter trawls and how they operate are found in Noel and Bowbeer (1976) and Thornton (1988).

The otter trawls used in the AGDP were constructed with polypropylene twine. Generally, mesh sizes were 7.5 inches in both body and cod end; however, some nets had 8-inch mesh throughout. At the beginning of the program, nets with 4.5-inch mesh were briefly tested on two vessels, one each in Monterey Bay (1986) and the Bodega Bay area (late 1987).

Eleven vessels fished with otter trawls during 1986 through 1988 in the test areas (Table 1). One of these vessels (Table 1; vessel 10) differed from the others in that it was a relatively small (26-ft) bowpicker; i.e. it operated trawl gear over the bow, rather than the more conventional method of setting the trawl off the stern. A description of the bowpicker and how it operates is found in Thornton (1988).

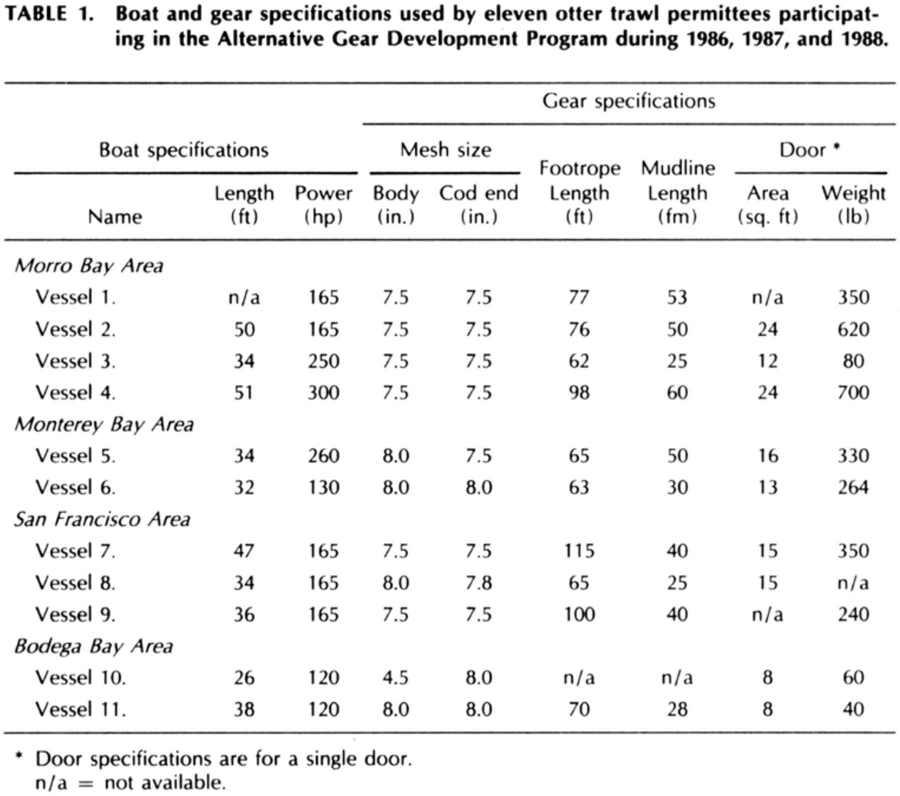

TABLE 1. Boat and gear specifications used by eleven otter trawl permittees participating in the Alternative Gear Development Program during 1986, 1987, and 1988.

Boat specifications			Gear specifications					
			Mesh size				Door *	
Name	Length (ft)	Power (hp)	Body (in.)	Cod end (in.)	Footrope Length (ft)	Mudline Length (fm)	Area (sq. ft)	Weight (lb)
Morro Bay Area								
Vessel 1.	n/a	165	7.5	7.5	77	53	n/a	350
Vessel 2.	50	165	7.5	7.5	76	50	24	620
Vessel 3.	34	250	7.5	7.5	62	25	12	80
Vessel 4.	51	300	7.5	7.5	98	60	24	700
Monterey Bay Area								
Vessel 5.	34	260	8.0	7.5	65	50	16	330
Vessel 6.	32	130	8.0	8.0	63	30	13	264
San Francisco Area								
Vessel 7.	47	165	7.5	7.5	115	40	15	350
Vessel 8.	34	165	8.0	7.8	65	25	15	n/a
Vessel 9.	36	165	7.5	7.5	100	40	n/a	240
Bodega Bay Area								
Vessel 10.	26	120	4.5	8.0	n/a	n/a	8	60
Vessel 11.	38	120	8.0	8.0	70	28	8	40

* Door specifications are for a single door.
n/a = not available.

TABLE 1. ***Boat and gear specifications used by eleven otter trawl permittees participating in the Alternative Gear Development Program during 1986, 1987, and 1988.***

Scottish Seine

Scottish seining ("flydragging") is the fishing technique used by two of the San Francisco-area permittees participating in the AGDP. Descriptions of this gear and how it operates are found in Noel and Bowbeer (1976) and Thornton (1988).

Vessels used by the permittees were 36 ft long (165 hp, diesel) and 45 ft long (225 hp, diesel). Both vessels operated out of San Francisco. Net configurations were changed frequently throughout the testing period to determine optimal use of the gear. Commonly-used gear measurements included 0.75-inch diameter warps that were six coils long on each side (12 coils = 8640 ft). Standard headrope length was 100 ft. Mesh size was 4.5 inches throughout body and cod end.

Pair Trawl (Halibut)

A description of the halibut pair trawling operation used in the AGDP is found in Thornton (1988).

The permittee testing this gear operated out of Bodega Bay Harbor. Fishing was conducted during two testing periods. Each set of tests used a different pair of boats and different net configurations. Initial tests were conducted during 1987. The lead vessel was 40 ft long (120 hp, diesel), and the second vessel was a 38-ft "double ender" (105 hp, diesel). The initial net was a "320 Vinge Scissor type net" consisting of a 15-fm mudline, 150-ft headrope, 7.5-inch mesh in the cod end, and 4.5- inch mesh in the wings and body. The second set of tests was conducted during 1988. The lead vessel was 38 ft long (165 hp), and the second vessel was 48 ft long (250 hp). The second net was similar to the first, except it had 8-inch mesh in wings and body. Operation of the boats and gear required four people, two on each boat.

Beam Trawl

A description of the beam trawling operation used in the AGDP is found in Thornton (1988). The permittee using this gear operated out of San Francisco. The vessel was 36 ft long (190 hp, diesel), and the net was a "standard Icelandic style trawl net" similar in size to the otter trawl nets used in the AGDP. Two 30-ft beams were tested. The first was constructed of "schedule 40" aluminum; the second used heavier "schedule 80" aluminum. The permittee operated the gear alone (i.e. no crew).

Traps

One fisherman designed and tested three styles of traps for the capture of halibut. The first style was tested during 1987 (two traps tested). This was an oversized version of the rectangular Maine lobster trap, and had a wooden structure with cotton webbing. A description of this design is found in Thornton (1988).

The second style, tested in 1988, was also rectangular (two traps tested). These traps had a metal rebar structure, with side panels of woven stainless steel, crab-pot wire (5-inch mesh). The traps measured 72 inches long, 48 inches wide, and 20 inches high (Figure 1). Wire-mesh ramps led to the two 44-inch entrances. Triggers were installed to prevent the escape of fish.

The third style was also tested in 1988. This was conical, and similar to a sablefish trap (five traps tested). These traps were also of metal rebar structure, and were strung with synthetic webbing (3- to 4-inch mesh). The bottom (48-inch diameter) and top (36-inch diameter) were circular and had draw-string webbing. The trap was 48 inches high. The single entrance was located just off the bottom; its opening was 24 inches wide by 6 inches high, with triggers (Figure 2).

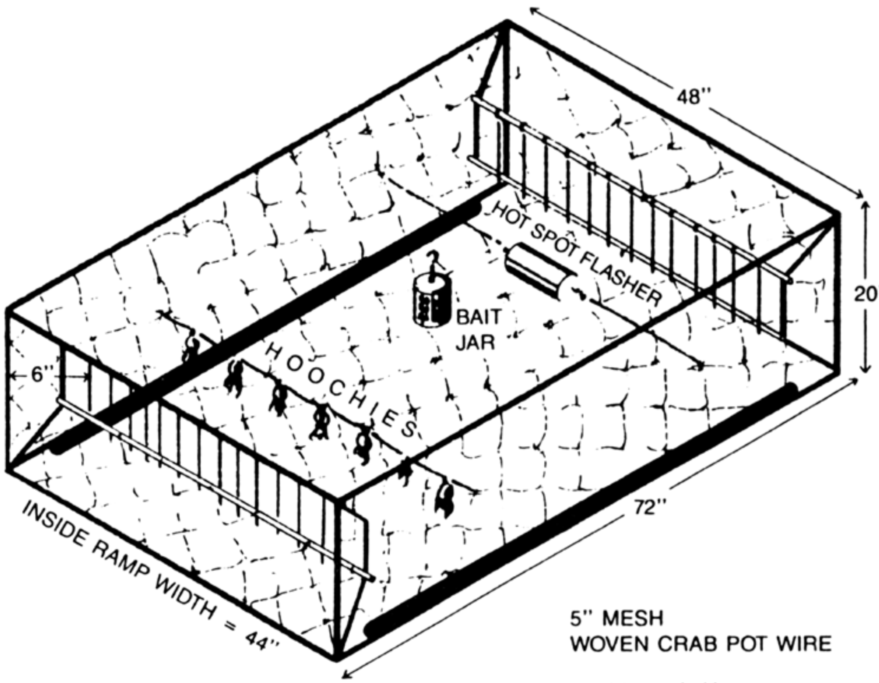

FIGURE 1. Rectangular trap tested in 1988 for the capture of California halibut.

FIGURE 1. Rectangular trap tested in 1988 for the capture of California halibut

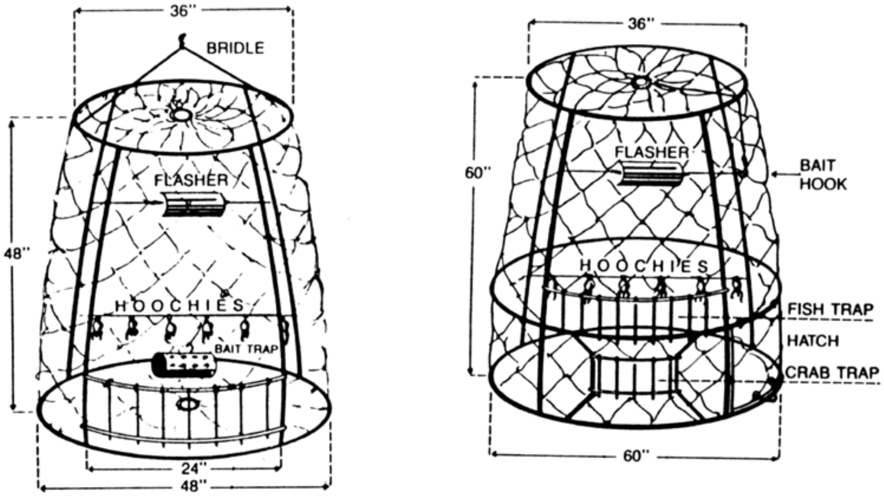

FIGURE 2. Conical trap tested in 1988 for the capture of California halibut.

FIGURE 2. Conical trap tested in 1988 for the capture of California halibut

All three trap designs included standard escape openings for crabs. The traps were utilized in a "longline trap system"; i.e. several traps were spaced at regular intervals, and attached to a groundline. The groundline was anchored at both ends, thereby allowing the trap string to be checked without changing the location of the string. Various combinations of fish attractors were used; these consisted of ground bait (squid, herring, or anchovies), and mechanical lures (flashers and sonic hoochies). The vessel used for the trap experimentation was a 24-ft former gill net boat. All field data for the trap operations were supplied by the fisherman; i.e. there were no onboard observers.

Pair Trawl (White Croaker)

A permit was issued to the VFAA for testing a small-mesh pair trawl for the take of white croaker. Seven former gill net boats were used during the 3-year test period (1986–88); however, only two boats worked as a pair at any given time. The Berkeley Marina was their home port. Throughout the test period gear was continually modified in an effort to increase the white croaker catch, and reduce the incidental catch. Gear specifications were: headrope = 59 ft, footrope = 60 ft, each mudline = 14 fm manila line with 71-ft chain extensions (for weight). Mesh sizes were changed slightly each year; however, they generally measured 4.5 inches in the body and 3 inches in the cod end. Onboard observers accompanied most of the trips and were employed by either the National Marine Fisheries Service or the CDFG.

Bottom Longline

Limited testing with a bottom longline was conducted by one fisherman. This gear involved an anchored horizontal ground line, to which was attached short "gangions" (leaders) carrying baited hooks. The fisherman experimented with various materials and gear configurations, and settled on the following: Circle hooks were tied to 2-ft lengths of 80-lb test monofiliment leaders, which were attached every 6–12 ft with snap-on gear to a groundline made of 3000–4000 ft of #-inch braided nylon. The preferred bait was squid (3–4 inches long). Soak times varied from 1 to 24 h.

Troll Gear

Halibut trolling consists of dragging a weighted, baited hook or lure through the water close to the bottom. Sometimes several hooks (up to 12) are fished simultaneously at different depths. Two series of tests were conducted during the alternative gear program, both in the Morro Bay area. The first series was conducted by the CDFG. Gear was sportfishing rods and downriggers, and bait was anchovies, squid, or salmon hoochie lures. The second series was conducted by a commercial fisherman working closely with the CRC. This later series used commercial gear that included outrigger poles, lead or cast iron sinkers, and gurdies to haul in the line. Spoons and hoochies were used as bait.

RESULTS

Otter Trawl

Morro Bay Area

Six permits were initially issued for the use of otter trawls; however, only four permittees were active in the program. Fishing began in May 1986. During 1986 through 1988, fishing was conducted principally in Estero Bay, and off Avila and Pismo Beach. Most halibut were taken at depths of 12–20 fm, and tow times averaged 45–60 min. Fishing occurred during all months of the year; however, halibut landings were highest during June through September. Halibut was the most abundant species caught by number and weight.

In 1988, approximately 117,000 lb of halibut were landed in the Morro Bay area. Observers were aboard during about 27% of the hours fished. This represented landings mainly by three permittees using otter trawls (Table 1; vessels 2, 3, and 4); their catch of legal-size halibut averaged about 80 lb/h of fishing. The incidental catch of sublegal halibut (less than 22 inches) averaged about 13% by numbers. Most sublegal halibut taken during the observed trips were tagged and returned to the water. Other than halibut, big skate, Raja binoculata, and starry flounder, Platichthys stellatus, were the most common species caught. The remaining incidental catch consisted of other elasmobranchs and flatfish, as well as a few surfperch, Embiotocidae; greenlings, Hexagrammos spp.; crabs; seastars; and jellyfish.

During 1986 through 1988 the Morro Bay permittees conducted 2124 tows with otter trawls. During the observed trips (573 tows) three California sea lions, Zalophus californianus, were drowned in the nets; however, there were no other marine mammal or seabird mortalities. No prohibited fish species were observed taken. Occasionally animal carcasses were brought up in the nets. These included one cormorant, Phalacrocorax sp.; four California sea lions; one harbor seal, Phoca vitulina; one northern elephant seal, Mirounga angustirostris; and one gray whale, Eschrichtius robustus.

Monterey Bay

Two permits were issued for the use of otter trawls. One permittee had been active since early 1986; the other began fishing in early 1987. During 1986 through 1988, fishing was conducted principally in the central and northern portions of Monterey Bay (Fort Ord to Santa Cruz). Most halibut were taken at depths of 5–10 fm; and tow times generally ranged between 60 and 90 min. Fishing occurred from January through December; however, halibut landings were highest during May through August.

In 1988, approximately 34,000 lb of halibut were landed in Monterey Bay by the two permittees. Observers were aboard during about 25% of the hours fished. The catch of legal-size halibut averaged about 37 lb/h of fishing. The incidental catch of sublegal halibut averaged about 6% by numbers; most sublegal halibut caught during observed trips were tagged and returned to the water. Starry flounder was the most numerous species caught; however, halibut was the predominant marketed species by weight. Big skates and California skates, Raja inornata, were also caught in large quantities and returned alive. Other elasmobranchs and flatfish constituted the remaining incidental catch. A few rockfish, Sebastes spp.; sculpins, Cottidae; greenlings; surfperch; northern anchovies, Engraulis mordax; seastars; crabs; and jellyfish frequently were seen in the nets.

During 1986 through 1988 the Monterey Bay permittees conducted 1974 tows with otter trawl nets. Prohibited fish species caught during the observed trips (494 tows) were two white sturgeon, A. transmontanus, and one king salmon, O. tshawytscha. Eight California sea lions were drowned in the nets; however, there were no other marine mammal or seabird mortalities. Two California sea lions were captured and released alive. Animals that apparently were dead prior to being caught included one sea lion and one porpoise (species unidentified).

Mesh size of 7.5 inches throughout the entire net proved satisfactory in selecting for legal-size halibut while allowing for escapement of most sublegal halibut. The initial experimentation (1986) with 4.5-inch mesh body (Table 1; vessel 5) proved unsatisfactory due to large numbers of sublegal halibut caught and to excessive drag on the vessel. The catch of sublegal halibut by the 4.5-inch mesh body was about 55% by numbers of the total halibut catch. The body mesh size was changed to 7.5-inches during 1987 and 1988; the sublegal halibut catch dropped to 4% and 6% respectively.

San Francisco-Bodega Bay Areas

Three permits were issued for the use of otter trawls in the San Francisco area and two in the Bodega Bay area. Initial activity was conducted by one permittee during August and September 1987 in the Bodega Bay area (Table 1; vessel 10). This activity involved mainly gear testing. Effort increased during 1988 when four additional permittees fished during June through November. Fishing ranged from Pigeon Point (San Mateo County) to Fort Ross (Sonoma County), with most effort occurring off the Golden Gate region. Most halibut were taken at 4–5 fm and tow times averaged about 90 min.

In 1988, approximately 25,000 lb of halibut were landed in the San Francisco and Bodega Bay areas by the permittees. Observers were aboard during about 28% of the hours fished (both areas combined). The catch of legal-size halibut averaged about 70 lb/h of fishing (both areas combined). Most halibut were caught during July through September, and most halibut landings were by one permittee (Table 1; vessel 7). Halibut was the most predominant species by weight landed. The incidental catch of sublegal halibut averaged about 4% by numbers. Most sublegal halibut taken during observed trips were returned to the water; none were tagged. Northern anchovy was the most numerous species caught. These also were returned to the water. The remaining incidental catch was mainly bat ray, Myliobatis californica, starry flounder, and other elasmobranchs and flatfish; the starry flounder were marketed. Dungeness crabs, Cancer magister, were also common in the nets. About 850 were taken during 68 observed otter trawl tows in 1988. The take of Dungeness crabs was highest in the Bodega Bay area. One permittee took an average of 26 crabs per observed tow during October 1988. All Dungeness crabs were returned to the water; however, many were damaged, with missing legs and crushed carapaces.

During 1987 and 1988 the San Francisco and Bodega Bay permittees conducted 248 tows with otter trawl nets. Prohibited fish species caught during the observed trips (68 tows) were 2 salmon; 14 striped bass; and 47 green sturgeon, A. medirostris. These fish all were returned to the water alive. No seabirds or marine mammals were taken during the observed trips, nor were any reported caught by the permittees on unobserved trips.

Initial experimentation (25 tows) by the bowpicker (Table 1; vessel 10) with the 4.5-inch mesh body proved unsatisfactory. After two months of trials (August and September 1987), fishing was discontinued when it was determined that excessive drag on the small vessel resulted in poor catch performance.

Scottish Seine

This gear was initially tested during September 1987; the five trips were mainly for gear testing. The same 36-ft vessel returned to the program in June 1988 and used the gear until mid-July 1988 (11 fishing days). A second permittee, using a 45-ft vessel, fished from July through October 1988 (34 fishing days). Fishing locations ranged from Pacifica (San Mateo County), to Drakes Bay (Marin County). Fishing depths were from 4 to 25 fm. The most successful fishing occurred from mid-August through September. Set durations averaged about 70 min.

During 1988, the combined marketed catch of halibut for the two permittees was approximately 8000 lb (observed and unobserved trips totaling 164 sets), with an average of about 46 lb/h of fishing. Most halibut were landed by the larger vessel. The incidental catch of sublegal halibut was exceedingly high, averaging about 71% of the total observed halibut catch. Most sublegal halibut taken during observed trips (about 20% observer coverage) were tagged and released. Other marketed species included starry flounder (about 1800 lb) and other flatfish. The incidental catch consisted mainly of northern anchovy, big skate, bat ray, and brown smoothhound, Mustelus henlei. Prohibited fish species taken during observed trips (24 sets) were 11 green sturgeon; 1 silver salmon, O. kisutch; and 1 king salmon. All the incidental species were returned alive. of sixty-seven crabs taken during the observed trips, 44 were identified as Dungeness crabs; all were returned (condition unrecorded). No seabirds or marine mammals were taken during the observed trips, nor were any reported caught by the permittees on unobserved trips.

Although Scottish seine catches were considered relatively successful, both permittees expressed concern over the amount of effort required to land sufficient quantities of fish to make the gear a feasible alternative to gill nets or otter trawls. By the end of October 1988 both permittees ceased operations with the seines and were issued permits authorizing them to test otter trawls in the San Francisco area.

Pair Trawl (Halibut)

The halibut pair trawl permittee fished during October 1987 (four fishing days), and August and September 1988 (12 fishing days). Fishing occurred in two relatively small areas, just north of Point Reyes and just north of Bodega Head. Tow depths ranged from 5 to 35 fm; however, most halibut were taken in the shallower depths. Mean tow duration was 130 min at an average fishing speed of 2–3 knots. Most effort during the initial testing period (ten tows in 1987) was spent becoming familiar with the gear and learning to work the boats in unison. Initial results were only moderately successful with catches of 145 lb of halibut and 1845 lb of starry flounder.

Fishing success improved in 1988 when the permittee switched to larger boats and a net of lighter construction (larger mesh). During 1988, 3792 lb of halibut were landed during 26 observed and unobserved tows with an average catch rate of 66 lb/h. During observed trips (about 47% observer coverage), the catch of sublegal halibut was approximately 44% of the total halibut catch. The numbers of skates (species unidentified) and starry flounder were high, totaling 2166 and 1068 fish respectively for the 14 observed tows; the starry flounder were marketed. The remaining incidental catch on the observed trips was mostly flatfish and Dungeness crabs (320 individuals on 23 observed tows). The physical condition of all fish caught was considered excellent, and the sublegal halibut, elasmobranchs, crabs, and the remaining unmarketed catch were released alive.

No prohibited fish species, seabirds, or marine mammals (live or dead) were taken during the observed trips, nor were any reported caught during unobserved trips. However, sea lions were frequently in the area and occasionally fed on the catch during net retrieval.

Beam Trawl

This gear operated during September and October 1987 (nine fishing days), and July and August 1988 (16 fishing days). Fishing activity was conducted just outside the Golden Gate in 4- 24 fm. Tow durations averaged about 85 min with a speed of 3–5 knots.

A major portion of the fishing effort was involved with gear familiarization and dealing with minor gear problems. During 1987, 25 halibut were landed during seven unobserved tows; halibut weights were unrecorded. The 1987 activity was cut short when the 30-ft "schedule 40" aluminum beam broke. The permittee felt the beam was structurally weaker than was required for the size of net used.

During 1988, the permittee found the stronger "schedule 80" aluminum beam to be satisfactory. However, landings of halibut were still poor, totaling only 307 lb (8 lb/h). No sublegal halibut were caught, and starry flounder was the only other fish marketed. The incidental catch during the three observed trips (six tows) included 33 big skates, 11 starry flounder, 2 bat rays, and 8 Dungeness crabs. The observed catch of prohibited fish species consisted of four striped bass. All incidental species were returned alive. No seabirds or marine mammals were taken during the observed trips (about 23% observer coverage), nor were any reported caught during unobserved trips.

The permittee felt the gear required a long learning period, could not match the effectiveness of gill nets or otter trawls, and was unsafe for a single fisherman who is relatively inexperienced at using this particular gear type. No further testing of the beam trawl was anticipated beyond August 1988.

Traps

Traps were tested in the Bodega Bay area, mostly near the harbor entrance where fishing depths ranged from 6 to 33 fm. Days spent checking and baiting traps were referred to as "pull days". Days spent moving or setting the gear were referred to as "set days". Most pull days were after approximately 24-h soak periods; however, soak periods occasionally lasted up to 96 h, depending on weather.

The first trap style (wooden, rectangular traps) were tested during November and December 1987 (seven set days). Nine pull days yielded three halibut (two were legal size). The incidental catch included 26 crabs (species unidentified), 3 rockfish, and 1 starry flounder.

The second trap style (metal, rectangular traps), and the third style (conical traps) were tested from October to December 1988 (total 36 test days). Data from these two trap styles tested during 1988 were combined. Thirty pull days (153 trap checks) yielded 34 legal and two sublegal halibut. In general, halibut were in good condition after 1- or 2-day soaks; however, if the traps were left for 3 days or longer, mortalities began to occur. Four legal-size halibut were lost to crabs and "sand fleas". The average weight of halibut caught in the traps was 5.1 lb. The incidental catch included 4 starry flounder; 6 small lingcod, Ophiodon elongatus; 32 Dungeness crabs; and 30 rock crabs.

The fisherman preferred the conical trap design over the two rectangular designs because it stacked easier, cost less, was more durable, and trapped more halibut.

No seabirds or marine mammals were taken by any of the traps. There was an abundance of common murres, Uria aalge, in the fishing area during the month of October 1988, but none were caught in the traps.

Pair Trawl (White Croaker)

Twenty seven trips (58 tows) were conducted during the 3-year period. Tests were conducted at irregular intervals from April through December. Fishing locations ranged from Half Moon Bay to Point Reyes, and fishing depths were from 7 to 35 fm. Tow times generally ranged between 55 and 95 min; tow speeds were usually between 1.5 and 4.0 knots. Onboard observers were present during 68% of the total hours fished.

The catch of white croaker increased progressively each year. In 1986, 250 lb were landed in nine fishing days; in 1987, 780 lb were landed in four fishing days; and, in 1988, 7881 lb were landed in 14 fishing days. The most successful fishing occurred during August 1988 off San Francisco and Pacifica where depths ranged from 12 to 15 fm. Other marketed fish included elasmobranchs (skates and rays), halibut (160 lb), and other flatfish. Common invertebrates included Dungeness crabs, rock crabs, and seastars; all invertebrates were returned to the ocean. No seabirds or marine mammals were taken during the observed trips, nor were any reported caught on unobserved trips.

Gear configurations and fishing techniques were continually modified over the 3-year test period. Catches of smaller fish were reduced by increasing the mesh size to 3 inches. The footrope was lifted off the bottom by adding floats, removing chains, and increasing speeds to 4 knots; these modifications appeared to reduce the catches of bottom species (e.g. Dungeness crabs).

Bottom Longline

This gear was tested for 22 days during October 1987. Fishing locations were off Morro Bay in waters less than 20 fm. Catch results for halibut were very poor with a total yield of two legal-size and two sublegal fish. The gear showed greater potential for catches of rockfish (209 lb of combined species) and pelagic species (640 lb of combined Pacific bonito, Sarda chiliensis, and Pacific mackerel, Scomber japonicus) than flatfish. Because of seastar predation, shorter soak times (less than 3 h) were preferred to the longer times. Two unidentified seabirds were caught during the tests: one while setting gear, and one after the gear was set. Both birds were released alive and unhurt. No marine mammals were encountered.

Troll Gear

The initial series of tests (CDFG), using sport gear, was conducted during April through October 1986 in Estero Bay. Depths ranged from 2 to 13 fm. A total of 68 hours of trolling effort yielded 21 legal-size halibut (0.3 fish/ fishing hour) and 64 sublegal halibut (75% by numbers of the total halibut catch). Anchovy was the most successful bait (0.11 legal-size halibut/hook/fishing hour), and squid was the least successful (no legal-size halibut caught).

The second series of tests (CRC), using commercial gear, was conducted during seven days from September to early December 1988. Fishing ranged from Estero Bay to Point Buchon, and depths ranged from 5 to 30 fm. Catch results for halibut were very poor with a yield of two legal-size and seven sublegal fish. Murres; gulls, Larus spp.; unidentified birds; sea lions; sea otters; and a harbor porpoise, Phocoena phocoena, were observed in the fishing areas. However, there was no incidental catch of seabirds or marine mammals during either series of tests.

DISCUSSION

Otter Trawl

Catch rates for halibut appear correlated with boat and gear size. The most successful halibut landings were in the Morro Bay area, which had the largest boats and gear (Table 1). During 1988, three permittees in the Morro Bay area landed about 117,000 lb (80 lb/h of fishing effort). The next largest boats and gear were in the San Francisco and Bodega Bay areas. During 1988, about 25,000 lb were landed primarily by one permittee in the San Francisco area (70 lb/h). By comparison, during 1988 the two permittees operating smaller boats in Monterey Bay landed about 34,000 lb (36 lb/h). To standardize fishing effort in the Morro Bay, Monterey Bay, and Bodega Bay areas, the CDFG required these otter trawl permittees to use "scaled-down" gear beginning in January 1989. The new requirements specify footropes not exceeding 65 ft in length, mudlines not exceeding 40 fm in length, and doors not exceeding 14 ft^2 each. With these new regulations, fishing may not be economically feasible for larger boats (Table 1; vessels 2 and 4). The San Francisco area permittees were allowed to have larger footropes; these were not to exceed 100 ft.

During 1988, halibut landings of the three otter trawl permittees in the Morro Bay area approximated the historic annual landings of 12–24 gill and trammel net (set net) fishermen during the preceding 10 years (about 100,000–150,000 lb/year). Also, legislative closures that moved set net fishing to waters deeper than 15 fm do not appear to have affected halibut landings in the Morro Bay area. For these reasons, the CFGC acting on the recommendations of the CDFG, discontinued testing nearshore otter trawls in the Morro Bay area after 15 May 1989. The AGDP otter trawl data from the other areas (Monterey Bay, San

Francisco, and Bodega Bay) will be further analyzed before being compared with set net halibut landings.

A mesh size of 7.5 inches throughout body and cod end was effective in providing for escapement of most sublegal halibut. The incidental catch of sublegal halibut was minimal in the Monterey Bay, San Francisco, and Bodega Bay areas. However, the catch of sublegal halibut was higher in the Morro Bay area. Reasons for these differences may be related to abundance of sublegal halibut. Generally, the sublegal halibut tagged during observed trips appeared to be in healthy condition upon their return to the water. The net with the smaller mesh size of 4.5 inches in the body, used early in the program by two boats, captured a greater portion of sublegal halibut. Also, the 4.5- inch mesh appeared to result in increased strain (drag) on the relatively small vessels (26 ft and 34 ft) using this mesh.

The incidental catch in all four areas consisted of typical sand-bottom species, principally flatfish and elasmobranchs. Many of the flatfish were marketed; most elasmobranchs were returned to the ocean. Concern over the condition of returned elasmobranchs has prompted the CDFG to initiate a tagging program for elasmobranchs, which is scheduled to commence January 1989. Low numbers of rockfish in the otter trawl catches indicate the 7.5-inch mesh is sufficiently large to provide adequate escapement for these species.

Prohibited fish species (salmon, striped bass, and sturgeon) were taken in the Monterey Bay, San Francisco, and Bodega Bay areas. Numbers taken were relatively low; and, those taken during observed trips were returned to the ocean in apparently healthy condition.

Dungeness crabs were taken in otter trawl nets in all four areas. Quantities were minimal in the Morro Bay and Monterey Bay areas, higher in the San Francisco area, and abundant in the Bodega Bay area. Dungeness crabs were always returned to the ocean; however, many were obviously damaged. The catch of Dungeness crabs will continue to be monitored during the remainder of the AGDP. The affect of otter trawls on benthic crabs (i.e. those not captured in the nets) has not been examined.

Direct observations indicate that otter trawls have negligible impact on seabirds or marine mammals. Although California sea lions were frequently in the vicinity of trawl nets being fished, only eleven sea lions were drowned as a result of over 1100 observed pulls during the 3-year period. Occasionally marine mammal carcasses were taken; however, these could not be attributed to alternative gear activity. Likewise, seabirds were also frequently observed near the nets. However, no birds were drowned in the nets during the observed trips, and none were reported caught on unobserved trips.

During the study period there were occasional conflicts (some real, some perceived) with other gear types and user groups. Conflicts were mainly with commercial halibut trollers, skiff and partyboat halibut sportfishermen, and scuba divers (spearfishermen). These competing user groups feel that halibut landings of the relatively few nearshore trawlers are at the expense of fishermen using less-efficient gear. They also feel that long-term halibut landings, as well as the short-term halibut "bite", are negatively affected by disruptions of shallow benthic communities, mainly during the summer months. To help alleviate some of these problems, permit conditions were modified several times during the AGDP by establishing "buffer areas" to separate the various user groups.

Scottish Seine

Although this gear was relatively successful in catching marketable halibut (46 lb/h), it is not considered a feasible alternative to gill nets for five reasons: i) It demonstrated a high incidental catch of sublegal halibut (71% by numbers), other flatfish, elasmobranchs, and prohibited fish species, although this problem may be reduced by increasing the mesh size. ii) The gear uses a large amount of warp, thus necessitating a large fishing area and precluding other fishing activities. iii) The gear is primarily designed for offshore use, and consequently is significantly affected by wind, currents, and tides in the nearshore areas. iv) The gear is costly and requires a long learning period, thus necessitating significant start-up and operating capital. v) The gear requires a boat larger than 40 ft, a length that precludes many smaller nearshore vessels. The high incidental catch of sublegal halibut may be a result of the 4.5-inch mesh. The small mesh was authorized by the CFGC for experimental testing because it conformed with federal groundfish regulations.

Pair Trawl (Halibut)

Several problems were evident during the relatively few tests conducted with this gear: i) The pair trawl demonstrated high incidental catches of sublegal halibut, skates, and Dungeness crabs. ii) Numerous vessel and equipment problems were encountered, resulting in overall lower-than-expected success. iii) The gear requires a long learning period. iv) There are difficulties in finding cooperative crews. v) Profits need to be split between two vessels and two crews. In spite of these problems, the pair trawl showed considerable potential for catching marketable halibut (66 lb/h) and starry flounder, and the gear was not a threat to seabirds or marine mammals during the test months (August through October). The permittee felt that with additional gear modifications and testing, the pair trawl may at least prove comparable to otter trawls in its ability to land halibut.

Beam Trawl

Landings of halibut were poor during the test months (July through October). The learning period for the beam trawl appears excessive, and the potential for gear problems and unsafe operating conditions are relatively greater than with other gear. Even though there was no threat to seabirds or marine mammals, the beam trawl could not match the effectiveness of otter trawls and is not a suitable alternative to gill nets.

Traps

The conical trap design was moderately successful in catching halibut. Total 1988 landings were low (34 legal halibut); however, the conical traps fished more successfully than the rectangular traps during the 3-month period (36 test days). Combined landings for 1988 averaged 4.8 halibut per trap. The incidental catch of sublegal halibut (about 6% by numbers) and other non-target species was low, and the physical condition of halibut was generally good. Also, none of the trap designs were a threat to seabirds or marine mammals. The fisherman suggests a minimum of 50 traps would be required for a successful, small-boat trap fishing operation, and he feels it would be reasonable for a single operator to handle that quantity. However, the vessel used for these tests was small (24 ft). The fisherman felt a larger vessel with greater speed and more working space would be preferable. He was concerned about the relatively low average weight of trapped, legal-size, halibut (5.1 lb per fish); the San Francisco area market prefers halibut over 10 lb. However, he felt that trapping during summer months when larger fish are concentrated nearshore, and additional modifications of trap design, may result in landing larger or more fish. Beyond the initial start-up expense of purchasing gear, the overhead of a trap operation is relatively low. Although trap landings of halibut cannot match the volume taken by nets, the fisherman feels they show sufficient potential for continued experimentation.

Pair Trawl (White Croaker)

Landings of white croaker improved through the 3-year test period. However, the permittee feels continued testing is needed to determine if favorable white croaker catches can be sustained, and if incidental catches, mainly Dungeness crabs, can be minimized. Further trials with additional gear modifications are planned through 1989.

Bottom Longline

Poor catch results during the bottom longline tests suggest this gear cannot be considered a feasible alternative to gill nets. Although the groundline used for these tests was #-inch braided nylon, the fisherman felt that ¼-inch Samson braid, #-inch lead line, or lighter stainless cable would also be satisfactory. However, such gear modifications would not be expected to improve catch results appreciably. More detailed test results and evaluation are found in Thornton (1988).

Troll Gear

A combination of limited effort and lack of experience contributed to poor results in both series of trolling tests. Different fishing seasons possibly accounted for success differentials between the two series. The first series was more successful. These tests (CDFG) were conducted during April through October, months that usually are more productive for halibut. The second series (CRC) was conducted from October to early December, months that are generally less productive. The CRC has scheduled further testing of troll gear during spring and summer 1989.

A viable "wire line" fishery exists for halibut off central California; however, catch and effort data are limited. Commercial salmon trollers and halibut gill netters are known to expend effort trolling for halibut with standard salmon trolling gear (flashers with hoochies). These fishermen have reported (undocumented) catches of one to four legal-size halibut per fishing hour. Such reports kindle optimism that trolling may occasionally be an economically efficient method for catching halibut. However, it is likely trolling will prove feasible only during favorable weather from late spring through early fall when halibut concentrate in nearshore waters.

CONCLUSION

All tested gear types satisfy one of the primary objectives of the AGDP; i.e. they do not appear to seriously threaten seabirds or marine mammal populations. However, results to date indicate only otter trawls catch halibut economically at rates approaching and exceeding gill and trammel nets. Prior to the AGDP annual landings from most gill net vessels were between 1000 and 10,000 lb of halibut per vessel; a few vessels occasionally landed 15,000–20,000 lb/year. The AGDP demonstrated that otter trawl vessels each have the potential to land 30,000–35,000 lb/year. Given this high efficiency of otter trawls in capturing halibut, it is unlikely they will be a reasonable alternative for the majority of displaced gill net fishermen.

Three other gear types, troll gear, pair trawls, and traps, are not as efficient as otter trawls at landing halibut. However, experimentation with these gears was limited and they may yet have potential as alternatives for at least for some displaced halibut fishermen.

The take of white croaker with a small-mesh pair trawl appears encouraging; however, catches are still inconsistent. Further experimentation is recommended if the permittee feels the gear has potential.

Alternative gear experimentation with both fisheries (halibut and white croaker) is scheduled to continue through 1989. Recommendations concerning the continuation of the AGDP, or the establishment of permanent fisheries, will be made at that time.

ACKNOWLEDGMENTS

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AN ANALYSIS OF THE CALIFORNIA HALIBUT, PARALICHTHYS CALIFORNICUS, RECREATIONAL FISHERY, 1980–1987

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ABSTRACT

We describe the results of analyses which examined the landings of California halibut, Paralichthys californicus, in the shore, private boat, and commercial passenger fishing vessel (CPFV) sectors of the California recreational fishery from 1980 through 1987. Data from the Marine Recreational Fishery Statistics Survey were used to ascertain the impact of each sector on the fishery and to generate total mortality estimates. Private boat fishermen exerted close to 75% of all effort on the fishery with an average of 72,000 fish landed annually. Shore and CPFV fishermen accounted for 11 and 14% of total landings, respectively. Estimates of total mortality showed an increasing trend towards the female population since 1984, which suggests that females may be particularly susceptible to overfishing by recreational anglers. While all three sectors of the fishery should be addressed in future management considerations, our results empahsize the need to consider the growing impact of private boat fishermen on the resource.

INTRODUCTION

The California halibut, Paralichthys californicus, is a highly esteemed food and game fish of considerable value to California's commercial and recreational fisheries. Annual landings[1] for both fisheries dating from 1947 have shown similar cyclic fluctuations with high landings in the late 1940s and mid-1960s, and low landings in the late 1950s and late 1960s (Frey 1971; Methot 1983; Reed and MacCall 1988). However, new recreational fishery regulations were adopted by California in 1971 that set a uniform legal minimum size limit of 559 mm (22 inches) with no tolerance for undersized fish (Klingbeil 1983). Since then, the total annual landing records of the two fisheries, as reported by the

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[1] *Landings* are fish caught and retained by the angler. Catch is defined as all fish caught regardless if they are retained or subsequently released by the angler.

California Department of Fish and Game (CDFG), have not paralleled one another. Commercial landings have steadily increased with 537 metric tons taken in 1987 (Pattison 1988) which may reflect the efficiency of set nets, now the dominant commercial fishing gear used (Methot 1983). In contrast, recreational landings, as reported in the logbooks of commercial passenger fishing vessel (CPFV) operators[2] , have remained consistently depressed.

Explanations for the lack of resurgence in CPFV halibut landings may include the overexploitation of adult stocks by commercial fishing, naturally occurring population fluctuations, a northern shift in the population center, alteration of nursery habitats, or some combination of these factors (Plummer et al. 1983).

Historically, the loss of habitat, specifically embayments which are occupied by young-of-the-year halibut (Allen 1988), has been a major contributor to the decline of many estuarine-dependent species. If habitat loss was a critical factor, one would expect a similar downturn in landings for the commercial fishery. Similarly, if overfishing, natural population fluctuations, or population-center shifts explained the low CPFV halibut landings, then a convergence in the commercial and recreational landings should occur rather than the observed divergence. With length frequencies of commercially caught halibut remaining relative stable (Reed and MacCall 1988), it must be questioned whether the recreational database itself—that is, the CPFV logbooks—accurately reflect the recreational fishery. It is this database that is frequently referenced to illustrate the extent this resource has been depleted (e.g. Martin 1983).

While arguments on the status of California halibut have reverberated for a number of years, there has been no attempt to determine the adequacy of using CPFV landing records for assessing halibut status. Inasmuch as CPFVs cannot profitably target on halibut due to their scarcity (Methot 1983), CPFV records on their own may be a poor measure of relative abundance. Because the halibut recreational fishery also includes a shore-based sector and a private boat sector, a more suitable approach may be the examination of all three sectors. The shore-based sector includes all fishing activity from man-made structures such as piers, docks, and breakwaters as well as from the beach. The private boat sector includes both moored and launched boats as well as rental boats.

The only comprehensive, long-term effort for the simultaneous monitoring of all three sectors of the recreational fishery is the Marine Recreational Fishery Statistics Survey (MRFSS) conducted by the National Marine Fisheries Service (NOAA Fisheries). The MRFSS has been conducted on the Pacific coast since mid-1979 and incorporates an elaborate data collection methodology for obtaining reliable data on the recreational fishery.

The MRFSS consists of two complementary surveys, a telephone survey of households and a creel or intercept survey of fishermen at fishing sites. The telephone survey of households is used to estimate fishing effort, while the intercept survey is used to estimate catch per unit of effort. The data from the two independent surveys are used to estimate total fishing effort, participation, and catch for all three sectors of the recreational fishery by species for six

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[2] In this paper, the CPFV fishery is defined as any boat operated by a licensed captain on which recreational fishing space and privileges are provided for a fee and can include both what are commonly referred to as "partyboats" as well as charterboats.

2-month sampling periods each year (U.S. Dept. Commerce 1984–87; Witzig 1988).

In this paper we examine the landings of California halibut in all three sectors of the recreational fishery in California since 1980. Data from the MRFSS were used to ascertain the impact of each sector on the recreational halibut fishery. Finally, we discuss the utility of the MRFSS and the CPFV logbook databases in assessing the impact of recreational fishing activity on important species.

METHODS

Data Sources

CPFV Logbooks

Landings data from the California CPFV fleet were obtained from monthly logbooks completed by CPFV operators and submitted to the CDFG. These logs of passengers' catch are tallied on a daily basis and are required of any vessel operator taking passengers fishing and charging a fee (Young 1969). California law mandates that vessel operators complete their fishing logs between the time that fishing has concluded for each trip and the time that passengers disembark from the boat. The number of boats reporting in 1980–87 ranged from 323 reporting vessels in 1984 to 291 vessels in 1981. While vessel operators report total landings per species, effort, and location information, only catch data for California halibut were used in this study.

Marine Recreational Fishing Statistic Survey

The MRFSS is comprised of a telephone survey of randomly selected coastal county households and an on-site intercept survey of saltwater anglers. From 1980 through 1987, 15,000–27,000 intercept interviews and 21,000–55,000 telephone interviews were conducted by the MRFSS annually in California.

The telephone survey was carried out in six 2-week periods of interviewing conducted near the end of each 2-month period of fishing activity. Each interview covered only fishing activity in each household in the previous 2 months. The prescribed telephone interview quota for each 2-month period varied with the amount of seasonal fishing activity expected, with increased sampling occurring during months of greater fishing activity. The telephone survey collected information on the number of fishermen per household, the number of finfishing trips by each angler in the last 2-month period, and the type of fishing (e.g. shore fishing, etc.) for each reported fishing trip.

The intercept survey was designed as a stratified random sample with the fishing trip being the primary sampling unit. Each stratum corresponds to one of the three fishing sectors in the fishery: shore, CPFV, and private boat. Data obtained from fishermen included information regarding the fishing trip just completed, (e.g. time of fishing, gear used); selected demographic information (e.g. state and county of residence), and identification and enumeration of species caught. Length data were recorded for a sample of each species retained by the fishermen. Lengths were subsequently converted to weights using length-weight formulas. Sampling was conducted continuously in six 2-month sampling periods from January through December for all years included in the analyses.

For estimation purposes, catch was recorded as catch available for identification (catch type A) and catch not available for identification (catch type B).

The latter category was further divided into two categories: catch used for bait, filleted, discarded dead, etc. (catch type B1) and catch released alive (catch type B2).

Data Analysis

Data were analyzed for statewide landings of California halibut from both surveys from 1980 through 1987. Because the MRFSS estimates are derived from aggregated bimonthly samples, monthly California CPFV data were pooled to form similar sampling units.

Estimates produced by combining data from the telephone and intercept portions of the MRFSS fall into three categories: estimates of the number of trips taken, the number of finish caught, and the number of participants in fishing activities. For the number of trips taken, the estimate of coastal county resident trips was derived from the telephone survey and projections of the number of full-time occupied housing units in the coastal dialing areas. The mean number of fishing trips reported in the telephone survey was multiplied by the estimated number of full-time occupied housing units in the survey dialing area to estimate the total number of marine recreational fishing trips taken by residents of coastal counties. Adjustments were made to account for fishing trips taken by state residents outside the dialing area of the telephone survey and for out-of- state residents.

Estimates of California halibut catch and landings for each fishing sector were calculated from the estimated total number of fishing trips per sector and the average number of fish caught per trip and sector. Pearson product correlation coefficients were used to measure the degree of association between catch estimates from the MRFSS and CPFV survey (Snedecor and Cochran 1967).

Estimates of catch at age were based on the development of sex specific matrices of length-at-age distributional probabilities derived from the estimation of parameters for von Bertalanffy growth curves for male and female fish. Parameters were estimated for male and female fish using a Marquardt modification of Gauss-Newton nonlinear least square regression analysis (Ratkowsky 1983). Data were fitted to the equation: $L_t = L (1 - e^{-Kt})$; where: L_t = estimated length at age t L = theoretical maximum length K = growth coefficient t = age (Everhart et al. 1975). Data for estimating the growth parameters were obtained from randomly sampled, aged, and sexed fish caught between 1955 and 1966 (C.A. Pattison, CDFG, pers. comm.). Ages were determined by otolith readings using whole surface for fish < 750 mm and "cut and burn" for fish > 750 mm. The length-age probability matrices were developed from the point estimates of length-at-age and the standard errors of the estimated lengths (L_t). The standard errors were used to calculate the probability that a fish at age$_i$ would be in length class$_j$. Probabilities were calculated for 50-mm length classes (i.e. 1–50 mm, 51–100 mm, etc.) for all ages from age 1 to the maximum age sampled for each sex. The matrices developed for male and female fish were combined to produce joint probability matrices where each cell of the matrix was the proportion of the population in size class$_j$ that would be age$_i$ and sex$_k$.

Intercept data, consisting of length measurements of individual fish were categorized into appropriate 50-mm length classes, and the frequency distributions of the measured catch for each year from 1980 through 1987 were compiled. The proportion of the measured catch in each size class was multiplied by the estimated landings for each year to obtain the estimated catch belonging to each size class. The estimated catches in each size class were then multiplied by the joint probability matrix to obtain the estimated catch-at-age and sex.

Instantaneous total mortality rates (Z) were estimated for each year and sex using linear regression analysis. Data were fitted to the equation: $\log(N_t) = \log(N_0)\text{-}Zt$; where: N_t = number of fish caught of age t N_0 = number of fish at age 0 Z = instantaneous total mortality (i.e. F + M [fishing mortality + natural mortality]) t = age (Everhardt et al. 1975; Ricker 1975). For purposes of calculating Z, N_t was set at the age at which the species was fully recruited to the fishery (Beverton and Holt 1957).

RESULTS AND DISCUSSION

Comparison of CPFV Data Sets

A comparison of bimonthly landings of California halibut between the reported CPFV logbook catch and the MRFSS estimates show similar patterns with consistent annual increases during the spring-summer months and reduced landings during the fall-winter months (Figures 1 and 2).

The bimonthly oscillations of the two databases were correlated significantly although they did not reflect a close association (r=0.27, P<0.0001). These seasonal pulses in landings as monitored by both databases may be related to the reproductive behavior of halibut when adults annually move from deeper offshore waters to spawn in shallower coastal waters during the spring months (Clark 1930a, 1930b).

While both databases depict similar catch patterns, the number of landings reported by the California database was generally lower than that reported by

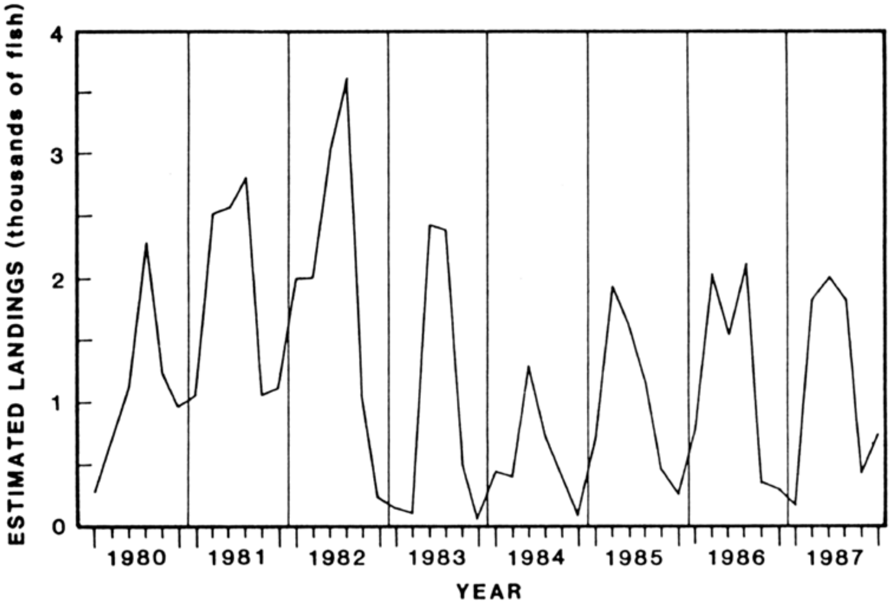

FIGURE 1. Bimonthly landings (in thousands) of California halibut taken by recreational fishermen on board commercial passenger fishing vessels (CPFVs) in California as recorded on CPFV logbooks. Each year is divided into 2-month periods.

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the MRFSS database (Figures 2 and 3. In 33 of the 47 bimonthly periods examined, the MRFSS estimates of halibut landings exceeded those of the reported California CPFV landings. In total landings for 1980–87 inclusive, the MRFSS estimated that 109,000 California halibut were taken by CPFV fishermen compared to the 58,000 reported by CPFV operators for a 88% difference.

The discrepancy between the two sets of estimates may reflect underreporting by CPFV vessel operators. In 1986, only 302 vessels of the 482 boats registered as CPFVs reported their catch for a 63% compliance rate. This is a substantial drop from 1969 when 372 of the 476 (78%) registered CPFVs submitted sportfishing logs (Young 1969). In contrast, the MRFSS is a statistically designed survey with its estimates derived from a random sample of fishing households and fishermen at fishing sites. It does not rely on the submission of data to generate catch estimates.

Total CPFV Catch

While the number of California halibut landings recorded in CPFV logbooks has been consistently low since 1971, there has been a resurgence in commercial landings. However, one of the more startling catch statistics frequently overlooked in commercial versus recreational arguments is the number of undersize halibut released alive by CPFV anglers. Prior to 1971, undersized halibut were counted as part of the total CPFV catch. As shown for MRFSS data in Figure 2, the number of halibut released by CPFV fishermen markedly exceeded the number of fish landed for all years. For the 8 years

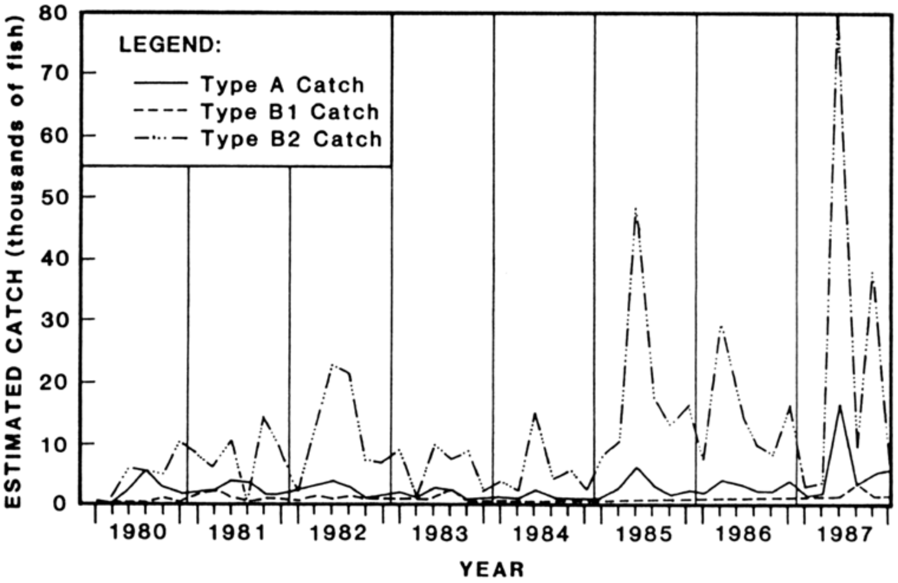

FIGURE 2. Bimonthly catch estimates (in thousands) of California halibut retained and observed by the interviewer (type A catch); caught and filleted, released dead, or discarded (type B1); and released alive (type B2) by recreational anglers on commercial passenger fishing vessels in California as estimated by the Marine Recreational Fishery Statistics Survey.

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included in the analysis, the annual average of legal-size fish caught by CPFV fishermen was only 18% of the total catch.

Total MRFSS catch values for CPFV fishermen, the sum of retained and released halibut, are somewhat reminiscent of particular peak landings reported by CPFV vessel operators prior to 1971 (Young 1969; Reed and MacCall 1988). For instance, the CPFV logbooks show peak landings in the years of 1947–49 and 1962–64, averaging 118,000 and 129,000 halibut, respectively. Based on MRFSS estimates, an average of 90,000 halibut were taken in 1985–87. The highest number of halibut taken prior to 1971 for any year during 1947–71 occurred in 1948 when CPFV fishermen landed 143,000 halibut. Based on the MRFSS, the highest estimated total catch of halibut by CPFV fishermen was 160,000 in 1987 (Figure 2).

Significance of CPFV Fishermen

Based on MRFSS estimates, the CPFV fleet as well as shore-based fishermen account for only a fraction of the total number of California halibut landed by recreational anglers. As illustrated in Figure 3, both shore and CPFV fishing segments reflect a consistently similar trend for the 8 years examined, with CPFV fishermen generally landing a higher number of halibut than shore-based fishermen. Annual summaries of the MRFSS estimates for all three sectors of the fishery in 1980–87 indicate that, of the total recreational landings of halibut, approximately 11% of the total are landed by shore anglers and 14% by CPFV

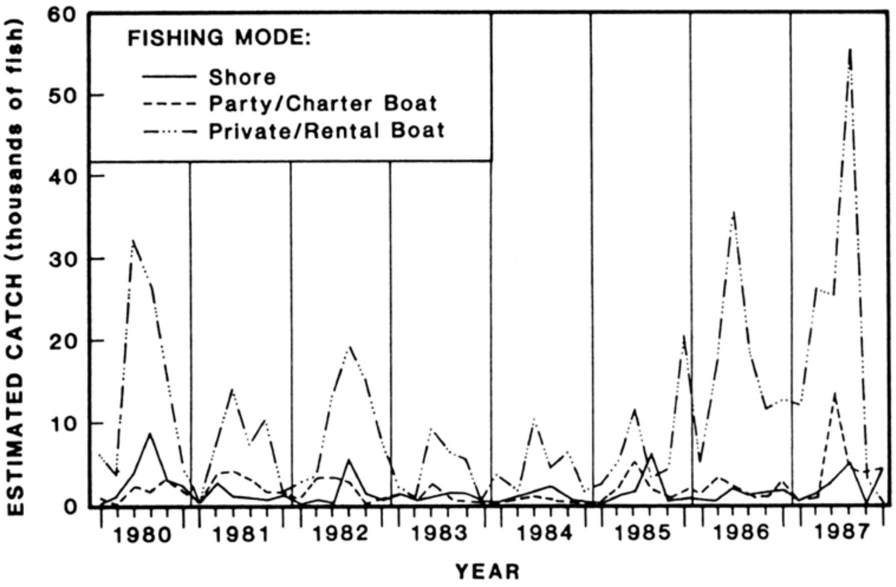

FIGURE 3. Bimonthly landing estimates (in thousands) of California halibut retained (catch types A + B1) by recreational anglers in California for three sectors (modes) of the fishery.

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fishermen. The private/rental boat sector of the fishery accounts for approximately 75% of the halibut landings. Comparisons of the MRFSS landings estimates found a significant but not particularly strong correlation between private boat fishermen and CPFV fishermen (r=0.37, P<0.01). No significant relationships in estimated landings were found between any other sector's estimates produced by the MRFSS and the CPFV landings estimates.

In addition to accounting for only a fraction of halibut landings, CPFV fishermen also account for the smallest percentage of the total marine recreational fishing effort exerted in coastal waters, exclusive of trips directed at salmon (Table 1). Based on MRFSS estimates for 1980–86, approximately 19% of all marine recreational fishing trips were taken by CPFV anglers compared to 36% for private boat fishermen and 45% for shore fishermen (U.S. Dept. Commerce 1984–87).

The lower effort by CPFV fishermen may account for the decline in the proportion of the recreational halibut attributable to the CPFV fleet compared to 25 years ago (Reed and MacCall 1988). In contrast, the proportion of landings coming from shore and private boat fishermen has increased (Methot 1983). One explanation for this shift is that the CPFV industry may no longer target halibut as it did prior to 1971. Halibut fishing is largely opportunistic which does not allow CPFV vessel operators to guarantee their patrons a successful day of fishing.

Graefe and Felder (1986) reported that overall satisfaction in fishing directly relates to such subjective evaluations of the fishing experience as "perceptions that fish were biting" and the "desire to catch more fish." With the exception

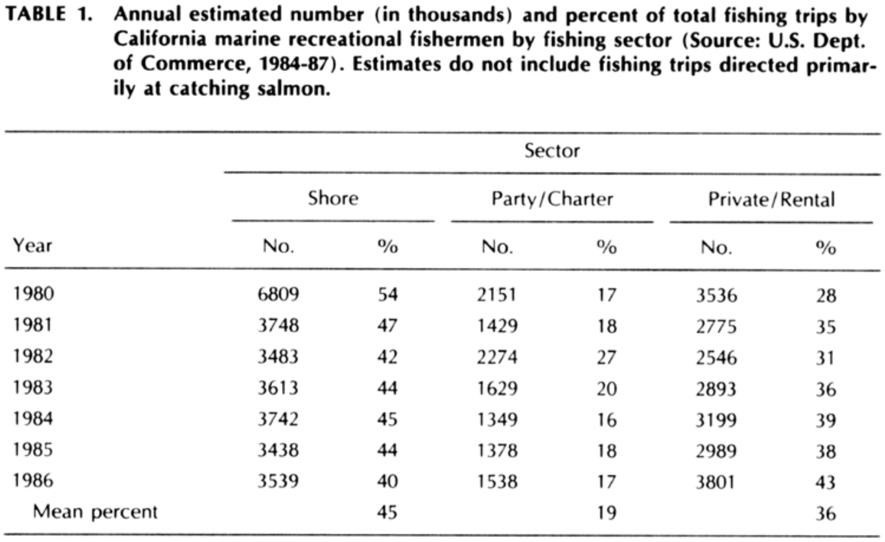

TABLE 1. Annual estimated number (in thousands) and percent of total fishing trips by California marine recreational fishermen by fishing sector (Source: U.S. Dept. of Commerce, 1984-87). Estimates do not include fishing trips directed primarily at catching salmon.

	Sector					
	Shore		Party/Charter		Private/Rental	
Year	No.	%	No.	%	No.	%
1980	6809	54	2151	17	3536	28
1981	3748	47	1429	18	2775	35
1982	3483	42	2274	27	2546	31
1983	3613	44	1629	20	2893	36
1984	3742	45	1349	16	3199	39
1985	3438	44	1378	18	2989	38
1986	3539	40	1538	17	3801	43
Mean percent		45		19		36

TABLE 1. ***Annual estimated number (in thousands) and percent of total fishing trips by California marine recreational fishermen by fishing sector (Source: U.S. Dept. of Commerce, 1984–87). Estimates do not include fishing trips directed primarily at catching salmon.***

of chartered trips, CPFV vessel operators, from an economic standpoint, would tend to fish in areas providing greatest fishing opportunities which precludes fishing in areas inhabited by halibut. California halibut occur on open sand bottoms which provide a low catch rate for bottom fishing patrons on the boat. Further, barren sand bottoms provide little opportunity for incidentally landing other species. Hence, the trend by the CPFV fleet away from targeting on halibut may not change as long as current fishing regulations remain intact.

Impact of Private Boat Anglers

Private boat fishermen consistently account for the majority of California halibut landings compared to the other two components of the recreational fishery (Figure 3). The average for 1980–87 landings was 72,000 fish annually. Since 1984, there has also been an increasing trend in annual landings by private boat fishermen while the other two segments of the fishery have remained generally stable.

With this fishing pressure placed on the fishery, a concern of management is knowing what proportion of the fishery is being harvested. Length-frequency distributions for each year show that the majority of fish retained by sportfishermen are at the 550-mm size class and have just recruited into the fishery (Figure 4). Interestingly, estimated landings by sportsmen of sublegal halibut range between 2 and 6% of total landings for any given year.

Based on recorded lengths-at-age data (C.A. Pattison, pers. comm.), the majority of males taken are between 5 and 8 years old (Figure 5) and the majority of females are between 3 and 6 years old (Figure 6). Haaker (1975) reported that males matured at approximately 200 mm and females at 375 mm. Thus the recreational fishery appears to be targeting fish which have had the chance to have spawned at least once.

Total mortality (Z) rates for male halibut have remained stable since 1980 with no significant difference among the annual estimates of Z since 1980

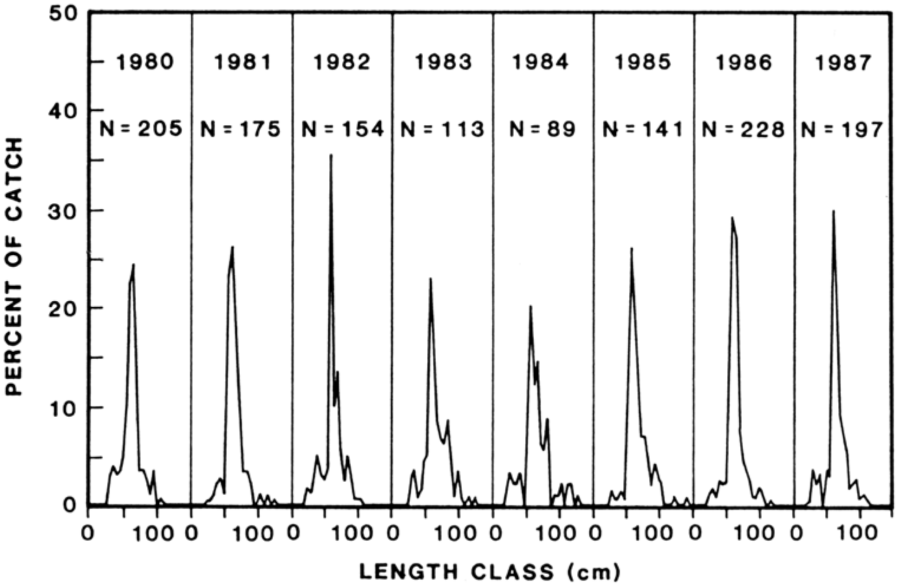

FIGURE 4. Annual length-frequency distributions as percent of catch for recreationally-caught California halibut by anglers fishing in waters off California.

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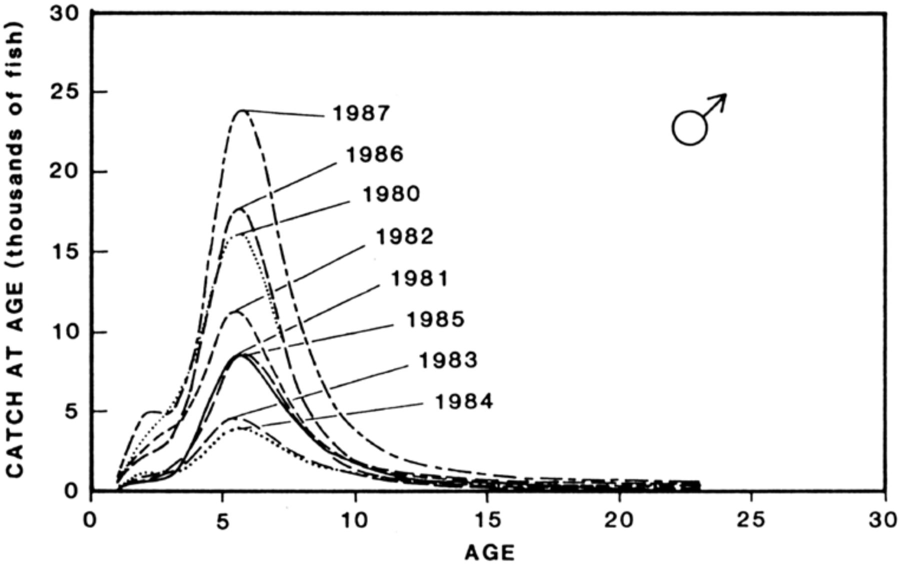

FIGURE 5. Estimated annual catch-at-age distributions of male California halibut landed by recreational anglers in California for 1980-87.

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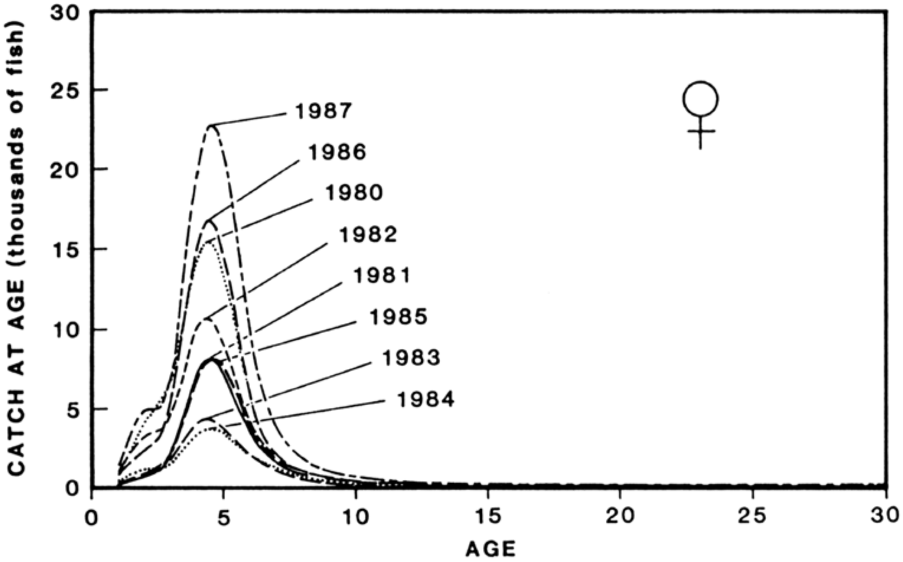

FIGURE 6. Estimated annual catch-at-age distributions of female California halibut landed by recreational anglers in California for 1980-87.

FIGURE 6. Estimated annual catch-at-age distributions of female California halibut landed by recreational anglers in California for 1980–87

(Figure 7). If natural mortality is constant, then the instantaneous fishing mortality rate (F) for the male population has not changed significantly over the last 8 years. Total mortality for the female population showed significant fluctuations in the early 1980s and a gradually increasing trend since 1984 (Figure 8). Assuming a constant natural mortality rate for the female population, these estimates indicate that the female population, may be particularly susceptible to overfishing by the recreational fishery. If the apparent increase in mortality rates continues then additional regulations should be considered.

CONCLUSIONS

1. The number of California halibut actually landed by CPFV fishermen is most likely higher than reported in the CPFV logbooks as not all CPFV vessel operators submit their logs. Compared to the MRFSS estimates, the number reported and the number landed may differ by as much as 90% percent for the 1980–87 study period.

2. Because released California halibut have not been considered a part of a fisherman's catch since the 22-inch size limit with no allowance for undersize fish was imposed in 1971, comparisons between pre-1971 and post-1971 CPFV logbook landings are not valid.

3. Due to the likelihood that CPFV vessel operators do not specifically target California halibut, this component of the recreational fishery is not considered an accurate indicator of relative abundance of halibut.

4. While California halibut may not be a target species of the CPFV fleet, many other species are targeted by the fleet. Consequently, the results presented in this paper do not preclude the use of the CPFV logbook database for assessing the relative abundances of other species. The use of the reported

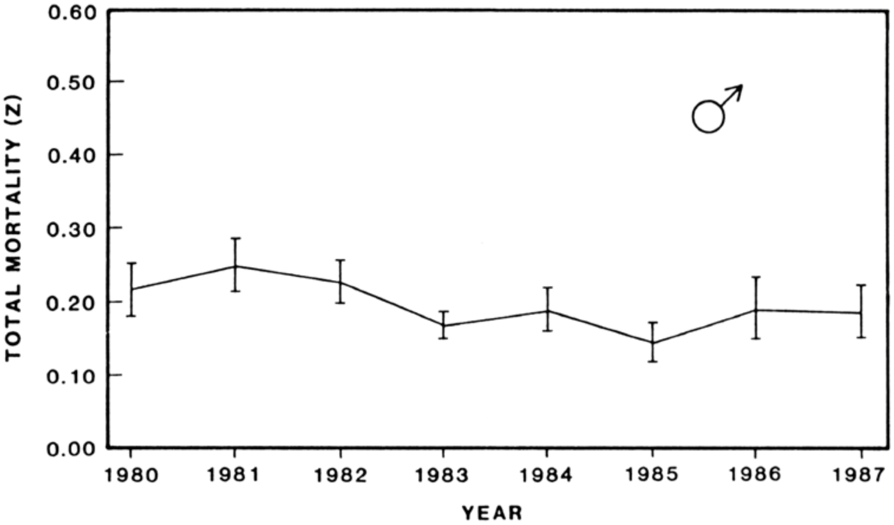

FIGURE 7. Estimated total annual instantaneous mortality rates for male California halibut. Vertical bars indicate the 95% confidence intervals for the estimates.

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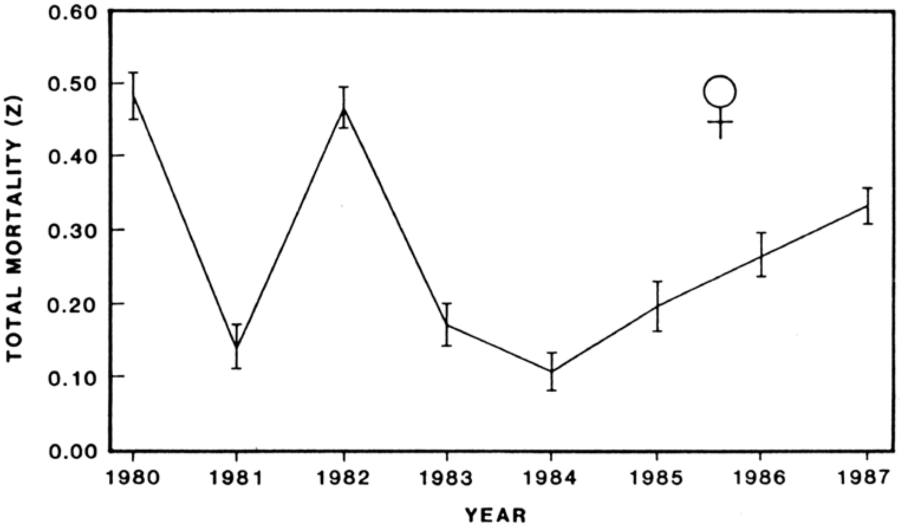

FIGURE 8. Estimated total annual instantaneous mortality rates for female California halibut. Vertical bars indicate the 95% confidence intervals for the estimates.

FIGURE 8. Estimated total annual instantaneous mortality rates for female California halibut. Vertical bars indicate the 95% confidence intervals for the estimates

CPFV catch for monitoring relative abundance of other species must be verified on a species-by-species basis.

5. Effort by shore-based fishermen directed toward California halibut is minimal and at a level comparable to CPFV fishermen.

6. Private boat fishermen exert close to 75% of all effort on the recreational California halibut fishery. This effort has remained consistently high since 1980 and there are indications that it may be increasing. Considering that private boaters catch more halibut and that they take more trips than CPFV and shore fishermen, it is reasonable to infer that private boat fishermen exert the greatest impact on this resource of all recreational fishermen.

7. While all three components of the recreational fishery should be addressed in future management considerations, primary emphasis needs to be given to the impact of private boat fishermen on this resource.

8. Estimates of total mortality indicate an increasing trend for the female population since 1984. Should this trend continue, additional regulations must be considered to prevent overfishing of the reproductive stock.

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HISTORICAL CATCHES OF CALIFORNIA HALIBUT, PARALICHTHYS CALIFORNICUS, BY THE COMMERCIAL PASSENGER FISHING VESSEL FLEET AND RECENT (1980–1987) BOAT CATCH ANALYSIS

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ABSTRACT

The California Department of Fish and Game has collected catch information from commercial passenger fishing vessels (CPFVs) since 1936. Landings of California halibut, Paralichthys californicus, and appurtenant regulations from 1936 through 1987 are reviewed. General catch areas were delineated showing Santa Monica Bay and the San Francisco Bay-Gulf of the Farallons areas as the greatest contributors. Analysis of boat catches revealed that a small number of vessels landed the majority of halibut. An index of presence and abundance showed highs in the spring and a lesser peak in the fall in Santa Monica Bay, while in the San Francisco Bay-Gulf of the Farallons area, the CPFV fishery for halibut was generally in the summer months.

A DESCRIPTION OF THE COMMERCIAL PASSENGER FISHING VESSEL FLEET

California's commercial passenger fishing vessel fleet (CPFVs or partyboats) had its beginning around the turn of the century (Young 1969). Vessels were small, around 20 ft (6 m), very expensive, not readily available to the general public, and generally sought larger game fishes. Over the years vessels became larger and more affordable. Through the 1920s and 1930s, the fleet grew in numbers and by 1939 had reached around 250 vessels. Although World War II brought a virtual halt to partyboat operations, after the war there was a rapid expansion and modernization of the fleet. Larger vessels with more powerful engines introduced greater ranges and better accommodations, e.g. bunks and food services. The number of vessels registered as partyboats peaked in the 1951–53 period at over 1000 boats. Today there are about 500 registered CPFVs. Boats range in size from 20 ft to luxurious long-range vessels of over 110 ft (33 m). The smaller vessels carry six or fewer passengers, require no formal U.S. Coast Guard inspections, and are referred to as "six packs".

Partyboats operate from San Diego to Crescent City from about 35 locations. San Diego is generally considered the saltwater sportfishing capital of the western United States, with five major landings: three on Point Loma and two on Mission Bay.

Since 1936, the California Department of Fish and Game has collected partyboat catch and effort data as required by the California Fish and Game Code, on logs provided by the Department. These logs form the basis for a long-term (over 50 years) record of CPFV catches.

California halibut, Paralichthys californicus, has long been sought and prized by partyboat fishermen. In a survey by Young (1969), CPFV operators ranked this halibut high on the list of importance to the southern California partyboat fishery.

This paper reviews CPFV halibut catches (figures are rounded) and appurtenant regulations from 1936 through 1987 and delineates general areas of catch. A brief boat catch analysis for recent years is presented along with an index of presence and abundance.

CPFV HALIBUT CATCHES 1936–87

Landings of halibut have experienced wide fluctuations over the years for which records have been kept (Figure 1), the highest catch (143,500 fish) occurring in 1948, shortly after fishing operations resumed following World War II. At this time, 10 halibut with no size limit could be taken under authority of a sportfishing license. Previously, halibut had been excluded from the list of species whose capture required a sportfishing license. The following year, 1949, experienced a 27% decline in catch to 104,600 fish. Annual landings continued a fairly sharp decline culminating in 1957 when only 10,800 halibut were recorded on CPFV logs. A limit of 10 fish with no more than 5 fish weighing less than 4 lb (1.8 kg) was put into effect in 1956, a limit of 2 fish with a 22-inch (559-mm) minimum size limit in 1957. Following a significant increase in partyboat halibut landings over the next 2 years, the 22-inch size limit was lifted but a two-fish limit was retained. By 1961 landings had jumped over 300% to 108,000 fish and to 125,700 in 1963. A five-fish limit with no size restrictions was initiated during 1963. CPFV catches continued to rise to the second highest on record (141,500 fish) in 1964. After 1964, landings declined precipitously to 1971 when only 10,600 halibut were logged by the partyboats. The current five-fish, 22-inch size limit became law in 1971.

GENERAL AREAS OF CPFV HALIBUT CATCHES

Based on port of landing, five general catch areas for halibut were delineated (Figure 2). Years were grouped by decades, except for the 1936–47 period, and percentage distributions determined for the catches. The five areas and their designators are:

1. Northern California (N.CA)—all catches north of Point Conception.
2. Santa Barbara to Port Hueneme (SB-PH)—all catches south and east from Point Conception to Port Hueneme.
3. Santa Monica Bay (SMB)—all Santa Monica Bay landings.

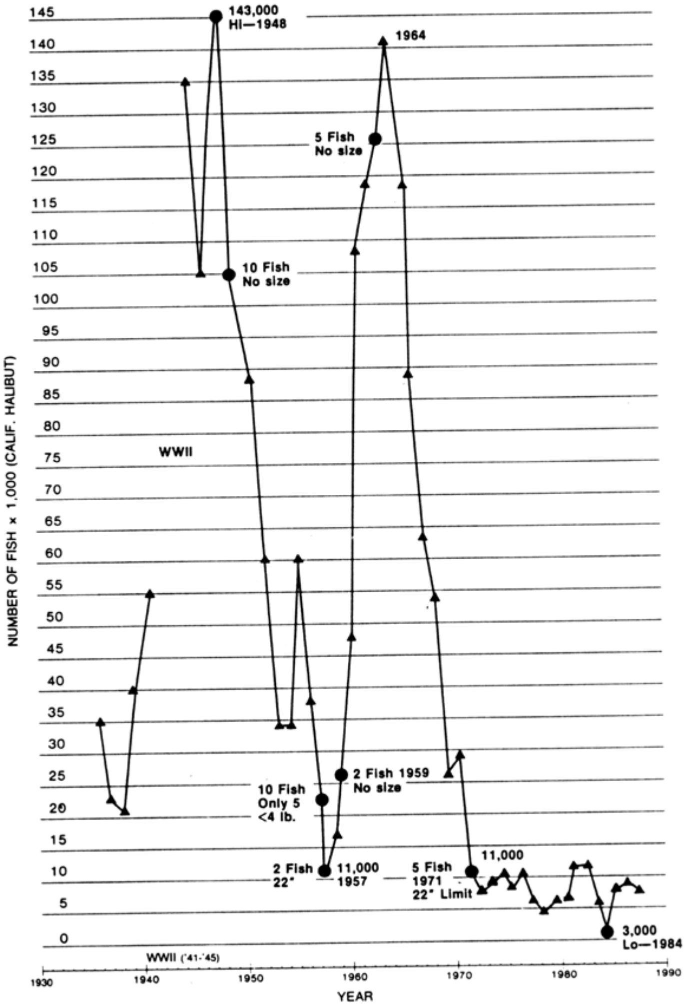

FIGURE 1. California halibut catches by commercial passenger fishing vessels, 1936—87. Since 1971, CPFV halibut catches have remained at historically very low levels, sinking to just over 3000 fish in 1984 during a warm oceanic regime. The 10-year average from 1978 to 1987 was only 7300 fish.

FIGURE 1. California halibut catches by commercial passenger fishing vessels, 1936–87. Since 1971, CPFV halibut catches have remained at historically very low levels, sinking to just over 3000 fish in 1984 during a warm oceanic regime. The 10-year average from 1978 to 1987 was only 7300 fish

4. Long Beach to Newport Beach (LB-NPT)—all San Pedro-Wilmington to Newport Beach landings.
5. South of Newport (NPT-S)—all landings south of Newport Beach including catches from Mexican waters landed in U.S. ports.

For the first three decades (1936–76), CPFV halibut catches were almost totally from southern California, south of Point Conception (Table 1). Between 1968 and 1977, northern California partyboat catches increased to 3% of the statewide total and to 24% of the total between 1978 and 1987. In 1983, the recorded northern California halibut take exceeded that of southern California for the first time. This increase in northern California is mostly a matter of fishing effort, with some partyboats seeking halibut more than in earlier years. During the 1982–84 El Niño there was a lower availability of halibut to the southern California partyboat fleet.

TABLE 1. Percentage distribution of California halibut catches by area, 1936–87.

	Areas [a]				
Years	N.CA	SB-PH	SMB	LB-NPT	NPT-S
1936–47 [b]	< 1	< 1	67	29	3
1948—57 [c]	1	2	32	39	26
1958–67	1	5	27	45	22
1968–77	3	11	22	32	32
1978–87	24	9	41	14	12

[a] Areas:
N.CA—North of Point Conception
SB-PH—Point Conception to Port Hueneme
SMB—Santa Monica Bay
LB-NPT—Long Beach to Newport Beach
NPT-S—South of Newport Beach

[b] No data for World War II years and 1947.

[c] No data for 1948–50.

TABLE 1. ***Percentage distribution of California halibut catches by area, 1936–87.***

Within southern California, the Santa Barbara-Port Hueneme area contributed least to CPFV halibut catches for the entire 1936–87 period. Santa Monica Bay had the highest percentage of catches (67%) in the earliest period (1936–47) and again in the most recent period (41%). Through the three intermediate decades, halibut catches were more evenly distributed over the three areas from Santa Monica Bay to the south (SMB, LB-NPT, and NPT-S).

Partyboats report catches to the Department of Fish and Game by a series of numbered statistical blocks which are each 10 min of latitude by 10 min of longitude. In northern California (N.CA), highest halibut catches were recorded in northern San Francisco Bay and Gulf of the Farallons areas.

In southern California, the Santa Monica Bay area (SMB) consistently had the highest halibut catches.

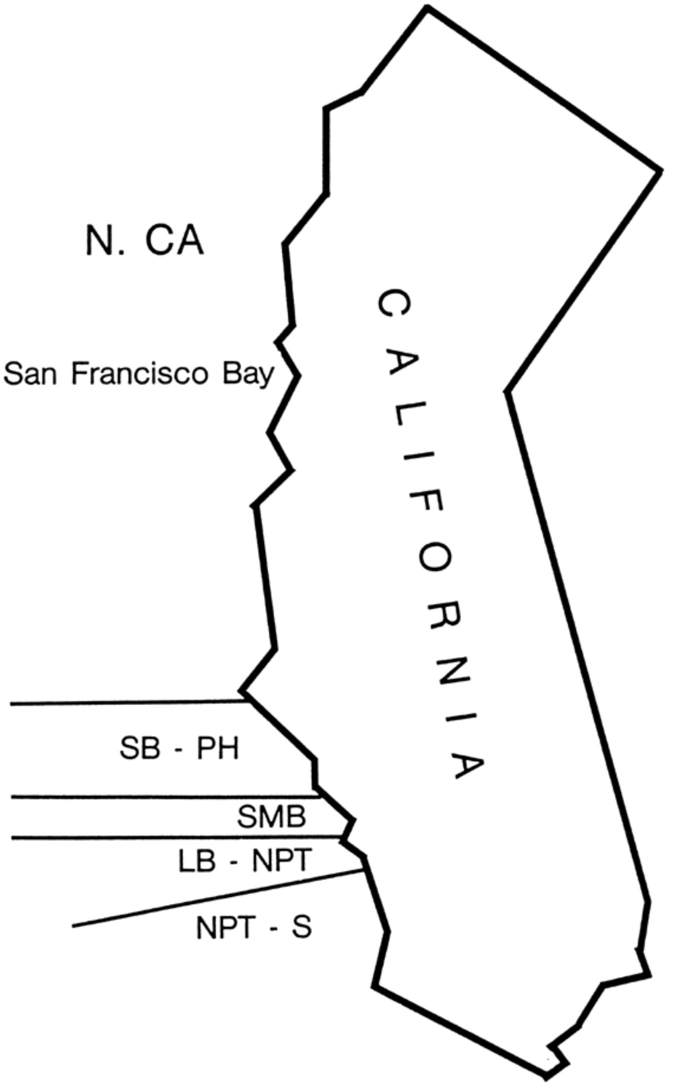

FIGURE 2. General areas of California halibut catches by commercial passenger fishing vessels. N.CA—northern California; SB-PH—Santa Barbara to Port Hueneme; SMB—Santa Monica Bay; LB-NPT—Long Beach to Newport Beach; NPT-S—south of Newport Beach.

FIGURE 2. General areas of California halibut catches by commercial passenger fishing vessels. N.CA—northern California; SB-PH—Santa Barbara to Port Hueneme; SMB—Santa Monica Bay; LB-NPT—Long Beach to Newport Beach; NPT-S—south of Newport Beach

BOAT CATCH ANALYSIS

Distribution of Catch by Numbers

Catch data for vessels which landed at least one halibut were examined for 1980, 1982, 1984, 1986, and 1987. The average number of CPVFs landing halibut was 169 and was fairly consistent except for the low catch year of 1984. For each year, vessels were grouped according to the number of halibut caught. Analysis revealed that relatively few vessels took the majority of fish (Table 2).

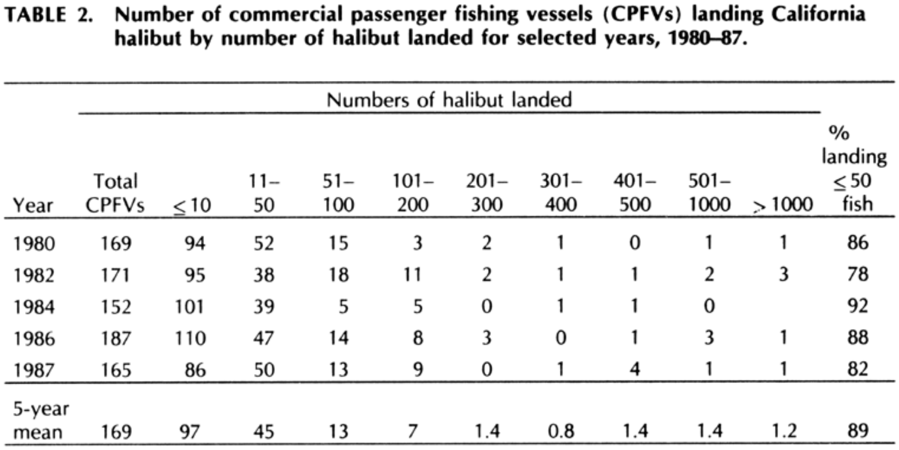

TABLE 2. Number of commercial passenger fishing vessels (CPFVs) landing California halibut by number of halibut landed for selected years, 1980–87.

		Numbers of halibut landed									
Year	Total CPFVs	≤ 10	11–50	51–100	101–200	201–300	301–400	401–500	501–1000	> 1000	% landing ≤ 50 fish
1980	169	94	52	15	3	2	1	0	1	1	86
1982	171	95	38	18	11	2	1	1	2	3	78
1984	152	101	39	5	5	0	1	1	0		92
1986	187	110	47	14	8	3	0	1	3	1	88
1987	165	86	50	13	9	0	1	4	1	1	82
5-year mean	169	97	45	13	7	1.4	0.8	1.4	1.4	1.2	89

TABLE 2. ***Number of commercial passenger fishing vessels (CPFVs) landing California halibut by number of halibut landed for selected years, 1980–87.***

For the years sampled, 15.6% of the boats took 54.8% of the fish. Excluding the low year of 1984, 17.5% of the boats took 60.3% of the fish. From a slightly different perspective, 89% of the CPFVs landing halibut took 50 or fewer fish, whereas only 11% took 51 or more.

Index of Presence and Abundance (IPA)

In order to better quantify the spatial and temporal relationships of halibut available to the partyboat fleet, individual boat catch records were used to identify key vessels in the two major catch areas of Santa Monica and San Francisco Bays. Several vessels which targeted halibut were identified by their consistent and high annual catches. For each vessel so identified, the average monthly catch per trip on which at least one halibut was caught was: IPA = C/T where: C = sum of numbers of halibut caught in a month for a vessel T = number of trips in a month for the vessel A trip was chosen as the base effort unit, rather than anglers, as an examination of raw data showed halibut catches to be independent of angler numbers. For example, a key vessel had over 90 fishermen aboard on consecutive days; however, 4 halibut were caught on one day and 48 on the next. Hours of fishing was rejected because of vagaries in reporting. Plotting IPAs against months for each of the 5 years for which data were examined readily demonstrated the seasons of greatest abundance for halibut in each of the major catch areas (Figure 3).

Santa Monica Bay Area

Six vessels were considered to target halibut. Only one boat was included in all 5 years, while two were trackable over 4 years and another for 3 years.

For Santa Monica Bay vessels, the years 1980, 1982, 1986, and 1987 had traditional high March-April levels of halibut. Nineteen eighty-two produced highs in January and February. Lesser periods of abundance were manifest in the fall months of October and November during 1980, 1982, and 1987. The lowest CPFV halibut catch year, 1984, showed a low value IPA peak in March for one vessel. The IPAs of other vessels were also low, thus confirming the scarcity of halibut in southern California during 1984.

Overall, the Santa Monica Bay IPA values range up to 21 for 1980. Values from 4.5 to 5.9 indicate moderate abundance while values of 6.0 and higher indicate seasonal concentrations. IPAs of less than 2.0 denote times of "slim pickins" for halibut fishermen.

San Francisco Bay Area

Trends in catch for partyboats fishing for halibut in the San Francisco Bay area were quite different than in southern California, although data were sparse. In all but 1 year only two vessels were trackable; the other year, three vessels. Catch was highest in the summer and almost no fishing for halibut occurred in the winter months, although there was a single case of moderate IPA in January of 1984. In 1982, one vessel recorded four consecutive months of extraordinarily high IPAs, ranging from 10.7 to 18.4 for June through September.

For both areas, the five year average IPAs for all vessels (Figure 3) showed similar patterns as for the individual years. Variances were not computed but are obviously high from the wide ranges and small number of vessels studied.

SUMMARY

Halibut landings from California's commercial passenger fishing vessels were analyzed from logbook records of the California Department of Fish and Game. Halibut catches fluctuated widely over the 1936–71 period, under varying regulations. Since 1971, a five-fish 22-inch minimum size limit has been in place. Catches by CPFVs have been at historically low levels, in a range of 3000 to 11,000 fish, during the last 10 years (1978–87) with an average catch of 7288 fish. The lowest recorded year, 1984, was during an anomalous warm water period (El Niño).

During the period 1936–77, partyboat halibut catches were predominately from southern California waters. However, during the past decade (1978–87) northern California contributed 24% of the statewide total.

Analysis of boat records showed that relatively few vessels took a majority of the CPFV halibut catches. An index of presence and abundance (IPA) was developed, which with simple calculations and temporal plotting, demonstrated periods of greatest abundance for halibut available to the partyboat fishery. These were in March and April in the Santa Monica Bay area and in the summer months in the San Francisco Bay and Gulf of the Farallons area.

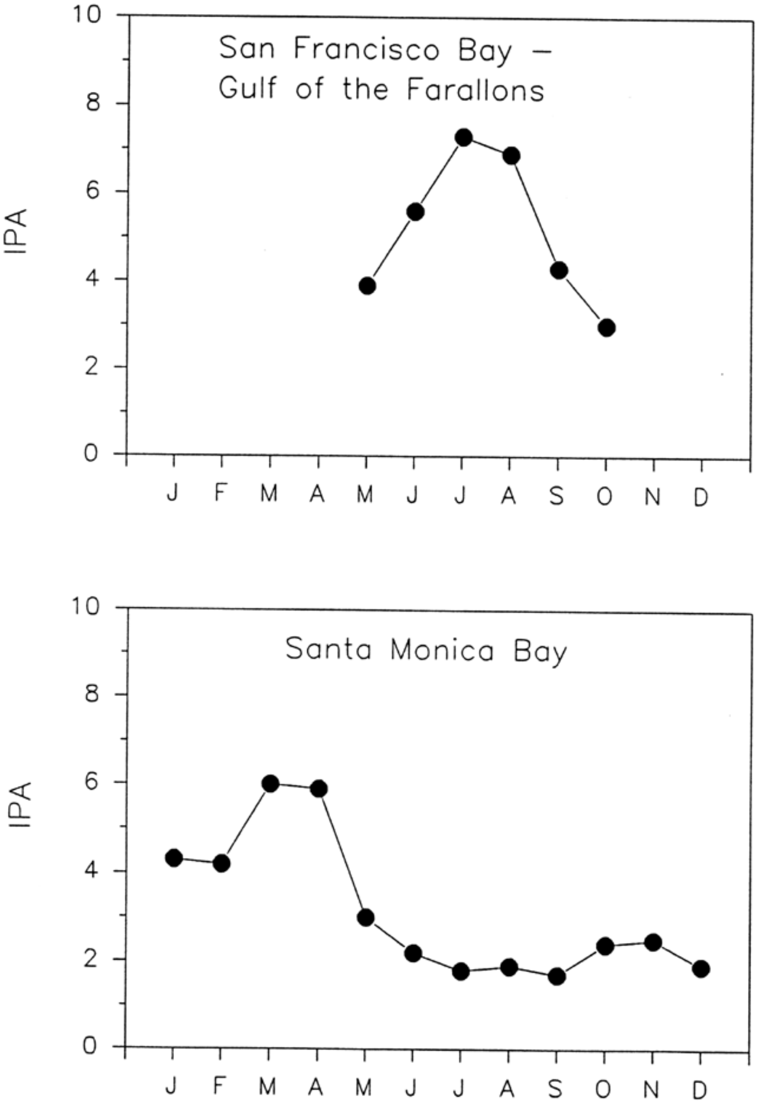

FIGURE 3. Five-year average indices of presence and abundance (IPA) of California halibut by month for selected areas of northern and southern California.

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LITERATURE CITED

Young, P.H. 1969. The California partyboat fishery 1947–1967. Calif. Dept. Fish and Game, Fish Bull. 145, 91 p.

CATCH ESTIMATES, SIZE COMPOSITION, AND DISTRIBUTION OF CALIFORNIA HALIBUT CAUGHT BY SOUTHERN CALIFORNIA COMMERCIAL PASSENGER FISHING VESSEL ANGLERS

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ABSTRACT

Because of the importance of California halibut, Paralichthys californicus, to the southern California commercial passenger fishing vessel (CPFV) industry, catch estimates and size composition of CPFV-caught halibut were determined for 1985 through 1987, and the key CPFV fishing grounds for 1986 and 1987 were identified. This information was gathered by onboard random sampling of CPFV trips between Point Arguello, California and the United States-Mexican border. The results show that the area from Port Hueneme to Point Vicente produced 60% of the retained halibut and 71% of the total catch in both 1986 and 1987. Catch estimates of retained halibut rose from approximately 7000 to 10,000 fish from 1985 to 1987. Catch estimates of released halibut remained stable at approximately 50,000 fish. Time of peak catches of retained and released halibut was February through May. Mean lengths of retained halibut changed little during the survey. Most of the halibut kept by anglers were near the 559-mm (22-inch) minimum size limit, which indicates that the majority of CPFV halibut landings are dependent on a narrow range of year classes. Retained halibut smaller than the size limit comprised 11.1% to 15.2% of the annual CPFV halibut landings between 1985 and 1987; however, most of the sublegal halibut were within 20 mm of the size limit. The average annual catch of legal halibut increased from about 5100 during 1976–78 to 7400 during 1985–87. The average annual catch of short halibut increased from about 15,000 during 1976–78 to 50,000 during 1985–87. The size composition of halibut was significantly different between the 1976–78 study and the present study. Most of the difference in size composition was attributed to a large increase in the number of short halibut caught during the present study.

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INTRODUCTION

Catch estimates and size composition of California halibut, Paralichthys californicus, caught by southern California commercial passenger fishing vessels (CPFVs) have been determined for 1985 through 1987, and key CPFV fishing grounds for 1986 and 1987 have been identified. The determinations are based upon data collected by the California Department of Fish and Game's (CDFG) Southern California CPFV Monitoring Program. This ongoing study has been collecting data on species composition, size composition, catch, and fishing effort in southern California since July 1984.

An important species for both the sport and commercial fishing industries in California, halibut range from the Quillayute River, Washington, to Magdalena Bay, Baja California, Mexico (Miller and Lea 1972), but the vast majority are caught in southern California. Sport-caught halibut are taken from shoreline, piers, jetties, barges, private boats, and CPFV's. Information about catch, size structure, and major fishing grounds of each sport fishing mode is incomplete for halibut.

According to the Marine Recreational Fishery Statistics Survey (MRFSS), 1981–86 annual sport catches of halibut from San Luis Obispo County to the Mexican border comprised from 95% to over 99% of the U.S. Pacific coast halibut sport catch. The MRFSS study also found that surveyed anglers annually ranked halibut either the first or second most frequently targeted species in southern California. In the late 1960s, southern California sport fish landing operators rated halibut fifth in overall importance to the southern California CPFV industry (Young 1969). Between 1981 and 1986, the annual total catch (i.e. retained plus released fish) of CPFV-caught halibut contributed between 6% and 18% of the total halibut sport catch (NMFS 1984, 1985, 1986, 1987). However, the CPFV fleet accounted for 32% of the total halibut sport landings (i.e. retained fish) in 1985, and 24% in 1986 (S.J. Crooke, CDFG, pers. comm.).

No individual study of the sport catch of halibut in southern California exists, but halibut are included in coastwide sport fish surveys such as the CPFV logbooks program or the MRFSS study. The MRFSS project provides a reliable long-term data base about sport fish catches throughout the nation, describing shoreline, man-made structures, private boat, and CPFV modes of fishing. In addition, the CDFG conducted launch ramp surveys from 1975 to 1978 and 1981 to 1982 of the southern California private boat fleet to determine the magnitude and impact of this segment of the sport fishery on southern California marine fish stocks (Wine 1982). The CDFG also gathered catch and length data of southern California marine sport fishes from the CPFV fleet during the mid-to-late 1970s (Collins and Crooke n.d.)

This paper provides more specific information about the catch, size composition, and major fishing grounds of CPFV-caught halibut than is now available from other sport fish surveys, and compares its results on the above subjects to the CPFV survey by Collins and Crooke (n.d.).

MATERIALS AND METHODS

Data Collection

The Southern California CPFV Monitoring Program survey area extends from the United States-Mexican border (but includes some fishing areas in Mexican waters such as the Coronado Islands) to Point Arguello, California (Figure 1). The program conducts onboard random sampling of weekday (excluding holidays) CPFV trips on a year-round basis. Only open-party ½-day, ¾-day, and full-day trips are sampled. Multiday, charter, weekend, and holiday trips are not sampled due to inadequate manpower and because these trips often are filled to capacity and cannot accommodate a sampler.

Samples are stratified by month and location in an attempt to reduce seasonal and geographical variability in passenger loads and in species and size composition of catches. The number and types of scheduled trips for an upcoming month is provided by the landing operators. We randomly sample approximately 5% of the monthly scheduled open trips at each complex (a landing or group of landings that usually fish a unique and distinct area of the coast).

Samplers are assigned a schedule of selected boat trips each month. While on board, the sampler records such data as number of anglers, amount of fishing time, type of trip, water depth, and the site (location) of each fishing stop. The sampler's highest priority is to identify (to species) and count all fishes caught, both retained and released. Recording fish lengths is a secondary priority; we measure fish to be released only when it does not interfere with counting and identification. However, a higher proportion of retained fish are measured because this task is accomplished as the boat returns to port.

As it is difficult for a sampler to keep an accurate count and measure fish concurrently, site-specific length data are not routinely gathered. The site-specific length data presented in this paper are from boat trips that either fished at only one site or from trips where fish lengths could be attributed to a specific site.

In this study, length-frequency measurements are categorized as "retained" or "released" halibut instead of "legal" or "short" halibut. "Legal" refers to halibut [>] the 559-mm (22-inch) minimum size limit, while "short" halibut are < 559 mm. "Retained" rather than "legal" better desscribes the harvested halibut because anglers may release legal-size halibut or, more commonly, keep short halibut.

Data Analysis

Catch estimates for weekday, open-party CPFV trips (that portion of the fishery randomly sampled) are expanded to include open holiday and weekend trips, plus chartered weekday, holiday, and weekend trips. The expansion assumes that weekday, open CPFV trips are representative of all CPFV trips. The boat trip information (the daily number of open and chartered ½-day, ¾-day, and full-day boats operated by each landing) used to determine the expansion factor is provided by the landings' records.

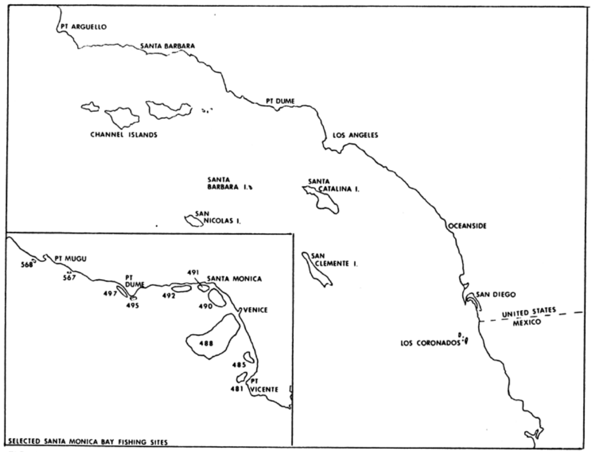

FIGURE 1. Southern California CPFV Monitoring Program survey area.

FIGURE 1. Southern California CPFV Monitoring Program survey area

Catch estimates are calculated by month and complex. Monthly complex catch estimates were summed to obtain annual, county, and southern California catch estimates. Catch estimates are calculated by the equation: CE = (F x Tt) / T_s, where CE = catch estimate, F = number of fish in sample, T_t = number of trips from a complex, and T_s = number of trips sampled.

Catch estimates within the text are accompanied by their standard deviations.

RESULTS AND DISCUSSION

Southern California Catch Estimates

The estimated catch of retained halibut rose steadily from 1985 to 1987 (Figure 2), while the estimated catch of released halibut remained stable (Figure 3). The ratio of released to retained halibut dropped from 6.5:1 in 1985, to 6.4:1 in 1986, and to 4.7:1 in 1987. The lower ratio in 1987 was caused by both increased halibut landings and decreased catches of released halibut. We found February through May was the time of peak catches for retained and released halibut.

According to the CPFV logbook records, halibut landings have been cyclic. Our landing estimates have increased during each survey year, but the time series is too short to be confident of any trend. Increased halibut landings could be due to an increase of CPFV fishing effort directed towards halibut. However, surveyed CPFV skippers and landing operators do not feel that fishing pressure has increased enough to account for the 43% increase in landings between 1985 and 1987. Unfortunately, a satisfactory method for estimating catch per unit of effort (CPUE) for CPFV trips targeting halibut has yet to be developed. Assuming fishing pressure remained relatively constant, the observed increase in landings may be due to increased survival of year classes spawned during the early 1980s reaching the minimum size limit.

Catch Estimates by Site

Halibut were caught at 85 of 162 (53%) sampled sites in 1986, and 94 of 166 (57%) sampled sites in 1987. Malibu Beach (Site 492, Figure 1) had the largest estimated halibut catch (retained plus released) of any individual southern California site in both 1986 and 1987 (Figure 4). The five sites with the highest catch estimates accounted for 57% of the southern California CPFV catch in 1986, and 50% in 1987. The site with the largest landing (retained halibut) estimate in 1986 was the Palisades on Santa Catalina Island (Figure 1), and Point Mugu to Port Hueneme (Site 568, Figure 1) in 1987 (Figure 5). The five sites with the highest landing estimates accounted for 58% of the southern California CPFV halibut landings in 1986, and 49% in 1987.

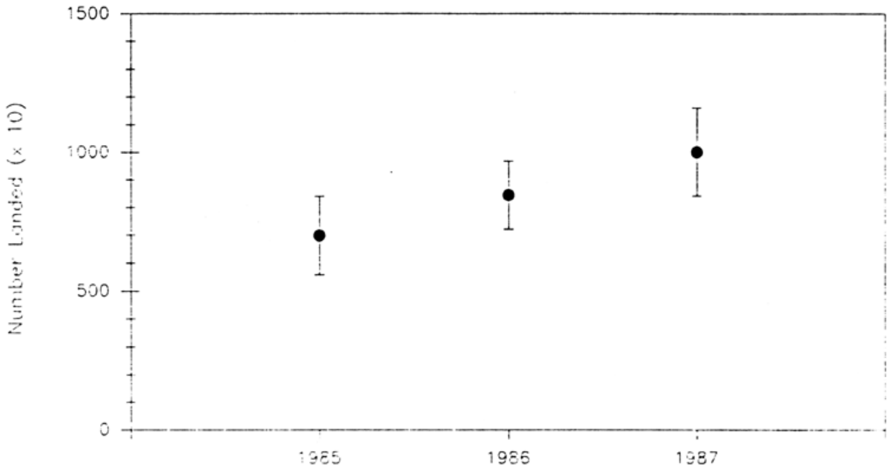

FIGURE 2. Yearly catch estimates and standard deviations of California halibut retained by CPFV anglers in southern California, 1985–87.

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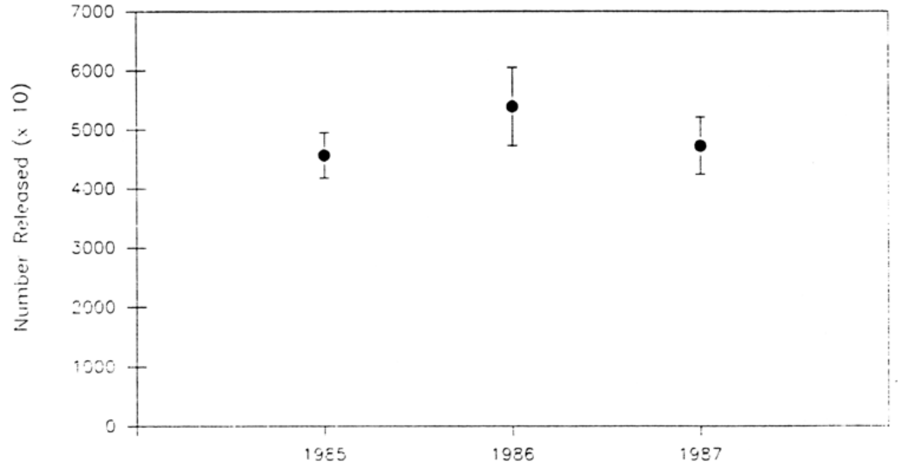

FIGURE 3. Yearly catch estimates and standard deviations of California halibut released by CPFV anglers in southern California, 1985–87.

FIGURE 3. Yearly catch estimates and standard deviations of California halibut released by CPFV anglers in southern California, 1985–87

The area from Port Hueneme to Point Vicente (Site 481, Figure 1) produced an estimated 60% of the southern California CPFV halibut landings and 71% of the total catch in both 1986 and 1987. In 1986, sites located in Santa Monica Bay alone produced 43% of the southern California CPFV halibut landings and 48% of the total halibut catch. In 1987, Santa Monica Bay sites produced 30% of the southern California CPFV halibut landings and 50% of the total halibut catch. The high halibut catches of this area are due not only to the abundance of halibut found there, but probably more importantly to its close proximity to

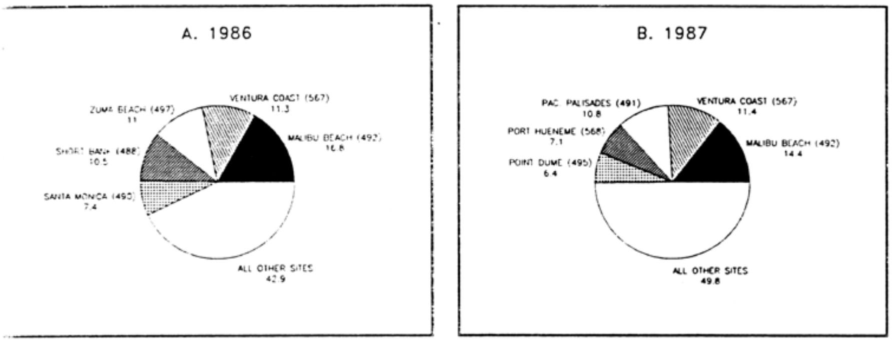

FIGURE 4. Southern California fishing sites which produced the highest catch (retained plus released) estimates of California halibut in: A. 1986 and B. 1987.

FIGURE 4. Southern California fishing sites which produced the highest catch (retained plus released) estimates of California halibut in: A. 1986 and B. 1987

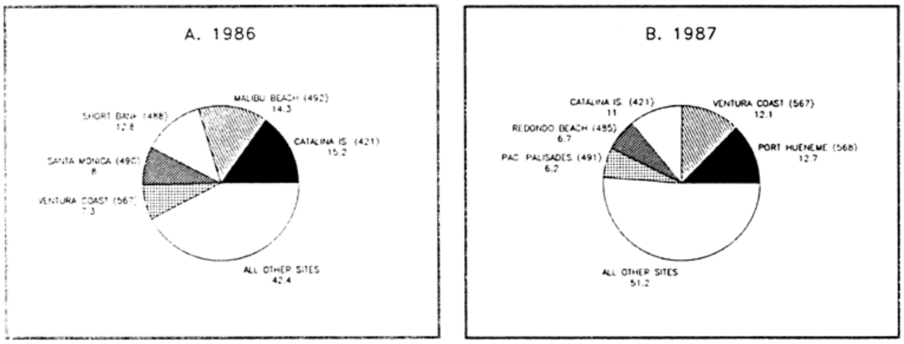

FIGURE 5. Southern California fishing sites which produced the highest landings (retained) of California halibut in: A. 1986 and B. 1987.

FIGURE 5. Southern California fishing sites which produced the highest landings (retained) of California halibut in: A. 1986 and B. 1987

large population centers and CPFV landings. Island and outer-bank sites produced only 8.0% and 5.6% of the CPFV total halibut catch in 1986 and 1987, respectively, but they accounted for 36% of the landings in 1986 and 20% in 1987.

In 1986, the mean size of retained halibut from nearshore sites was 611 mm ± 77.66 SD (*N* = 181) compared to 699 mm ± 182.82 (*N* = 48) for retained halibut caught at island and outer-bank sites. In 1987 the mean size for retained halibut caught from nearshore sites was 624 mm ± 105.85 (*N* = 184) compared to 726 mm ± 151.93 (*N* = 35) for halibut caught at island and outer-bank sites. Halibut caught from San Diego County were not included in the above data because of the inability to match fish length data to specific sites. Because of the larger average size of halibut caught at island and outer-bank sites in 1986, anglers retained 55% of all halibut caught at these sites compared to 11% at nearshore sites. In 1987 anglers retained 70% of all halibut caught at island and outer-bank sites but only 15% at nearshore sites. This indicates anglers have a greater chance of catching a legal-size halibut at island and outer-bank sites, but anglers seem unwilling to pay for long trips to catch halibut. Thus most of the CPFV fishing pressure for halibut is directed to nearshore sites.

Catch Estimate by County

More halibut, both retained and released, were caught in Los Angeles County than in any other southern California county during each year of the survey. Los Angeles County accounted for 76% and 73% of all landed halibut in 1985 and 1986, respectively, but produced only 51% in 1987. Ventura County showed the greatest growth in landings during our sampling by increasing its share from 6% in 1985, to 17% in 1986, and to 34% in 1987. Even though there seems to be a significant shift in halibut landings from Los Angeles County to Ventura County, most of the difference is due to changes in landings from sites geographically close to one another. No site-specific data exists for 1985, but, according to Ally (1988), most of the increase in Ventura County landings from 1986 to 1987 are due to increased landings at the two southernmost Ventura County sites, Point Mugu to Port Hueneme and South Ventura Coast (Sites 568 and 567 respectively, Figure 1). Los Angeles and Ventura counties showed a similar, if less distinct, pattern for released halibut.

Length Frequency

Mean lengths of landed halibut rose slightly in southern California between 1985 and 1987. Mean lengths among counties were similar to one another (Figure 6). Most of the halibut kept by CPFV anglers were close to the minimum 559-mm size limit. Length-frequency histograms for retained halibut showed that the modal size class was 560–579 mm in 1985 and 1986. In 1987 the modal size classes were 560–579 mm and 580–599 mm (Figure 7). These halibut were probably 5 and 6 years old (J.S. Sunada, CDFG, pers. comm.). Approximately 35% of the measured retained halibut were between 560 mm and 599 mm, and about 60–70% of the retained halibut were between 560 mm and 659 mm. This means that the majority of the CPFV halibut landings are dependent upon a very narrow range of year classes, and the CPFV fleet is probably susceptible to decreased landings with the failure of even one year class.

Modal size classes of released halibut were 420–439 mm (probably 3- and 4-year-old fish) in 1985, 480–499 mm (probably 4-year-old fish) in 1986, and 340–359 mm (probably 2- and 3-year-old fish) in 1987. Length-frequency histograms for released halibut are probably skewed towards the larger fish because we measure a higher proportion of released halibut as they approach the minimum size limit. When halibut at or near the size limit are caught, they are held on board the vessel while being measured by anglers and crew. This allows our samplers a greater chance to measure these fish, as opposed to the clearly short halibut that are released immediately. Because of this bias, we did not calculate mean lengths for released halibut. The emergence of the 340–359 mm halibut as the modal class in 1987 may mean another strong year class is being recruited into the fishery.

Halibut less than the minimum 559-mm size limit accounted for 11.1% to 15.2% of the annual CPFV halibut landings between 1985 and 1987 (Table 1). Most of the short halibut kept were within 20 mm of the minimum size limit.

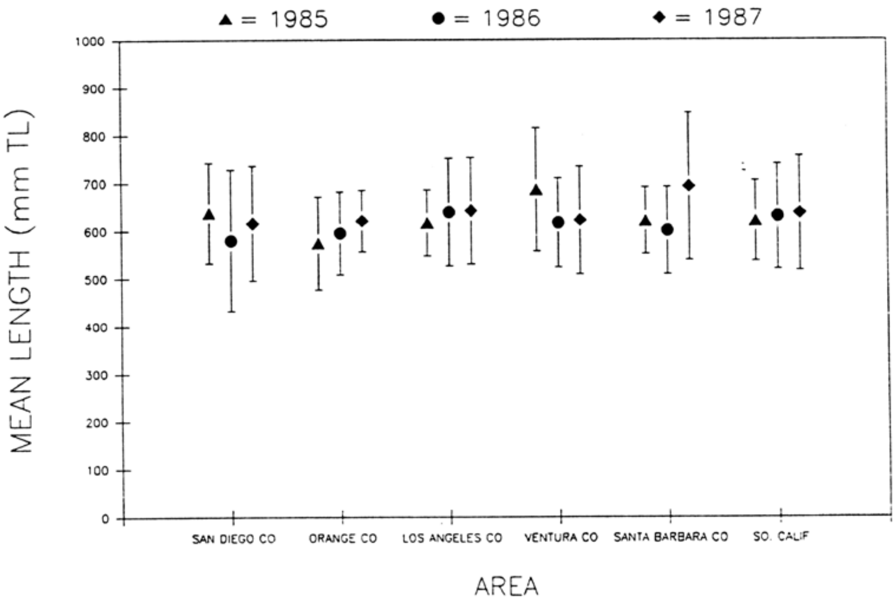

FIGURE 6. Mean length and standard deviation of California halibut retained by southern California CPFV anglers by county, 1985–87.

FIGURE 6. Mean length and standard deviation of California halibut retained by southern California CPFV anglers by county, 1985–87

Halibut less than 540 mm made up 2.6% of the measured retained halibut in 1985, 4.5% in 1986, and 6.0% in 1987. This suggests that inaccurate measuring (by anglers or samplers), fish shrinkage, or the temptation to keep a barely short halibut, rather than misidentification of fish or ignorance of the minimum size regulations, are responsible for most of the sublegal halibut being kept by CPFV anglers.

TABLE 1. Percent of California halibut shorter than the 559-mm (22-inch) size limit kept by southern California CPFV anglers each year, 1985–87.

Year	No. fish kept > size limit	No. fish kept < size limit	Percent fish kept < size limit
1985	169	21	11.1
1986	207	37	15.2
1987	217	33	13.2
1985–1987	593	91	13.3

TABLE 1. ***Percent of California halibut shorter than the 559-mm (22-inch) size limit kept by southern California CPFV anglers each year, 1985–87.***

However, compliance with the minimum size limit by CPFV anglers is good when compared to compliance by private boat anglers. Between 1975 and 1978, short halibut made up between 41% and 44% of the private boat anglers' annual landings (Wine 1978, 1979a, 1979b). Short halibut accounted for 29% of the private boat landings in 1981 (Wine 1982), and 28% in 1982 (Ono 1982, Racine 1983, Ono 1983, Ono and Wolf 1986).

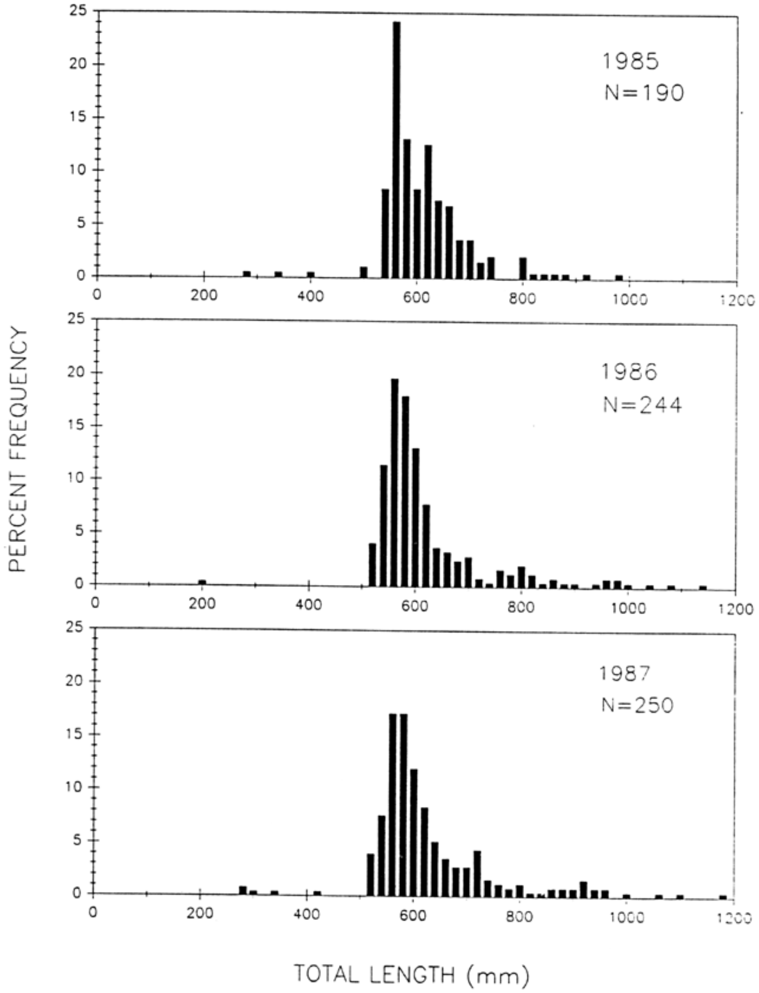

FIGURE 7. Yearly length-frequency distribution of California halibut retained by southern California CPFV anglers, 1985–87.

FIGURE 7. Yearly length-frequency distribution of California halibut retained by southern California CPFV anglers, 1985–87

Comparison to the CPFV Survey of 1976–78

The estimated annual catch of halibut has increased since the mid 1970s (Figure 8). The consensus among questioned CPFV skippers and landing operators is that the CPFV industry now exerts more effort for halibut because fishing success has improved over that of the 1970s. The average annual catch of legal halibut increased from 5148 ± 935 SD during 1976–78 to an average of 7410 ± 1239 during 1985–87.

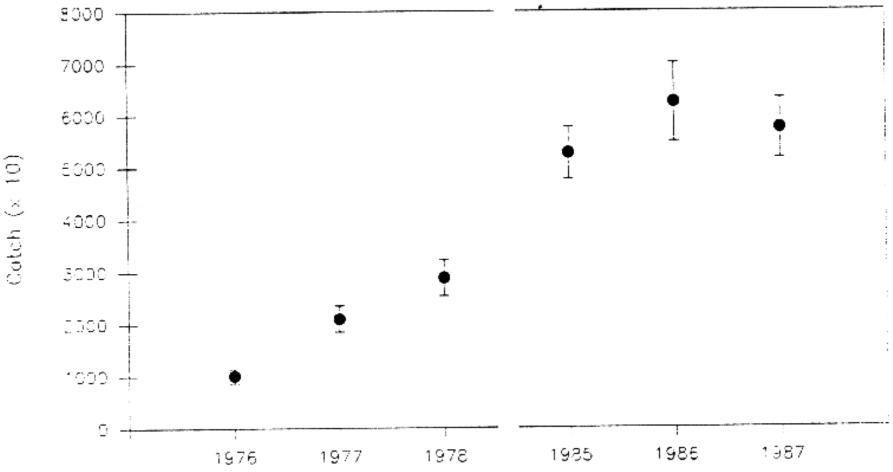

FIGURE 8. Comparison of yearly catch (legal plus short) estimates of California halibut from CDFG's 1976–78 study (Collins and Crooke n.d.) with that of 1985–87 (Ally et al. in prep.).

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There was an even greater increase in the annual estimates of sublegal halibut. Collins and Crooke's (n.d.) data showed an average annual catch of 14,951 ± 2417 halibut during 1976–78 compared to an average of 49,947 ± 5248 during 1985–87.

Most of the increase in the catch of sublegal halibut is probably due to the increased catch of very small halibut. There was a significant difference ($x^2 = 74.8$, 8 df, $P < .001$) between the length distributions of sublegal halibut from the two studies, with most of the difference due to changes in the three shortest size groups (Figure 9). The 1985–87 size distribution has a higher frequency of halibut caught in the < 300 mm and the 300–399 mm size groups. The 1976–78 distribution has a higher frequency of halibut in the 400–499 mm size group, but I feel this number is inflated. More halibut of this size were kept during 1976–78 than during 1985–87 (S.J. Crooke, pers. comm.). The CDFG launch ramp study of private boat anglers showed a decrease in the percentage of short halibut being kept between the mid 1970s and the early 1980s. CPFV samplers measure a greater percentage of retained than released halibut, so if a higher number of 400–499 mm halibut were landed during 1976–1978, it would increase the number of measured halibut in that size group. Increased compliance to the minimum size limit is probably due to the increased availability of legal halibut and increased acceptance and greater awareness of the 559-mm minimum size limit by the CPFV fleet and anglers.

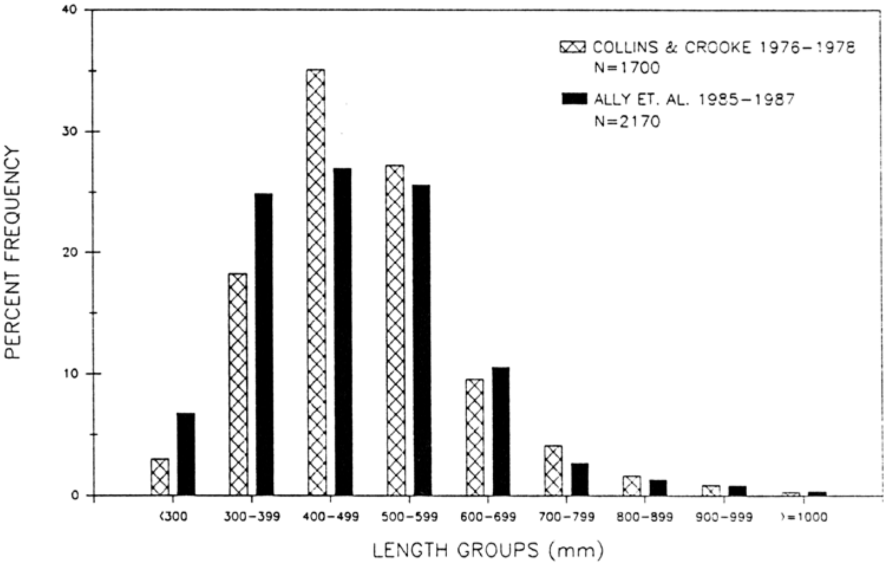

FIGURE 9. Comparison of length frequency distributions of California halibut retained by southern California CPFV anglers from CDFG's 1976–78 study (Collins and Crooke n.d.) with that of 1985–87 (Ally et al. in prep.).

FIGURE 9. Comparison of length frequency distributions of California halibut retained by southern California CP-FV anglers from CDFG's 1976–78 study (Collins and Crooke n.d.) with that of 1985–87 (Ally et al. in prep.)

The annual estimated catch of short halibut was increasing sharply from 1976 to 1978, but seems to have stabilized by the time of our 1985–87 survey (Figure 10). Collins and Crooke (n.d.) felt that halibut benefited greatly from the 1971 law that prohibited the take of halibut less than 559 mm. Our data show that there has been a significant increase in the number of short halibut since the mid 1970s, possibly in part due to the same law.

The annual estimated catch of legal halibut increased by roughly 45% between the 1976–78 survey and the 1985–87 survey (Figure 11). This is well below the increased catch of short halibut between the two surveys. Although CPFV anglers are now catching more than three times the number of short halibut than a decade ago, they are not experiencing the same success with legal halibut. If the number of halibut caught by CPFV anglers is assumed to be an indication of the population size of halibut, then either the population of legal-size halibut has not grown at the same rate as the population of short halibut, or other modes of fishing such as private boat sport anglers or commercial fishermen are benefiting more from the increased availability of legal halibut.

Recommendations

The purpose of this report was to provide information about halibut from an ongoing CPFV study (Ally et al. in prep.) which was designed to provide data to discern general trends in catch and size compositions of fishes caught by the

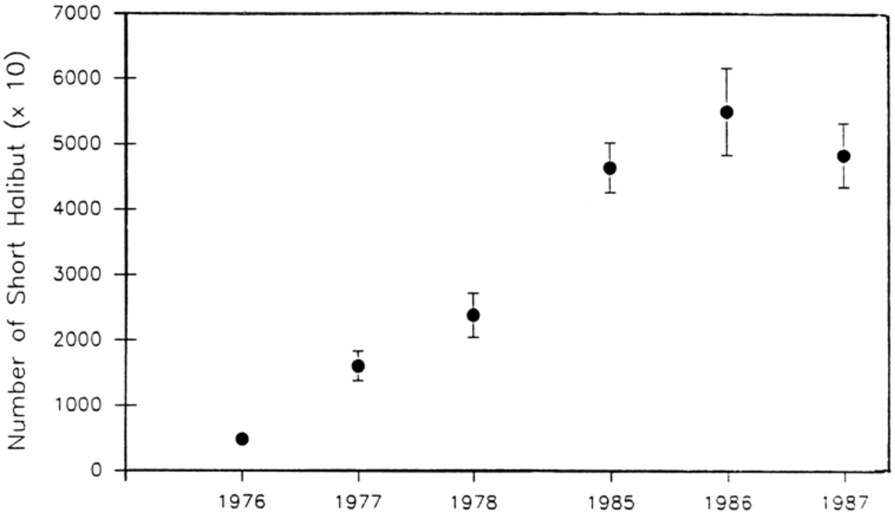

FIGURE 10. Comparison of yearly catch estimates of short California halibut from CDFG's 1976–78 study (Collins and Crooke n.d.) with that of 1985–87 (Ally et al. in prep.)

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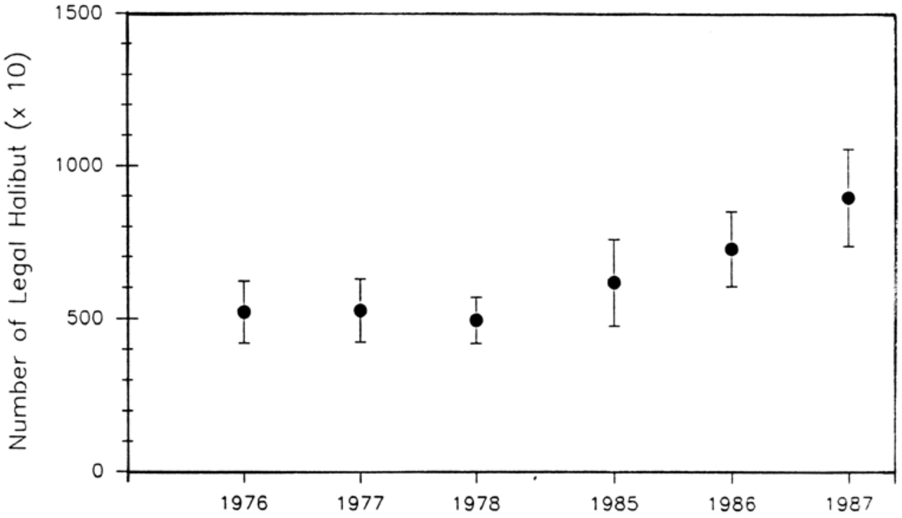

FIGURE 11. Comparison of yearly catch estimates of legal California halibut from CDFG's 1976–78 study (Collins and Crooke n.d.) with that of 1985–87 (Ally et al. in prep.)

FIGURE 11. Comparison of yearly catch estimates of legal California halibut from CDFG's 1976–78 study (Collins and Crooke n.d.) with that of 1985–87 (Ally et al. in prep.)

CPFV fleet. Because the CPFV study produces only limited information on individual species, the management recommendations for halibut are necessarily limited to the following.

The 559-mm minimum size limit should remain in place to protect the young halibut and maintain a large spawning potential. A workable method for establishing a CPUE estimate for CPFV trips targeting halibut needs to be developed. Monitoring the catch of sublegal halibut should be expanded since this data provide an indication of the number of prerecruits and, hence, an early warning of diminishing halibut stocks.

Because generating catch estimates was the CPFV study's highest priority, too few released halibut were measured to sufficiently describe the size structure of sublegal halibut. For more precise information about these small halibut, the sampling procedure would need to be changed so that length-frequency data become the top priority, thereby sacrificing the accuracy of catch estimates. Since this is not desirable, other viable options are either to augment the length-frequency data by sampling CPFV trips expected to target halibut and measure all halibut caught, or to begin to gather catch-estimate and length-frequency data for halibut alone.

However, to more fully understand the effects of sport fishing on the halibut resource, most research should be directed towards the private boat fleet, since according to the MRFSS surveys (NMFS 1984, 1985, 1986, 1987), they catch far more halibut than any other group of sport anglers.

ACKNOWLEDGMENTS

This project has been supported by Dingell-Johnson/ Wallop-Breaux Federal Aid in Sport Fish Restoration Act funds (California Project F-50-R; The Southern California Marine Sport Fish Monitoring Project). I thank Ray Ally, Steve Crooke, Herb Frey, Dave Ono, and Bob Read for their assistance with data collection and much needed comments on the manuscript. Finally, onboard sampling of the southern California commercial passenger fishing vessels would not have been possible without the cooperation and assistance of the skippers, crews, and landing operators. To the whole fleet I wish "limits around".

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A CATCH-PER-EFFORT MODEL USED TO STUDY RECRUITMENT PATTERNS OF CALIFORNIA HALIBUT

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ABSTRACT

This study examines the population dynamics of California halibut to provide information needed for improved management. A model is developed based on the assumption that catch-per-unit-effort data are proportional to the population size of fish available to the fishery. The model identifies recruitment patterns into the fishery and ranges of estimates for population and recruitment size. Simulations are used to investigate the effects of maintaining current catch levels with alternative recruitment scenarios in the future.

Results indicate that levels of recruitment in 1985–87 were two to three times higher than levels in 1981–83. Simulations demonstrate that if recruitment remains at this high level and current catches continue, the population will remain near, or continue to increase beyond, present high levels. If recruitment rates decline to the low levels of 1981–83 and catches continue at their current level, the population will decrease rapidly and the current catches would not be sustained.

Management policy could be designed to react to any of the likely possibilities for varying recruitment. By monitoring levels of prerecruits, management could have knowledge of good or bad years in advance. Policy could then be set, using quotas, closures, etc. on a year-by-year basis to meet the expected number of new recruits.

INTRODUCTION

The California halibut, Paralichthys californicus, is important to both the recreational and commercial fishery in California. Both are subject to management regulations. Regulations are usually proposed in an attempt to improve halibut catch and to allocate it among the fisheries. Personnel of the California Department of Fish and Game (CDFG) try to predict the effect of proposed regulations on the resource and the fisheries.

Discussions about the need or impact of new regulations often focus on how regulating one component of the fishery might affect the other. As an example,

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it is often asked how increasing the commercial halibut catch might decrease the recreational catch, and vice versa. often these discussions portray the system as one fishery directly affecting the other, but this is an oversimplification. Only by knowing the capability of the halibut population to reproduce and survive can an adequate discussion take place concerning the impact of various harvest strategies on the halibut population and, thus, the impact of one fishery on the other.

For example, if recruitment is high, the harvest to both components of the fishery might be increased. Or if recruitment is low, the current harvests for one or both components might not be sustained.

Improved resource management requires a better understanding of the dynamics of the halibut population. This paper presents additional information and develops a population dynamics model to increase our understanding.

MATERIALS AND METHODS

The Model

The model is based on the assumption that catch per unit effort (CPUE) is proportional to the population size each year: $N_t = P_t$ X k (1) where: N_t = the number of fish available to the fishery at time t P_t = an index of CPUE for the fishery at time t k = a proportionality index A simple balance model connects the years (Walters 1986): $N_{t+1} = [N_t - C_t]$ X S + R_{t+1} (2) where: C_t = the harvest in numbers at time t S = the annual natural survival rate R_{t+1} = the recruitment in year t+1 By substituting equation 1 into equation 2 the formula becomes: P_{t+1} X k = [P_t X k - C_t] X S + R_{t+1} (3)

The Data

Information needed includes total catch over time, an index of CPUE over time, and an estimate of natural survival. The total catch consists of a recreational component and a commercial component.

Recreational Catch

Estimates of the recreational catch for the years 1980–86 were available from the Marine Recreational Fishing Statistics Survey (MRFSS; NMFS 1984a, 1984b, 1985, 1986, 1987) and for 1987 (S.J. Crooke, CDFG, pers. comm.). (Original estimates are shown as open circles in Figure 1.) Estimates of the total catch for 1981–87 were obtained from MRFSS Table 1A and an estimate for 1980 was obtained from adding MRFSS Tables 2 and 3 as Table 1A was not available.

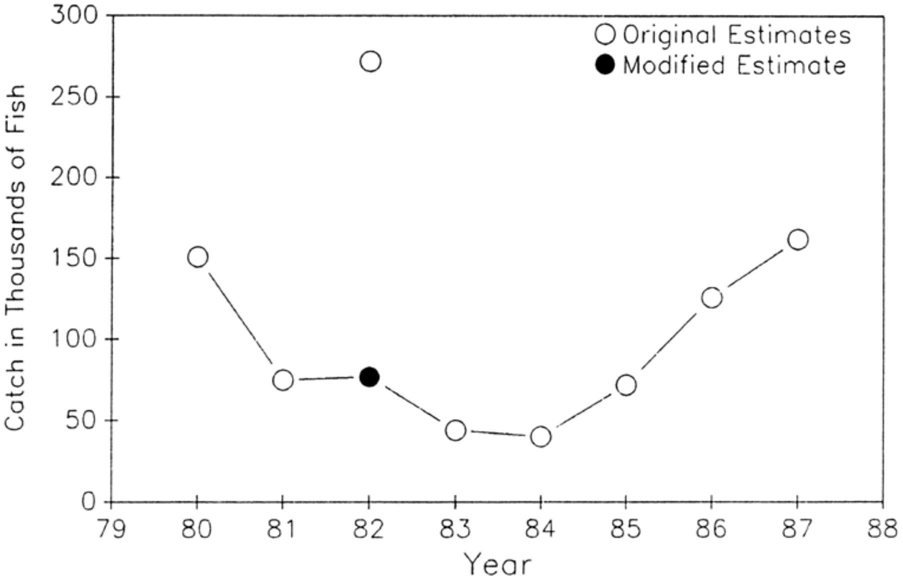

FIGURE 1. **Recreational catch estimates.**

FIGURE 1. Recreational catch estimates

The estimate for 1982 appears to be inconsistent with adjacent years, since it was the only component of the halibut fishery that increased 300 percent from 1981 to 1982.

Most of the halibut brought ashore in whole form were available for identification, enumeration, and measuring. They are designated type A by MRFSS. Those that were not brought ashore in whole form but were used as bait, filleted, or discarded dead are type B1.

Estimates of the total catch by number and weight are available for type A fish (Table 1). By number, the catch of 1982 was unusually large; by weight it was not. The average weight shows that very small fish were caught in 1982 (Table 1). There is no other information supporting an unusually large catch of unusually small halibut in 1982. I assume this value to be in error.

To correct for this inconsistency, calculations of the 1982 catch were revised (Table 2). The weight of the type A catch divided by the average fish weight for 1981 and 1983 combined was used as a revised estimate of the number caught in 1982. The number of type B1 fish from 1981 and 1983 divided by the corresponding number of type A fish was used to estimate the percentage of type B1 fish expected for 1982. A combination of the two estimates gives a revised estimate of the total recreational catch in 1982 (shown as the filled circle in Figure 1).

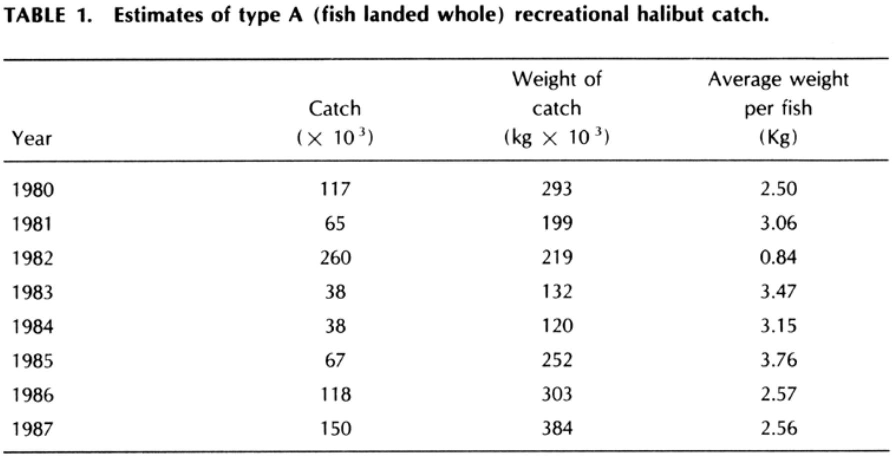

TABLE 1. Estimates of type A (fish landed whole) recreational halibut catch.

Year	Catch (× 10³)	Weight of catch (kg × 10³)	Average weight per fish (Kg)
1980	117	293	2.50
1981	65	199	3.06
1982	260	219	0.84
1983	38	132	3.47
1984	38	120	3.15
1985	67	252	3.76
1986	118	303	2.57
1987	150	384	2.56

TABLE 1. ***Estimates of type A (fish landed whole) recreational halibut catch.***

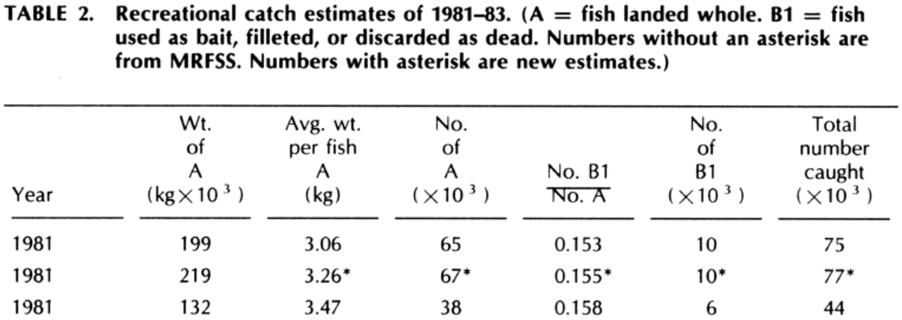

TABLE 2. Recreational catch estimates of 1981–83. (A = fish landed whole. B1 = fish used as bait, filleted, or discarded as dead. Numbers without an asterisk are from MRFSS. Numbers with asterisk are new estimates.)

Year	Wt. of A (kg×10³)	Avg. wt. per fish A (kg)	No. of A (×10³)	No. B1 / No. A	No. of B1 (×10³)	Total number caught (×10³)
1981	199	3.06	65	0.153	10	75
1981	219	3.26*	67*	0.155*	10*	77*
1981	132	3.47	38	0.158	6	44

TABLE 2. ***Recreational catch estimates of 1981–83. (A = fish landed whole. B1 = fish used as bait, filleted, or discarded as dead. Numbers without an asterisk are from MRFSS. Numbers with asterisk are new estimates.)***

Commercial Catch

The weight of commercial halibut landings for each year is available from the CDFG Marine Fisheries Statistics Unit in Long Beach. Since the average fish weight was not available, two estimates were used: a heavy weight of 3.5 kg/fish and a light weight of 2.0 kg/fish. These estimates were used to calculate a high and a low time series of total commercial catch in numbers (Figure 2). The true value should be somewhere between the two (M. Vojkovich, CDFG, pers. comm.).

Total Catch

The total halibut catch for each year was obtained by adding the total recreational catch to each of the total commercial catch estimates (Figure 3).

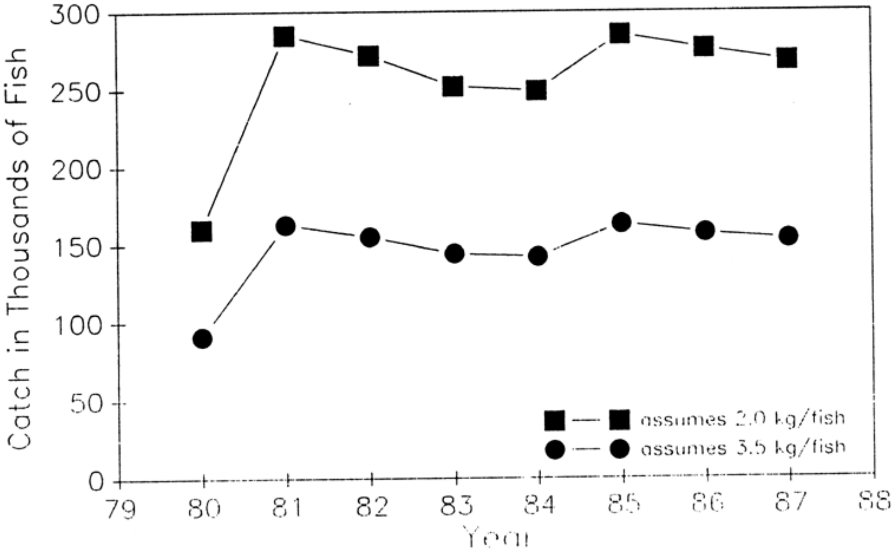

FIGURE 2. Commercial catch estimates.

FIGURE 2. Commercial catch estimates

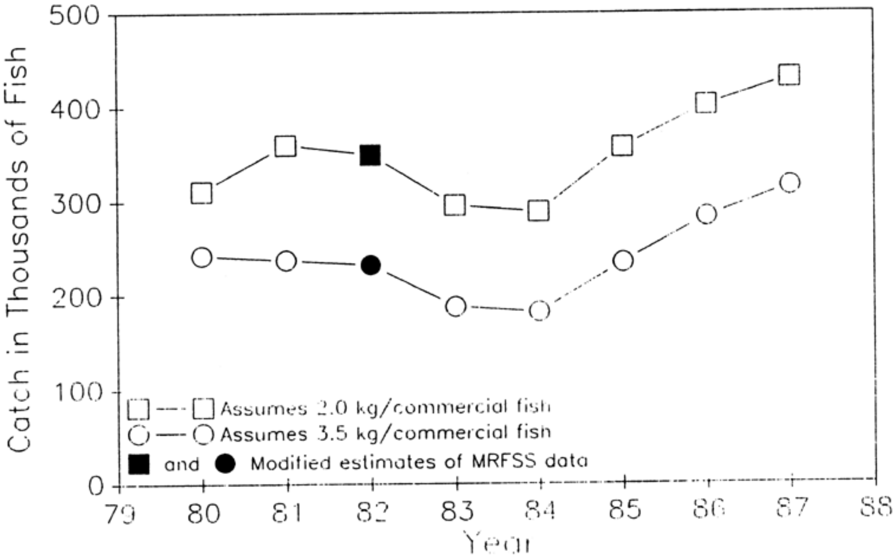

FIGURE 3. Total catch estimates.

FIGURE 3. Total catch estimates

Catch Per Unit Effort

Estimates of CPUE are not available for the fishery, overall. The CPUE for the recreational fishery is available from MRFSS for 1980–87 (S.J. Crooke, pers. comm.; Table 3; Figure 4). The MRFSS conducts a telephone survey each year asking if respondents fished for halibut, if so how many hours did they fish for halibut, and how many halibut did they catch when they were specifically fishing for halibut. This provides a consistent annual index of CPUE for directed halibut catch expressed as halibut caught per hour fished. The model assumes that this index is representative of the halibut population and the fishery, overall.

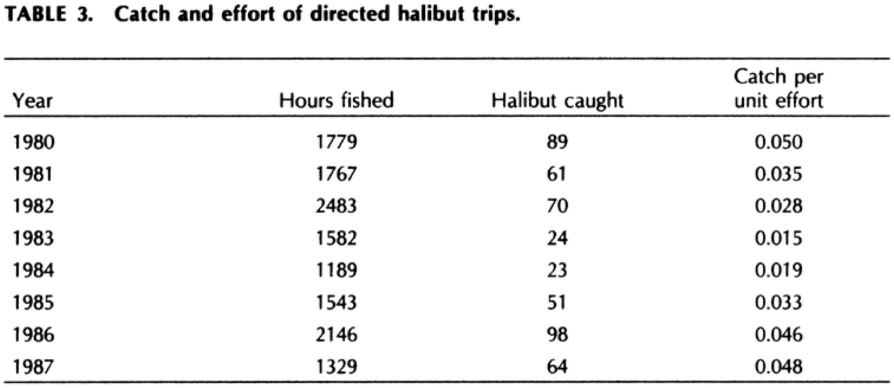

TABLE 3. Catch and effort of directed halibut trips.

Year	Hours fished	Halibut caught	Catch per unit effort
1980	1779	89	0.050
1981	1767	61	0.035
1982	2483	70	0.028
1983	1582	24	0.015
1984	1189	23	0.019
1985	1543	51	0.033
1986	2146	98	0.046
1987	1329	64	0.048

TABLE 3. ***Catch and effort of directed halibut trips.***

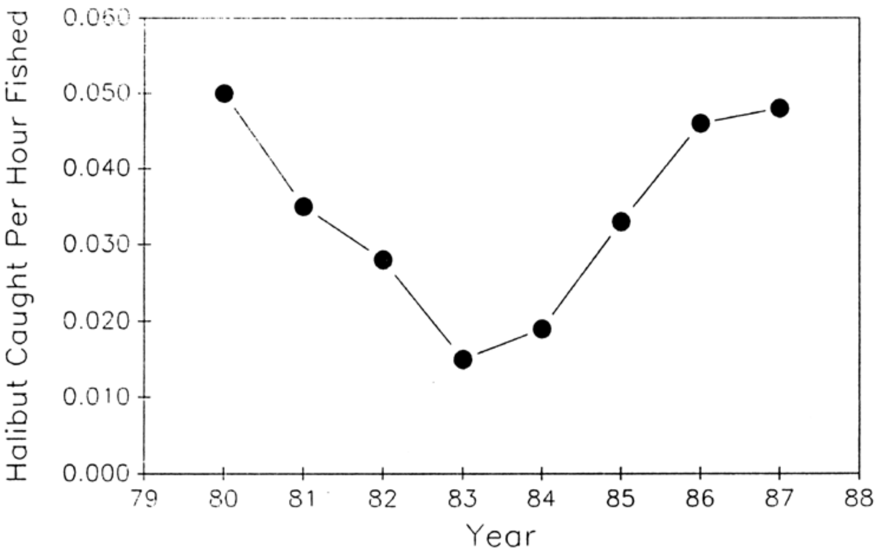

FIGURE 4. Recreational catch per unit effort.

FIGURE 4. Recreational catch per unit effort

Natural Survival

The annual natural survival rate of recruited halibut is presumed to be between the high (0.9) and low (0.8) estimates of Reed and MacCall (1988). Both values are used. The two data sets of total catch combined with the two natural survival rates produce four versions of the model to test and use.

Recruitment

Recruitment is modeled with the following two components: $R_t = A_t$ X r (4) where: A_t = recruitment strength coefficient in year t r = recruitment constant The model then becomes: P_{t+1} X k = [P_t X k - C_t] X S + A_{t+1} X r (5)

By changing the values in the A vector, several alternative recruitment scenarios can be tested.

If constant recruitment is assumed, the expected number of recruits would not change each year. This is modeled by letting all values of the A vector equal 1. If recruitment is limited to a set number over time, and if the smallest observed populations produce sufficient eggs to allow recruitment to reach the number, then this representation of recruitment would be appropriate for our purposes.

Recruitment, however, may not have been constant. Values for each of the individual elements of the recruitment strength vector cannot be estimated due to the small number of degrees of freedom. Although year-to-year variation cannot be estimated, longer time scale patterns can be inferred. One part of the time series may have had lower levels of recruitment than another. This is modeled by setting A to a value less than 1 for the period of lower recruitment.

Fitting the Model

Since data are available for the total catch, CPUE, and natural survival, the values to be estimated are the proportionality constant (k) and the recruitment constant (r).

Values for the recruitment strength vector (A) were supplied prior to estimating the values for k and r. Caution was used in adjusting values within A to avoid overfitting the data. Rather than make a number of changes to individual members of the A vector, sections of the A vector were adjusted.

Parameters were estimated by rearranging equation 5 into the form of a multiple regression with no intercept. Pt+1 - P_t X S = (1/k) X C_t X S - (r/k) X A_{t+1} (6)

Regression parameters became the following: B_1 = 1 / k B_2 = r / k (7)

Model parameters are easily calculated once the regression parameters are known: $k = 1 / B_1$ $r = B_2 / k$ (8) Variances and confidence intervals are also calculated by standard multiple regression methods.

Testing the Model

Two stages of testing were performed. The first looks at the statistical relevance of the model by examining plots of the model fit. The second tests for biological relevance by comparing observed to predicted harvest rates.

Testing the Statistical Fit of the Data

The statistical fit of the model is tested by comparing the observed to predicted population size, over time. Observed population sizes are based on the current year's CPUE. Predicted population sizes are based on the preceding year's CPUE. With estimated values for k and r, an observed data set can be compared to an expected data set. This follows from equation 5: $O_t = P_t X k$ (9) $E_t = [P_{t-1} X k - C_{t-1}] X S + A_t X r$ (10) where: O_t = observed population estimate in year t from CPUE information from year t E_t = expected population estimate in year t from CPUE information from year t-1.

Plots of the observed and the expected population estimates show the fit of the model and whether systematic biases exist.

Testing for Appropriate Harvest Rates

If the model still appears appropriate, harvest rates are calculated for the final 2 years by using the following equation: $H_t = C_t / [P_t X k]$ (11) where: H_t = harvest rate at time t

With harvest rates and natural survival rates known, a rough estimate of the age structure of the fish available to the fishery can be constructed. Proportions can be calculated in the following way: $F_a = 1 X ([1 - H] X S)^a$ (12) where: a = age in years past full recruitment

F_a = fraction present at beginning of age H = composite harvest rate (average of recent years)

Assuming that the harvest rate is similar for ages older than the age at full recruitment, the series of fractions can be compared to a histogram of catch by age. At very high harvest rates, fish are not likely to survive to be seen at older ages.

Catch-at-age records are available from gill net and trawl landing samples for the years 1985–88 (Sunada et al. 1990). The structure of the observed catch by age, for fully recruited ages, is compared to the structure calculated using equation 12.

If the model is appropriate in its fit to the data and to biological realism, it can be used to estimate population and recruitment sizes over the time series. In addition, it can be used to project population sizes in the future with alternative recruitment and harvest scenarios.

Simulations Based on the Model

The population size can be projected forward using a combination of equations 2 and 4: $N_{t+1} = [N_t - C_t] X S + A_t X r$ (13)

Using population estimates predicted for 1987 together with annual catch data and several alternative recruitment strength coefficients, simulations can continue projecting the population forward. Simulations investigated the effects of maintaining current catch levels with a range of recruitment scenarios.

RESULTS

Constant Recruitment

Testing the Model

Testing the Statistical Fit. The model representing constant recruitment clearly did not fit the data. Values of k and r that best fit the model produce residuals that are positive for the first half of the time series and negative for the second half (shown for the model version with the low catch time series and the high survival rate, Figure 5).

The same general pattern held for all four versions of the model. When constant recruitment data were forced on the model, it produced values for k and r that overestimated early population sizes and underestimated late population sizes.

Variable Recruitment

Testing the Model

Testing the Statistical Fit. Due to the residual structure found under constant recruitment, the recruitment strength coefficients were decreased for the beginning of the time series in an effort to correct the bias. When the values for

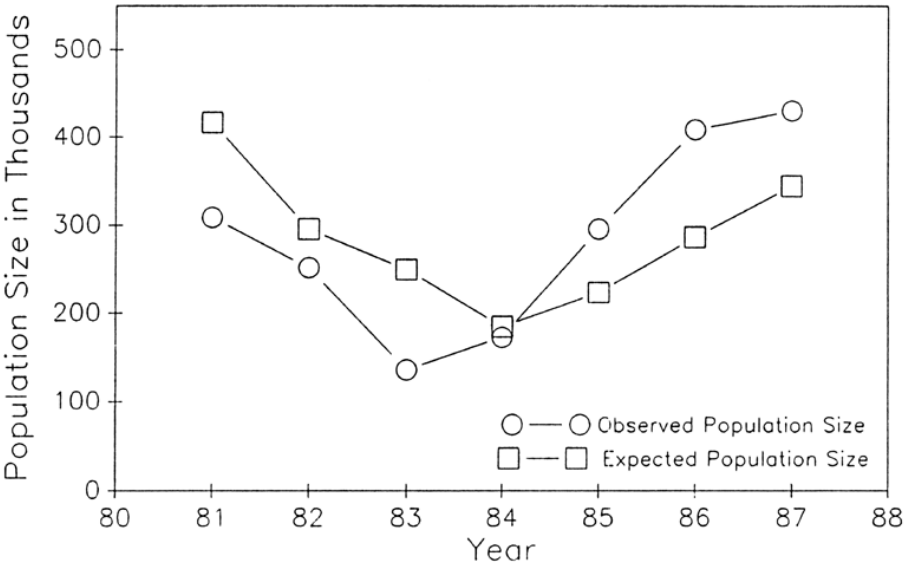

FIGURE 5. Model fit with constant recruitment.

FIGURE 5. Model fit with constant recruitment

the first 4 years were adjusted downward, the data fit the model very well (shown for the model version with the low catch time series and the high survival rate, Figure 6). Values for the recruitment strength coefficient were 2 to 3 times lower for 1981–83 than for 1985–87 (Table 4). The same pattern of recruitment was found to best fit all versions of the model.

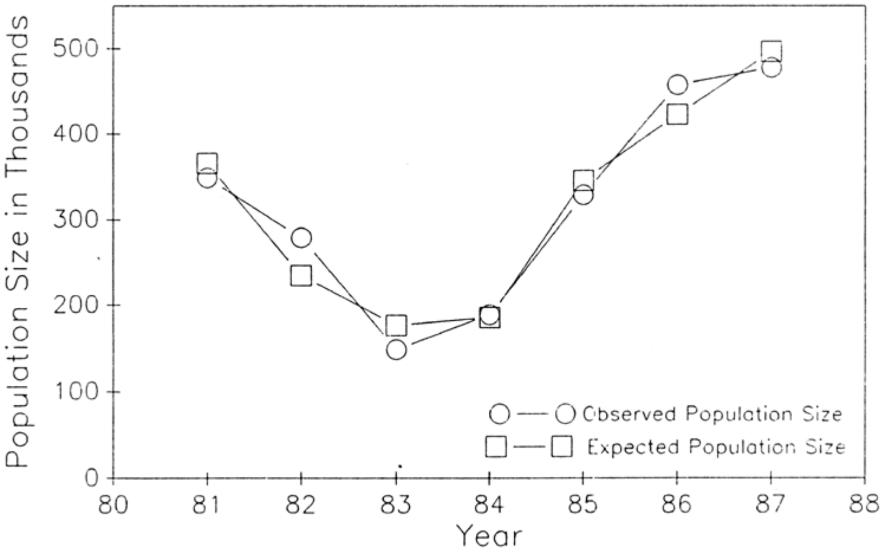

FIGURE 6. Model fit with variable recruitment.

FIGURE 6. Model fit with variable recruitment

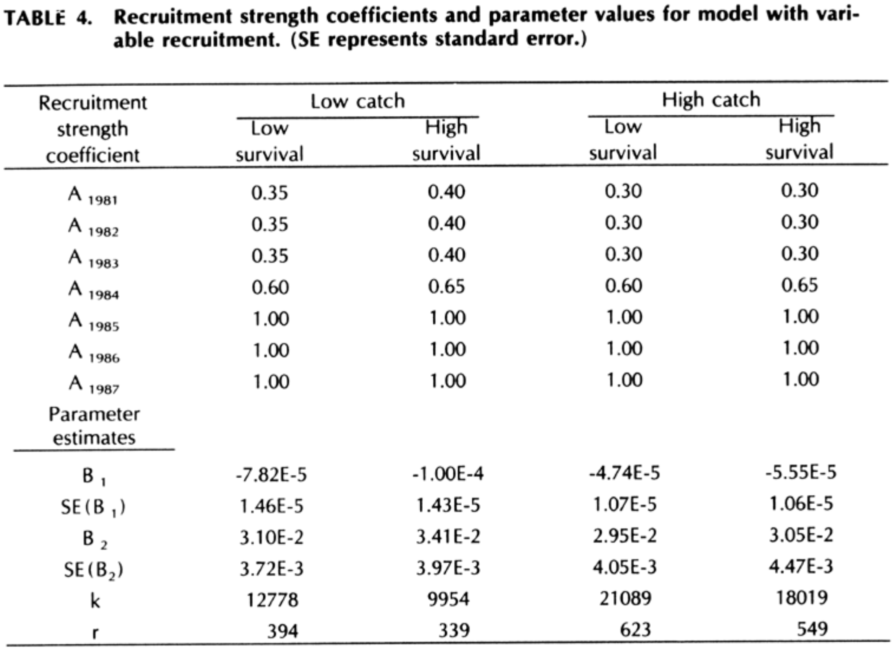

TABLE 4. Recruitment strength coefficients and parameter values for model with variable recruitment. (SE represents standard error.)

Recruitment strength coefficient	Low catch Low survival	Low catch High survival	High catch Low survival	High catch High survival
A_{1981}	0.35	0.40	0.30	0.30
A_{1982}	0.35	0.40	0.30	0.30
A_{1983}	0.35	0.40	0.30	0.30
A_{1984}	0.60	0.65	0.60	0.65
A_{1985}	1.00	1.00	1.00	1.00
A_{1986}	1.00	1.00	1.00	1.00
A_{1987}	1.00	1.00	1.00	1.00
Parameter estimates				
B_1	-7.82E-5	-1.00E-4	-4.74E-5	-5.55E-5
SE(B_1)	1.46E-5	1.43E-5	1.07E-5	1.06E-5
B_2	3.10E-2	3.41E-2	2.95E-2	3.05E-2
SE(B_2)	3.72E-3	3.97E-3	4.05E-3	4.47E-3
k	12778	9954	21089	18019
r	394	339	623	549

TABLE 4. **Recruitment strength coefficients and parameter values for model with variable recruitment. (SE represents standard error.)**

Testing for Appropriate Harvest Rates. Average harvest rates over 1986–87 were calculated using equation 12 (Table 5). Knowing harvest and natural survival rates it is possible to calculate the fraction present at the beginning of age from equation 12. The model predicts that the ratio of the number of fish captured in one age class to the number captured in the preceding age class should roughly be 33 to 52%. Data from Sunada et al. (1990) show the ratio actually ranges from 30 to 44%. The estimates from the model compare favorably with values estimated from the gill net and trawl sampling data.

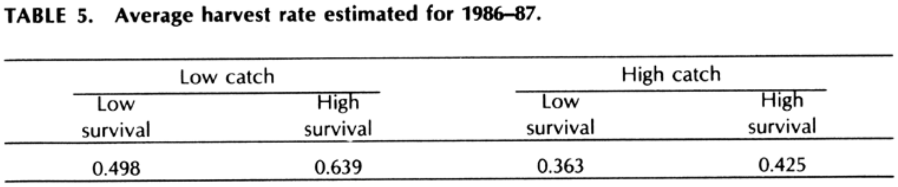

TABLE 5. Average harvest rate estimated for 1986–87.

Low catch Low survival	Low catch High survival	High catch Low survival	High catch High survival
0.498	0.639	0.363	0.425

TABLE 5. **Average harvest rate estimated for 1986–87.**

Parameter Estimates. The population values calculated using equation 9, together with the recruitment values over time for the four versions of the model, are listed in Table 6. The estimates vary depending on the version of the model. As additional information is obtained about natural survival and about mean commercial fish weight, these estimates can be fine tuned.

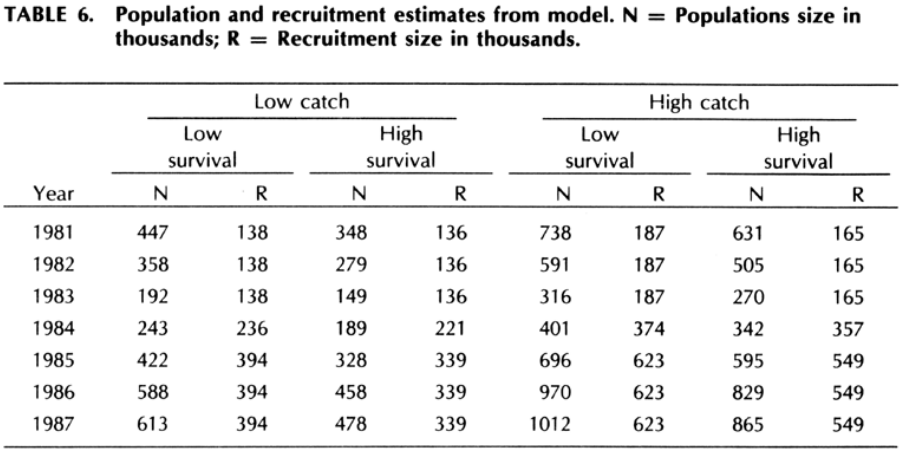

TABLE 6. Population and recruitment estimates from model. N = Populations size in thousands; R = Recruitment size in thousands.

	Low catch				High catch			
	Low survival		High survival		Low survival		High survival	
Year	N	R	N	R	N	R	N	R
1981	447	138	348	136	738	187	631	165
1982	358	138	279	136	591	187	505	165
1983	192	138	149	136	316	187	270	165
1984	243	236	189	221	401	374	342	357
1985	422	394	328	339	696	623	595	549
1986	588	394	458	339	970	623	829	549
1987	613	394	478	339	1012	623	865	549

TABLE 6. ***Population and recruitment estimates from model. N = Populations size in thousands; R = Recruitment size in thousands.***

Simulations Based on the Model

Recruitment rates greatly increased over the time series causing an upswing in the overall population levels. While recruitment was low, the population was declining. While recruitment was high, the population was increasing. It is uncertain as to what recruitment will do in the future. Possible scenarios include the following two extremes: that recruitment could stay at the high 1985–87 levels, or that recruitment could return to the low 1981–83 levels.

Simulations tested the effect of keeping the catch at its current level under the two alternative recruitment scenarios. Equation 13 was used to simulate each of the four versions of the model. Catch levels were estimated as the average catch for the years 1986–87.

High Recruitment. Results showed that if recruitment rates remain high, the population will remain near or continue to increase beyond present high levels (Figure 7). Current catch levels could continue. A large population would also bring other benefits. For a time, additional fish could be caught, reducing the population back to a smaller size. Alternatively, the population would be better protected against occasional bad years, or years of low recruitment, if maintained at high levels.

Low Recruitment. If recruitment rates decline to 1981–83 levels, the population will decrease rapidly with present catch levels (Figure 8). The number of recruits expected and the 1986–87 average catch level are listed in Table 7. The decline in the simulations occurs because more fish are caught or die of natural causes than are recruited each year. The current number of fish caught would not be sustained. Current levels would not be caught as early as 1987 to 1989 (Table 7).

To have a constant population and harvest size, the number of recruits must equal the number of fish that die due to both natural and fishing mortality. Catches would have to be reduced to 45 to 52% of current levels in order to balance the lower recruitment (Table 7). This new catch is far below current catch levels and could be allocated between the commercial and recreational fisheries in a number of ways.

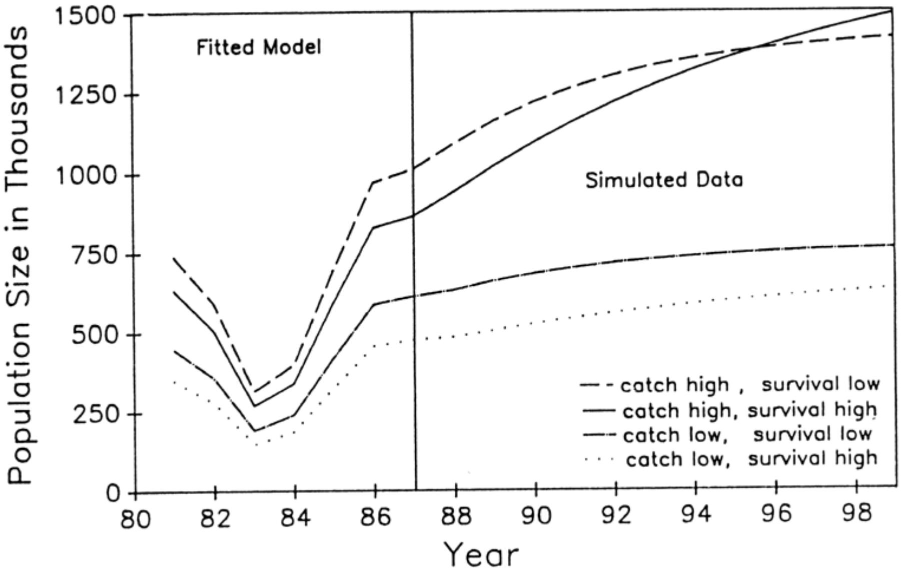

FIGURE 7. High recruitment simulations.

FIGURE 7. High recruitment simulations

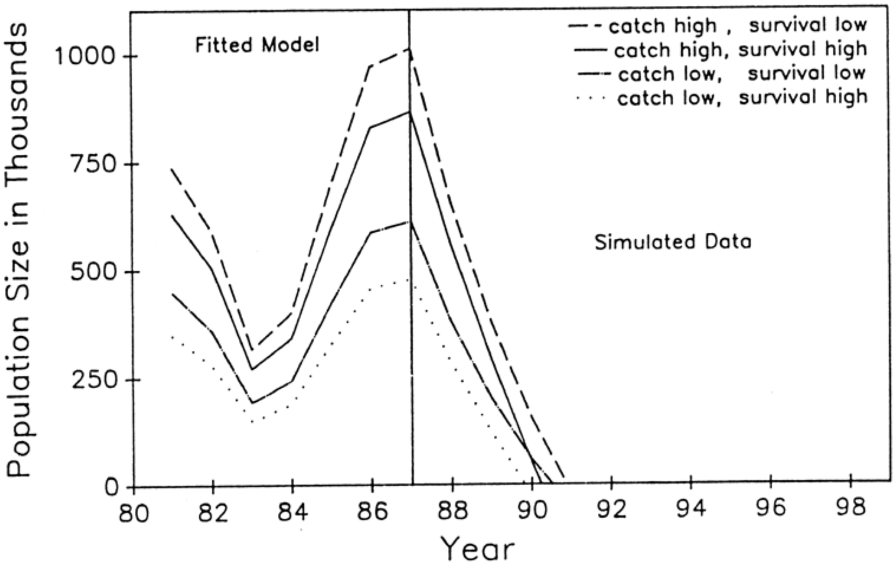

FIGURE 8. Low recruitment simulations.

FIGURE 8. Low recruitment simulations

TABLE 7. Results of simulations.

Model Catch	Surv.	Low recruit. (target catch level)	86–87 catch level	Last year with current catch	Prescribed catch proportion
High	Low	187,000	358,000	1989	52%
High	High	165,000	358,000	1989	46%
Low	Low	138,000	299,000	1988	46%
Low	High	136,000	299,000	1987	45%

TABLE 7. ***Results of simulations.***

It is important to note that the population sizes and recruitment sizes are likely overestimated and that the sustainable catch should actually be below the recruitment rate, to allow for natural mortality. Because of this, catch levels would likely need to be reduced below those suggested, and current catches would likely not be met earlier than suggested.

DISCUSSION

Development of the Model

The model is potentially limited by a number of factors. Some involve the biology and design of the model, such as the way recruitment is represented or the way recreational CPUE represents the entire fishable population. Other factors involve the mathematics of the model, such as the potential overfitting of the data. The most fundamental limiting factor, however, is the small number of data points on which the model is based.

Only 8 years of data are used due to the unavailability of information on the recreational fishery prior to second half of 1979. Although catch data from commercial passenger fishing vessels (CPFV) are available prior to 1979, these data are only one component of the overall recreational catch and would not provide figures for the total recreational catch. Similarly it would not be appropriate to construct figures for the recreational catch from the commercial catch data as the dynamics of the two are significantly different. Without a longer time series of total catch, the model is limited.

Recruitment in this model is not based on an earlier stock size or an overall recruitment rate. Reed and MacCall (1988) assume that the majority of a cohort enters the fishery at age 5. In order to identify a stock-recruit relationship, the population size in one year would need to be compared to the population size 5 years earlier. With only eight data points available, a stock-recruit relationship would be based on only three points. This is clearly not enough to produce a viable relationship.

Recruitment, as it is modeled here, assumes that sufficient eggs will be produced even at small population sizes. This is supported by the work of R.J. Lavenberg (Natural History Museum of Los Angeles County, pers. comm.) which found that 22-inch female halibut could produce 300,000 eggs per week, conservatively, in the laboratory. The current representation of recruitment also supports density dependent recruitment rates, as the number of recruits does not increase as the population size does.

Changes in the recruitment strength coefficient might also be due to changes in availability, or changes in immigration or emmigration, etc. It is possible that during the time period a much larger segment of the population became available to the fishery. Whether the change was due to recruitment or availability, the question still remains: will it continue?

Recreational CPUE in this model is used as an index of population size available to the fisheries (Beverton and Holt 1956, 1957). An overall index is not available at this time. And CPUE cannot be obtained from each component of the fishery. Even if it could, a common measure of effort would be difficult to find.

The recreational CPUE is based on a fishery that should not have become more efficient at catching fish during the last 8 years. Information is based on trips directed at catching halibut and excludes undirected trips. The estimates are based on straight telephone surveys and are not converted, expanded, extrapolated, or manipulated. The recreational fishery includes CPFV anglers, private boat anglers, and shore anglers. Since an overall CPUE estimate is not likely to be reliable, and other CPUE indices for the fishery have associated limitations and problems, the recreational index appears to be the most useful as an index of available population size.

Potential problems exist with the mathematics of the model. Seven data points are used to fit two parameters, k and r. In addition, appropriate values are found for the recruitment strength coefficients. This could easily be conceived as overfitting the data. Values of the recruitment strength coefficient were selected to be adjusted based on the fit of the constant recruitment model. It was clear from the fit that the values for 1981–83 would have to be lower than the values for 1985–87, with the value for 1984 at an intermediate value. One value was used for the 3 years 1981–83 and an intermediate value was used for 1984. Although these values were not estimated by multiple regression methods, perhaps it does bring the number of parameters estimated closer to three or four.

The number of parameters which are estimated is not unreasonable and there are two major benefits. A much better understanding of the system is possible through the current parameterization, and the current structure of the model demonstrates the need for additional data and a longer time series.

Policy Implications

This work indicates that recruitment increased greatly over the observed time series. Simulations demonstrated that the catch could continue at current levels if recruitment remained high, but if recruitment returned to low levels, catch would need to be greatly reduced. The range of alternative scenarios provides an interesting challenge to the resource manager.

If management knew the cause of the recent increase in recruitment, management may be able to predict future recruitment levels. An El Niño event took place warming the sea surface of the northeast Pacific from September 1982 to November 1983 (Squire 1987). Such ocean warming may have caused changes in the population dynamics of halibut. Laboratory work has shown that an increase in water temperatures improves growth and survival of halibut prerecruits (R.J. Lavenberg, pers. comm.). Increasing the growth and survival of prerecruits would increase the expected number of recruits of each cohort involved. Since halibut don't fully recruit into the fishery until age 5, increased recruitment would be expected for at least 5 years, when all of the prerecruits affected by the El Niño entered the fishery.

If the El Niño was responsible for the higher recruitment levels, recruitment will likely return to the lower levels of 1981–83. In order to avoid overexploiting the halibut population, management could gradually reduce the allowable catch in line with sustainable yield projections, perhaps to 45–50% of current catches. This could be accomplished through direct methods such as catch limits combined with season closures or through indirect methods such as gear restrictions. Reductions of this magnitude would have additional benefits, as suggested by Reed and MacCall (1988), based on yield per recruit analyses. They stated that reducing fishing effort would raise the catch biomass, and that optimal levels of fishing intensity were at approximately half of current levels.

Although the El Niño explanation is plausible, there is no proof that it caused the increase in recruitment or that recruitment will return to 1981–83 levels. An alternate explanation for the observed recruitment pattern is that recruitment may be highly variable and dominated by a range of environmental effects. A developed management plan should be able to react to any of the likely possibilities: recruitment staying at high levels, recruitment returning to 1981–83 low levels, or recruitment varying greatly. In this case the policy must be to be able to gather information on upcoming recruitment and react accordingly to the information.

If management would monitor the prerecruits over time, future recruitment and population sizes could be predicted. The knowledge of good or bad upcoming years would allow the fishery to react by using direct regulations such as quotas and season closures when the quotas were met. Prerecruits could be monitored by sampling sublegal halibut in the sport or commercial catch or in surveys. Harvests could be adjusted on a year-by-year basis to meet the expected number of new recruits. This policy would be flexible enough to face a large variety of alternative recruitment scenarios.

Additional Data and Research Needed

Continued monitoring of the halibut population and the collection of additional data are needed to improve the present model. A longer time series of data would mean more accurate parameter estimates and/or the estimation of additional parameters. At the very least, the time series of data on catch, effort, and CPUE should be continued for all components of the fishery.

At present, population and recruitment estimates vary between versions of the model. Additional information on natural survival rates and on average fish weight of the commercial catch would allow an analysis of one time series of population and recruitment numbers instead of four.

Increasing the length of the data time series would also allow for a better understanding of the recruitment process. Is there a stock-recruit relationship underlying the recruitment process that can be estimated, or is recruitment dominated by environmental factors? To make more effective management policies, a better understanding of the recruitment process is necessary.

If recruitment is based on a stock-recruit relationship, policies should facilitate experimentation with stock sizes in order to estimate those which produce optimal yield (Walters and Hilborn 1976; Walters 1986).

Recruitment may be largely driven by environmental factors. Caution is urged against spending large amounts of money to study environmental processes; these usually involve correlative studies which do not show the causes. Even if causative factors could be identified, environmental factors cannot be satisfactorily predicted, usually. For a more detailed discussion see Walters and Collie (1988).

Current allocation arguments between the commercial and recreational fishermen will continue in any case. This model can be used as an underlying population model in future attempts to study the effects of proposed management policies on the fisheries and the population.

The monitoring of prerecruits and the collection of catch, catch at age, and effort information of the fishery, overall, should be increased to improve assessment of the halibut population. This model should be thought of as a rough beginning for halibut assessment. Additional data will allow for improved population and recruitment estimation. The parameters currently in the model are inherently necessary. Additional parameters or model specifications could be eventually added to increase the model's ability to answer specific management questions.

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BIOECONOMIC EVALUATION OF THE CULTURE/STOCKING CONCEPT FOR CALIFORNIA HALIBUT

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ABSTRACT

We describe development of a model used to evaluate the bioeconomics of culture for stocking of the California halibut, Paralichthys californicus. Results from this model provide guidance for future research and preliminary estimates of feasibility. The model mimics growth of a cohort in culture from postlarvae to release, then in the ocean from release to mortality from natural causes or the fishery. Costs of culture and the benefits of cultured fish to the fishery are calculated. The latter are given in terms of number of released fish caught, biomass caught per release, cost per fish caught, and net benefit per released fish. The cost of post-larval fish is shown to be a substantial part of culture costs and should be reduced if possible. We demonstrate a graphical method for determining the release time that minimizes cost per recruit. For current parameter values this value is about 300 d. Both culture costs and optimal release time are sensitive to costs of food and space. We graphically show the trade-off between high growth rate and high costs of culture feeds. The cost of producing a recruit depends on post-release survival rate, but is not as sensitive as expected because of a compensatory shift in optimal release age. Costs per released fish caught could be near $5/fish if natural growth rates could be achieved in culture and the culture period could be extended to 300 d.

INTRODUCTION

In 1984 the Ocean Resources Enhancement Program (OREHP) began research to develop the biological and physical means to culture and stock California halibut, Paralichthys californicus, for fisheries enhancement. In addition to the biological research on culture and early life history (Gadomski et al. 1990), development of the culture/stocking concept required concurrent economic evaluation. On the basis of past experience, we began this kind of evaluation in the early stages of this project even before all of the data necessary to establish economic feasibility had been obtained. Although the ultimate goal of our economic evaluation was to determine feasibility and optimal manage ment policy, the main purpose of our early evaluation was to guide research and planning.

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We developed the mathematical models necessary for economic evaluation and performed the economic analysis possible with currently available data. We did this by developing several computer programs based on these models and incorporating available data into them. We then provided these models to other OREHP researchers so that they could continue the economic evaluation as additional data became available. These models will enable them to continue to evaluate the culture/stocking concept as research progresses by refining estimates of parameter values in the models and conducting further analysis. For information about the programs themselves see Appendix B.

Although the ultimate general goal of the evaluation is to determine economic feasibility (or at least to project the total costs of culture and benefits of stocking), other specific goals have been important in the early stages of the project. The primary purposes of the initial model were: (1) to evaluate dynamic behavior (i.e. to get an idea of how the system "works"), (2) to establish which of the needed pieces of information were available and which were outstanding, (3) to evaluate sensitivity of net benefits to unknown or poorly known parameters, and (4) to obtain a rough idea of the costs of culture and stocking.

We first present the relevant background on California halibut. This is a review of what is known about the life history, existing fisheries, and culture of these and related species. We then describe the models used in the computer programs that were developed to evaluate culture and stocking of this species. These use parameter values from the background section. Finally we present results of analyses using these programs and discuss their economic implications.

FISHERY AND CULTURE BACKGROUND

Development of a model of the culture, stocking, and fishery systems requires a review of available information. In this section, we describe existing information on life history, the fisheries, and culture performance for the California halibut. Information available on culture performance is limited; hence, some parameters from other similar species that have been cultured are used.

Life History and Fisheries

The California halibut supports both commercial and sport fisheries in southern California (Figure 1). It is fished in California and in Mexico and has experienced well-documented declines in catch leading to concern about the health of the stocks. The U.S. commercial catch reached a peak of 4.7 million pounds in 1919 and declined to 0.26 million pounds in 1971. Since then there is some evidence of a recovery. It is not known whether this is a result of the more restrictive regulations or due to natural fluctuations in abundance or availability (Methot 1983). For a more complete historical perspective see Barsky (1990).

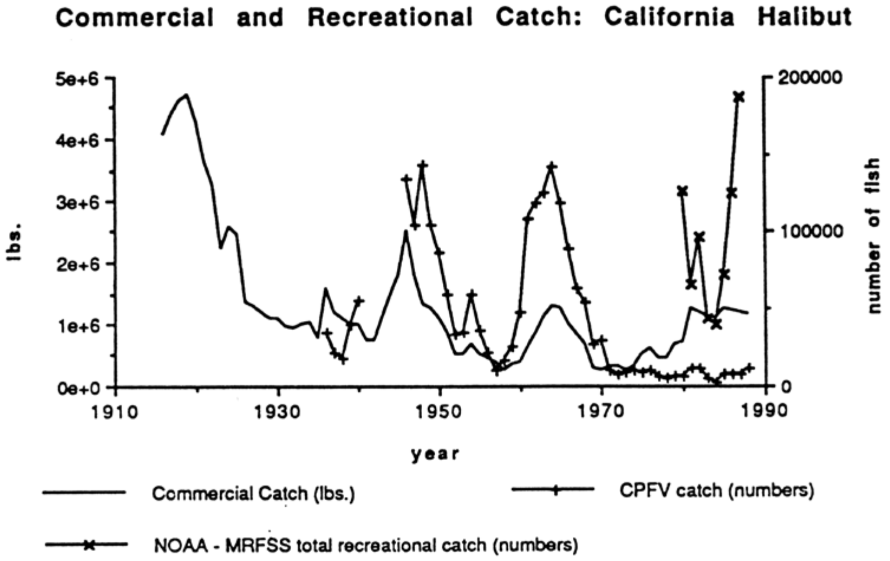

FIGURE 1. History of the California halibut fisheries. The solid line is the total harvest by commercial fishermen. The +'s are the harvest by commercial passenger fishing vessels. The X's are total harvests by sport fishermen.

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The commercial fishery for California halibut has traditionally been primarily an otter trawl fishery but, in recent years, entangling nets have dominated the catch (Methot 1983). Since 1911 the use of otter trawls has been restricted in nearshore waters in southern California (Clark 1931). In 1971, regulations were enacted that allowed trawling within 3 mi of shore in the Santa Barbara Channel area. These same regulations established a minimum mesh size of 7.5 inches, a minimum size limit of 4 lb for commercially caught halibut, and season closures during the spawning season (Karpov 1981).

The sport fishery for California halibut is primarily a hook-and-line fishery that has operated from commercial passenger fishing vessels (CPFVs), man-made structures, shorelines, and private boats. The gear used is specialized and there is little incidental catch of other species. Since the late 1960s, CPFVs have not been able to profitably target on California halibut, and the proportion of the sport catch taken by private boats has increased (Methot 1983). Recently a sport fishery involving SCUBA gear and pole spear or spear gun has developed (C.A. Pattison, California Department of Fish and Game, pers. comm.). For a more complete historical description of the recreational fishery see Oliphant (1990) and Helvey and Witzig (1990).

In spite of the long history and the economic importance of this fishery, relatively little is known about the life history of California halibut. They spawn at depths of 6–20 m during the winter and spring, with the greatest frequency occurring from February to May. The larvae and postlarvae are pelagic (Frey 1971; Plummer et al. 1983; Lavenburg 1987). Young fish are common in embayments where they are believed to remain through the early juvenile phase, but it is not known whether the larvae settle in bays or migrate there after settlement (Plummer et al. 1983). The size distributions of fish caught in embayments and in shallow coastal waters suggest that juvenile halibut can reside in bays for a period of 2–3 years, reaching sizes there up to 30 cm standard length, but that most migrate to sea when they reach a length of about 20 cm (Frey 1971; Haaker 1975; Barry and Cailliet 1981; Kramer and Hunter 1987; Kramer 1990; Hammann and Ramirez-Gonzalez 1990). Males may begin to mature when they are in their second year, females 1 to 2 years later, and all fish are probably mature when they are 5 or 6 years old (Frey 1971). California halibut may live as long as 30 years and attain weights up to 23 kg (Frey 1971).

Growth patterns of the California halibut have have been reported in terms of length-at-age data and length-weight data. Length-at-age has been reported by Hulbrock (1974) for males ages 1 through 19 years and females ages 1 through 18 years, by Frey (1971) for females ages 1 through 12 years, and by Haaker (1975) for males and females ages 1 to 3 years. The three data sets appear to be consistent, so the data from Hulbrock were used to describe growth. We fit von Bertalanffy growth equations to the length-at-age data to obtain $L_t = 1130 [1 - e^{(-0.1234 t - 0.1114)}]$ (1a) for males and $L_t = 1440 [1 - e^{(0.118 t - 0.0852)}]$ (1b) for females where L_t is total length in millimeters at age t years. The length-weight relationship for both sexes was determined by regression of Hulbrock's data to be $W_L = 7.811 \times 10^{-6} L^{3.048}$ (2) where W_L is weight in grams at length L in millimeters. Reed and MacCall (1988) report parameter estimates similar to these.

The growth rate of juvenile fish during the first 2 years is less well known. A linear growth rate with intercept set at the initial post-larval size and the slope chosen so that size at 1 year corresponds to the von Bertalanffy growth equations for the California halibut population (analysis of data from Hulbrock 1974), would lead to a slope of 0.061 cm/d. However, the slope of the von Bertalanffy growth equation itself at 1 year is lower, 0.030 cm/d for males and 0.038 cm/d for females. Kramer and Hunter (1987, 1988) report a growth rate of 0.033 cm/d (10 mm/month from laboratory studies) and a size of 150 mm in bay/lagoon habitats at 9 months post settlement (0.039 cm/d). Growth of halibut in Todos Santos Bay fit a line with a slope of 9.51 cm/year and an intercept at 8.98 cm for ages 1 through 7 which indicates a growth rate of 0.051 cm/d during the first year and 0.026 cm/d in subsequent years (Hammann and Ramirez-Gonzalez 1990).

Adult mortality rates have not been directly estimated for California halibut. Reed and MacCall (1988) used a method based on the longevity of the species (cf. Hoenig 1983) to estimate the average annual instantaneous total mortality rate to be 0.15/year. This method is biased low depending on sample size (Hoenig 1983). In their analysis of the California halibut fishery, Reed and

MacCall (1988) used the values 0.1 and 0.2/year. The natural mortality rate for Pacific halibut, Hippoglossus stenolepis, off the coasts of Washington, British Columbia, and Alaska has been reported as 0.31/year, but this estimate may be biased upward because of loss of tags from fish used in these studies (Myhre 1967). The Pacific halibut used to estimate mortality rates were larger than the average size of the California halibut and so would be expected to have lower natural mortality rates (if mortality were due to predation). However, because of the potential bias in the estimate of mortality for Pacific halibut, 0.3/year is a reasonable upper limit for the natural mortality rate of adult California halibut. This value is consistent with values for similar species (Pauly 1979).

Mortality rates of juvenile halibut differ from those of adults but are similarly poorly known. Annual instantaneous mortality rates for a similar species, the speckled sanddab, Citharichthys stigmaeus, were estimated by Ford (1965). He estimated mortality rates both from the rate of decrease in density and directly from the age structure in 1962 and 1963. Because his age-structured estimates assume that recruitment has been constant, we have used only the estimates from the rate of decrease in density. The averages of the annual instantaneous mortality rates corresponding to the monthly percent survival reported by Ford are 2.286, 0.624, and 1.080/year for fish of age 0, 1, and 2, respectively. All three age classes of sanddabs are smaller than 1-year-old California halibut, thus the halibut would be expected to have lower mortality rates at age. In view of the paucity of mortality rate estimates for California halibut, we use a range of natural mortality rates in our economic evaluation.

Culture Performance

The information required to develop a model of the culture system comes from several sources. Biological information on culture of this species is relatively scarce, hence we have had to rely in part on information from other cultured species. Information on the components of the physical plant and their costs are also occasionally borrowed from other culture schemes.

The biological information needed for aquaculture is a description of how the organism responds to the environment provided in the culture system. In particular this would be growth, survival, food and oxygen consumption, waste production, and subjective criteria such as fitness for stocking or condition of flesh. Ideally each of these could be fully described over a range of environmental parameters such as temperature, oxygen levels, and feeding rates that affect the cultured species. Some of this information has been and is being developed within the OREHP project—in particular, information on the maintenance of spawning stock and growth and survival of the egg, larval, and juvenile stages. For older life history stages, information has been limited to observations of growth of captured individuals and growth data incidental to other experiments which may not reflect the potential growth rate of cultured fish. This presents a significant limitation to the precision of a detailed model, because costs are sensitive to growth rate. Preliminary estimates of parameters such as food conversion rates and tolerances for minimum dissolved oxygen levels and maximum ammonia concentrations have been taken from culture systems for similar species.

For many species, the aquaculture environment is adjusted so that growth rate is greater than that observed in the natural environment. Stephens et al.

(1988) in Table 7 of their annual report indicate growth rates of 0.019 and 0.028 cm/d for the first 97 d after hatching of California halibut at approximately ambient temperatures (16°C) and elevated temperatures (28°C) respectively. These growth rates are somewhat lower than estimates for the wild population but include the metamorphosis to the juvenile form during which the fish changes its shape significantly. Captured individuals raised in the laboratory yield similar growth rates (0.026 cm/d, Kaupp 1989 and 0.025 cm/d, Innis 1990) when raised over several years. The juvenile growth rates eventually attainable in an aquaculture system may be higher when the environmental requirements of the larval and juvenile stages are better known.

The nutritional energy requirements of fish can be partitioned into two categories: growth and maintenance. Maintenance requirements include basal metabolism and activities such as movement and feeding. For fish the caloric requirement for maintenance is commonly considered to be a power function of weight with the exponent falling between 0.6 and 0.8 and a coefficient dependent on activity level and body temperature. We have used a value of 0.69 for the exponent (from Townsend and Calow 1981, p. 27), and .05 kilocalories (kcal)/d for the coefficient in the power function. Schmidt-Nielsen (1979, p.186) gives a value of 0.001 kcal/h for poikilotherms at 20° C (for body weight in grams). However, this is a minimum estimate; active swimming can increase energy expenditures significantly. For the purpose of this model we have assumed a level twice the minimum.

In rapidly growing fish a large portion of the diet is used in growth. In aquaculture, growth is often expressed in terms of conversion efficiency, kilocalories of fish produced per kilocalorie of food. Food conversion efficiencies for cultured fish vary depending on species, feed type, and culture system. Typically, values of 1:3 or 1:4 (Bardach et al. 1972, p. 12) are considered to be very good. Reported values often include maintenance requirements. We use 1:3 in our standard model runs so that for each kilocalorie equivalent of weight gain the fish must be fed three times that many kilocalories of food. This is added to the energy required for maintenance to determine total food kilocalories in a time interval.

Oxygen requirements of cultured fish can be calculated using a mass balance equation by assuming that all food that is not converted to tissue is oxidized. Approximately 0.275 g of oxygen are required to metabolize each kilocalorie of food. Aeration requirements can be calculated as the difference between the available dissolved oxygen and this requirement. A value of 6.75 mg oxygen per liter is recommended as a minimum level that should be maintained for nonanadromous marine species (Poxton and Allouse 1982).

The most important waste product in this culture system will be ammonia. The effect of ammonia on the fish is dependent on temperature and pH because ammonia is only toxic in the unionized form. The unionized portion is sensitive to pH, being about 1% of total ammonia at a pH of 7 and 10% at a pH of 8 (Allen et al. 1984, p. 163). We have assumed an intermediate value of about 5% which corresponds to a pH of about 7.5. Increasing levels of ammonia first begin to inhibit growth, then at higher concentrations lead to mortality. For example, growth of Dover sole, Solea solea, and turbot, Scophthalmus maximus, were unaffected by unionized ammonia concentrations of around 0.1 mg/L, but levels of 0.3–0.9 mg/L prevented all growth (Poxton and Allouse

1982). Brownell (1980) found values of 24-h LC50 near 0.4 mg/L and values that inhibited first feeding > 0.1 mg/L for marine fish larvae of several species. Setting the unionized ammonia tolerance at 0.1 mg/L yields a total allowable ammonia concentration of 2.0 mg/L.

Waste products are removed from a culture system with the waste water that flows out of the tanks. In a fish culture system, ammonia concentrations can be calculated using a mass balance equation involving the excess nitrogen in the feed (above that consumed by growth) and the inflow and outflow rate of water (Allen et al. 1984). Water flow rates can then be set so that ammonia is removed from of the system at the same rate that it is produced while maintaining the ammonia concentration in the tank below the critical concentration.

The composition of the food and the feeding rate affect growth and mortality rates directly but also determine the waste levels in the culture unit which affect the aeration requirement and water flow rate. A cost effective food composition should balance the nutrition requirements of the fish against the costs of waste removal and is necessarily species and culture system specific. We have limited the food composition parameters in the model to caloric content and ammonia equivalent. The feeding rate is calculated to satisfy the caloric requirements for growth and maintenance. We have arbitrarily set the feed parameters at an energy content of 5 kcal/g and an ammonia equivalent of 32 mg/g; these values are equivalent to a feed composed of 20% fat, 20% protein, and the rest carbohydrate (cf. Deniel 1976; Kuhlman et al. 1981).

The density of fish in the culture unit and the size and shape of the units affect growth and mortality rates in a complex and subtle manner. Optimal rearing densities are often dependent on poorly understood interactions such as the shape and water flow patterns of the tanks, the possibility of disease transmission, and species-specific behavioral patterns such as schooling, individual spacing, and cannibalism. Flat fish require a large benthic surface which places some constraints on the size and shape of the tanks. We have arbitrarily assumed the tanks to be 20,000 L; this corresponds to a tank 1 m deep by 6 m in diameter that is kept ¾ filled. We have used tilapia and trout as representative of species for which densities have been optimized. Tilapia have been successfully reared at densities of 50 g/L of water (Ballerin and Haller 1982) and trout are reared at densities in excess of 10 g/L (cf. Leitritz and Lewis 1976). The number of tanks required is calculated to satisfy the biomass density criterion during the time step.

CULTURE AND FISHERY MODELS

To evaluate culture and fishery independently, then combine results, we divided the life history of a cultured, then stocked, fish into two phases. The point dividing these phases had to be greater than the maximum size to which fish would be cultured and less than the lower size limit of the current fishery. We chose this point somewhat arbitrarily to be 24 cm, which is a size at which the juveniles have typically left the nearshore environment. We refer to fish above this size as being in the potentially fishable population, and when we use the word "recruitment" we mean recruitment to this population. We stress that this is a somewhat arbitrary dividing point, and its exact value, as long as it is greater than the maximum culture size and less than the lower size limit in the fishery, will not affect the cost/benefit analysis. This separation results in three consecutive periods in the life history of a cultured, then stocked, fish: the culture phase, post-release phase, and post-recruitment phase (Figure 2). The first phase covers the period from hatching to release. The second phase covers the period from release to the size of recruitment into the potentially fishable population (24 cm), and the third covers the period from that size through adulthood and possible capture in the fishery. The specific release size can vary from post-larval size (i.e. no juvenile culture) to the size of recruitment into the fishable population (24 cm). During the time between release and the recruited size, fish are assumed to be in the "juvenile habitat" and are subject to different growth and mortality rates than after the recruited size when they are assumed to have adult growth and mortality rates.

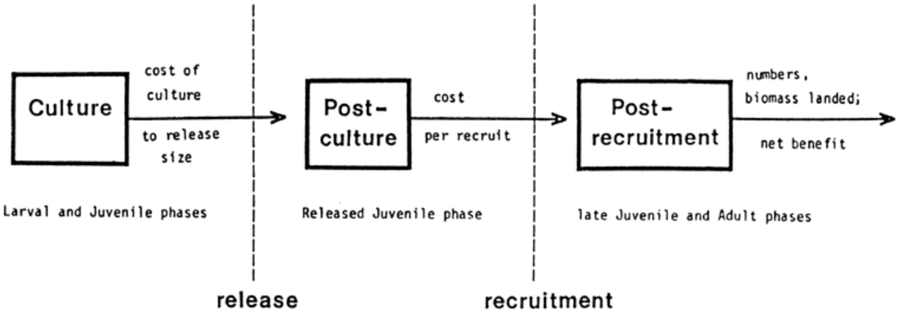

FIGURE 2. A schematic of the culture/release process as described in the computer programs for eocnomic evaluation.

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Culture System Model

The model of the culture system has been developed to provide a means of examining the economics of culture based on the limited information presently available. The culture system model consists of three submodels: biological, physical, and economic (cf. Allen et al. 1984). The biological submodel defines the behavior of the fish in the environment of the culture system. The physical submodel is a description of the physical plant itself and the necessary inputs, and the economic submodel calculates the costs associated with running the culture system. The model is calculated iteratively. Each iteration represents a time step (usually 7 or 10 d) and begins with the growth of the fish. Then, using the growth, present size, and the environmental requirements of the fish, the necessary physical plant is sized and inputs are calculated. Finally, the costs are totaled to complete the iteration. The model is structured in this way to allow extrapolation of limited data for analysis over a wide range of size classes.

Biological Submodel

The biological model calculates growth and mortality during each time step. Growth in length is calculated as a function of time. We have used a linear model for increase in length so that,

$$L_{t+1} = L_t + (g_c \times \delta_t) \quad (3)$$

with $L_0 = L_m$

where

L_t = length at time t

L_m = initial length

g_c = daily growth rate in the culture system

δ_t = time interval.

EQUATION

For our baseline model we have used approximately the estimated wild population growth rate (cf. Hammann and Ramirez-Gonzalez 1990) of $g_c = 0.05$ cm/d and an initial length of $L_m = 2.5$ cm.

Weight is calculated using the length-weight relation for the natural populations

$$W_t = w_c \times L_t^{w_e} \quad (4)$$

where

W_t = weight at time t

w_c = weight-at-length coefficient

w_e = weight-at-length exponent

EQUATION

In our model we used the values given above computed from Hulbrock's (1974) data. Weight gain is the difference between weight at the beginning and end of the time step.

$$\delta_w = W_{t+1} - W_t = \text{weight gain per fish per time step} \quad (5)$$

We use an exponential survival function so that

$$N_{t+1} = N_t \times \exp(-m \times \delta_t) \quad (6)$$

where

N_t = number of fish at time t

m = mortality rate per day

EQUATION

In the baseline model the mortality rate $m = 0.005$/d.

Physical Submodel

The environmental variables—food, water flow rates, aeration requirement, and tank numbers—are calculated to meet the minimum caloric requirements for growth and maintenance, as well as maintain required dissolved oxygen levels, ammonia concentration and biomass density of fish.

The caloric requirements per time unit are partitioned into a growth requirement and a maintenance requirement that includes both basal metabolism and active swimming (Allen et al. 1984). Total food is calculated to meet these two needs as

$$F_t = \frac{(\delta_w \times k_b \times r_f) + (\delta_t \times b_c \times W_t^{be})}{k_f} \qquad (7)$$

where

F_t = weight of food required per fish per time step

k_b = kilocalories per unit of fish biomass

r_f = food conversion rate, kilocalories of fish gain per kilocalorie of food

b_c = maintenance coefficient

b_e = maintenance exponent

k_f = kilocalories per unit of food.

EQUATION

Using a mass balance equation, we calculate the oxygen required to metabolize all of the food, minus the amount which becomes fish biomass. It is

$$O_{2t} = [(F_t \times k_f) - (\delta_w \times k_b)] \times 0.275 \text{ g/kcal} \qquad (8)$$

where

O_{2t} = oxygen requirement per fish per time step

0.275 g/kcal = the amount of oxygen required to metabolize a specified amount of food.

EQUATION

The latter ratio (oxygen to energy) is for a hypothetical food which is 50% fat and 50% carbohydrate and protein by energy content. This constant is chosen conservatively so that the oxygen requirements of most common diet mixtures will be met. A higher fat content would require a higher rate but not greater than 0.30 g/kcal.

Ammonia production is also calculated from a mass balance equation as the amount of ammonia in the food, less that which becomes fish flesh. It is

$$NH_{3t} = (f_t \times n_f) - (\delta_w \times n_b) \qquad (9)$$

where

NH_{3t} = ammonia produced in time step t

n_f = grams of ammonia per gram of food

n_b = grams of ammonia per gram of biomass.

EQUATION

This assumes that all the nitrogen in food is excreted as ammonia or in a form that is converted to ammonia in the tank system. Because not all of the nitrogen is excreted as ammonia, it is a conservative (high) estimate.

For this evaluation, we have assumed a flow-through system with no water treatment. Water flowing through the system adds dissolved oxygen and removes ammonia. Flow rates must be set to provide a specified safe level of ammonia, but the additional required amount of oxygen can be met through aeration. Regardless of whether the tanks are aerated, the flow rate must be sufficient to prevent the ammonia concentration from exceeding a critical level. Flow per fish is

$$H_2O_t = \frac{NH_{3t} \times 2.0}{NH_{3c}} \qquad (10)$$

EQUATION

where H_2O_t = total water required per fish in time step t NH_{3c} = maximum allowable ammonia concentration. Because of the variable nature of ammonia excretion due to noncontinuous feeding and incomplete mixing of water, we have included a safety factor of 2.0.

If the tanks are aerated, H_2O_t is the required flow rate per fish. If the tanks are not aerated, the dissolved oxygen in the inflowing water is assumed to be the primary source of dissolved oxygen in the system. The aeration deficit is calculated as O_{2d} = minimum [H_2O_t x (O_{2in} - O_{2c}) - (O_{2t} x 2.0) or 0.0] (11) where O_{2d} = deficit in grams of dissolved oxygen per fish per time step O_{2in} = dissolved oxygen concentration in inflowing water O_{2c} = minimum allowable dissolved oxygen concentration minimum = function which selects the minimum of two values. We have again included a safety factor of 2.0 to allow for the effects of imperfect mixing and nonconstant usage. If the oxygen deficit is zero, the flow necessary to remove the ammonia is satisfactory for the oxygen requirement as well. A nonzero oxygen deficit must be met by increasing the inflow of water, so that

$$H_2O_t = \frac{O_{2t} \times 2.0}{O_{2in} - O_{2c}}$$

EQUATION

The number of tanks required is based on a maximum biomass density criterion, so that

$$T_t = \frac{N_t \times W_t}{d_c \times t_v} \qquad (13)$$

EQUATION

where T_t = number of tanks required at time t d_c = maximum allowable density t_v = tank volume.

Economic Submodel

The cost per individual entering the fishery is the total cost to raise a cohort divided by the number of that cohort that survive to enter the fishery. The total cost is the sum of the accumulated costs for food, electricity, water, and space. These are calculated on a per time step basis as the fish grow from post-larval size. We have not included economies of scale or discounting of future value. The cost of food per time step for the cohort is $C_{ft} = F_t \times N_t \times P_f$ (14) where P_f = price per unit of food ($/kg). The cost of electricity per time step for the cohort is $C_{et} = (H_2 O_t \times N_t \times H_2O_e) + (T_t \times T_e) \times P_e$ (15) where H_2O_e = electrical use per unit water (pumping) T_e = electrical use per tank (lights, aeration, circulation pump) P_e = price per unit of electricity (dollars/kwh). The cost of water per time step for the cohort is $C_{H2Ot} = H_2 O_t \times N_t \times P_{H2O}$ (16) where P_{H2O} = price per unit of water (treatment, prorated pumps and piping).

The total capital cost during a time step is proportional to the number of tanks used during the time step, so that CTt = $T_t \times P_T$ (17)

where P_T = price per tank per day (maintenance, labor, and prorated tank, building, and accessories). The total accumulated cost of culturing a cohort up to age t is $C_{At} = C_{At-1} + C_{ft} + C_{et} + C_{H2Ot} + C_{Tt}$, (18) beginning with the initial cost of the cohort (as either postlarvae or eggs), $C_{Ao} = N_o \text{ x } P_{pl}$ (19) where P_{pl} = price per postlarva or egg. Electrical use is calculated as that required to pump the total water flow 10 m vertically plus a fixed amount for lighting and aeration of tanks. The prices and parameter values are listed in Table 1.

Post-Release, Pre-Recruitment Model

The total accumulated cost of the cohort at age t is the total cost per stocked fish if the cohort is stocked at that age. However, the cost per recruit (24 cm) depends on the rate of survival to 24 cm as well as cost per stocked fish. The survival rate to recruitment depends on the time required to grow to the minimum entry size (24 cm) and the size-specific survival rate during that time. To describe post-release growth, we have used the linear growth model which is equivalent to growing the fish from post-larval size to the size at 1 year in the natural population over the span of 1 year, so that

$$t_L = \frac{L_r - L_t}{g_n} \qquad (20)$$

EQUATION

where t_L = time to reach the fishery L_r = minimum length in the fishery (size at recruitment) L_t = length at time of release g_n = linear growth rate for the natural population. For the baseline model we use the approximate estimated natural growth rate of juveniles (0.05 cm/d). We have assumed the mortality rate is a linear function of length in this phase. Because growth is linear, the rate is equal to the rate for the mean size during the time period prior to entering the fishery, so

$$m_L = m_p + \left[\left(\frac{L_t + L_r}{2} - L_p\right)\left(\frac{m_r - m_p}{L_r - L_p}\right)\right] \qquad (21)$$

EQUATION

TABLE 1. Parameters and baseline values for culture system model.

Symbol	Parameter	Baseline value
L_m	Initial length, length of postlarva	2.50 cm
g_1	Growth rate	0.050 cm/d
δ_t	Time interval per time step	10 d
w_c	Coefficient for length to weight function	0.00872
w_e	Exponent for length to weight function	3.048
m	Mortality rate per day	0.005
k_b	Kilocalories per unit of fish biomass	1.3 kcal/g
r_f	Food conversion rate, kcal of fish gain per kcal of food	0.30
b_c	Coefficient in basal maintenance function	0.05
b_e	Exponent in basal maintenance function	0.69
k_f	Kcal per unit of food	5.0 kcal/g
n_f	Ammonia concentration in food	0.032 g NH3/g
n_b	Ammonia per gram of fish biomass	0.016 g NH3/g
NH_{3c}	Maximum allowable ammonia concentration	0.10 mg/L
O_{2in}	Dissolved oxygen concentration in inflowing water	8.0 mg/L
O_{2c}	Minimum allowable dissolved oxygen concentration	6.75 g O_2/L
d_c	Maximum allowable biomass density	50.00 g/L
t_v	Volume of tanks	20000 L
P_f	Price per unit of food	$ 1.00/kg
H_2O_e	Electrical use per unit of water	0.03 kwh/1000 L
T_e	Electricity used per tank	7.0 kwh/tank/d
P_e	Price per unit of electricity	$ 0.10/kwh
P_{H2O}	Price per unit of water	$ 0.00/1000 L
P_T	Prorated price per tank per day	$ 3.50/tank
N_0	Initial number of post-larval fish	100,000
P_{pl}	Price per post-larval fish	$ 0.15/postlarva
L_r	Length at recruitment	24.00 cm
g_n	Linear growth rate for the natural population	0.05 cm/d
m_r	Instantaneous yearly mortality rate at recruitment	0.3/year
m_p	Instantaneous yearly mortality rate at post-larval size	7.0/year

TABLE 1. ***Parameters and baseline values for culture system model.***

where L_p = length of post-larval fish m_L = average mortality rate for fish growing from L_t to L_r m_r = instantaneous yearly mortality rate at size of recruitment m_p = instantaneous yearly mortality rate at post-larval size For the mortality rate at post-larval size we use m_p = 7.0/year, and for the mortality rate at recruitment we use m_r = 0.3/year, the baseline value of natural mortality of adult fish.

The survival rate for the period from stocking to recruitment into the fishable population for fish of size L is $S_L = \exp(-m_L \times t_L)$ (22) and the cost per fish stocked at time t that will actually reach recruitment is

$$N_t = N_0 \times S_t \qquad (24)$$

where

N_t = number of fish at time t

N_0 = number of fish at time 0 (recruitment or age 1)

S_t = portion surviving from recruitment.

EQUATION

Post-Recruitment, Fishery Model

The post-recruitment fishery model must describe the bioeconomic dynamics of stocked fish after recruitment to the potentially fishable stock so that the economic benefit of the culture/stocking program can be evaluated. These dynamics depend on individual growth and mortality, as well as how the fishery is managed (i.e. the size limit and mortality due to fishing; c.f. Botsford and Hobbs 1984). Because yearly fishing mortality rates are poorly known and we may wish to examine possible benefits of changes in management, we evaluate the benefits of stocking over a range of fishing mortality rates and size limits. We consider here only a single fishery. This can be thought of as the combined recreation and commercial fishery. For a more detailed analysis of the catch distribution among multiple users with use-specific regulations, see Reed and MacCall (1988).

The impacts of stocking on the fishery can be separated into two areas: the direct, short-term impact and the indirect, long-term impact. The former includes effects of stocked fish entering the fishery and the latter includes the effects of descendants of stocked fish entering the fishery. Because prediction of the indirect, long-term impacts requires knowing the processes that control recruitment, we concern ourselves here with only the direct, short-term effects.

Several aspects of the post-recruitment dynamics are of potential economic interest. The most obvious characteristic is fishery catch per stocked fish both in numbers and in biomass. These depend only on post-recruitment growth and mortality rates, however, and do not reflect culture costs. Another way of looking at the post-recruitment effects of stocking, therefore, is in terms of the cost per fish caught. To account for the size and value of the fish caught, a fourth way of evaluating stocking is in terms of net value (gross value minus cost) of fish caught, assuming gross value of a fish is proportional to weight.

The model assumes that yearly mortality rates (both fishing and natural) are constant and that growth follows a von Bertalanffy curve. The number of recruits at any age past recruitment is $N_t = N_0 \times S_t$ (24) where N_t = number of fish at time t N_0 = number of fish at time 0 (recruitment or age 1) S_t = portion surviving from recruitment.

Survival prior to entering the fishery is given by

$$S_t = \exp(-m \times t) \qquad \text{for } t \leq t_c \qquad (25)$$

EQUATION

where m = instantaneous yearly natural mortality rate t_C = time at which fish reach the minimum size limit.

We use an intermediate value of 0.2/year as a baseline for our analysis here but also evaluate the sensitivity of the results to a range of values from 0.1 to 0.3/year. Botsford et al. (1989) presented results for a more conservative analysis using a mortality rate of 0.3/year. After the age of entry into the fishery $S_t = \exp[-(m \times t) - (f \times [t-t_C])]$ (26) where f = instantaneous yearly fishing mortality rate.

Catch per recruit is the fraction of recruited, stocked fish (numbers) caught in the fishery. This is calculated as

$$S_t = \exp[-(m \times t) - (f \times [t-t_c])] \qquad (26)$$

EQUATION

Biomass yield per recruit is the average weight increase in the total catch per recruited, stocked fish (biomass). The yield is calculated by numerical integration from

$$Y_r = \frac{f}{m+f} \int_0^{\infty} S_t \, W_t \, dt \qquad (28)$$

EQUATION

where $W_t = a_1 \times L_t^{\,b_1}$ = weight in kilograms at time a_1 = the coefficient in the length-weight relationship b_1 = the exponent in the length-weight relationship $L_t = a_2 \times [1-\exp(-b_2 \times [t-c_2])]$ = length in cm. For the parameters in the von Bertalanffy growth equation (a_2, b_2, and c_2), we used values estimated from Hulbrock's (1974) data.

Culture cost per fish caught is calculated as

$$P_f = \frac{P_r}{C_r} = \frac{\text{cost per recruit}}{\text{catch per recruit}} \qquad (29)$$

EQUATION

and net benefit of yield per recruit is $B_r = (p_k \times Y_r) - P_r$ = value of yield per recruit - cost per recruit (30) where p_k = value per unit weight of fish to the fishery in \$ / kg P_r = cost per recruit, obtained from the culture cost model.

RESULTS

Our analysis thus far is limited by the results available from culture research. We have developed an understanding of the dynamics of the culture/stocking system (i.e. how the system "works") and a preliminary estimate of culture costs and benefits. We have also identified aspects of the system to which costs are particularly sensitive and used these sensitivity analyses to evaluate results from biological experiments. The third category can be useful in planning future research. Cost or benefit figures should be considered preliminary at this stage.

Culture

The simplest view of how a culture system would work can be obtained by following the development of a cohort of fish as they grow through culture (Table 2). As the fish increase in size, the number of tanks required increases even though the number of fish declines because of mortality. Costs per time step increase as the fish increase in size and metabolic demand, and the total cost of culture per fish begins with the cost per postlarva and increases to higher values. For purposes of determining the sensitivity of culture costs to changes in the system due to further research, it is valuable to know the distribution of costs. Early in culture the costs of post-larval fish dominate total costs, but they constitute a lower proportion relative to costs of food, labor, and the physical system as fish are cultured longer (Figures 3 and 4).

Optimal Size of Release

A critical open question with regard to the culture/stocking system is how long the fish should be cultured before being released. Shorter culture time will incur less culture costs, but fewer fish will survive after release to be fishable recruits. The number that survive depends on juvenile mortality rate which decreases with age and size of the fish. Consequently, there is a tradeoff between the increased cost of larger fish and the decreased survival of smaller fish (Figure 5; see Table 1 for parameter values). As the possible release size increases, both the cost per fish released and the fraction that would survive to recruitment size increase, but at different rates. The cost per recruit is the cost per fish released divided by the survival to recruitment (23)]. This value initially declines, then increases, and the optimal size of release is the minimum of this curve. For example, Figure 5 indicates that to minimize overall cost per cultured

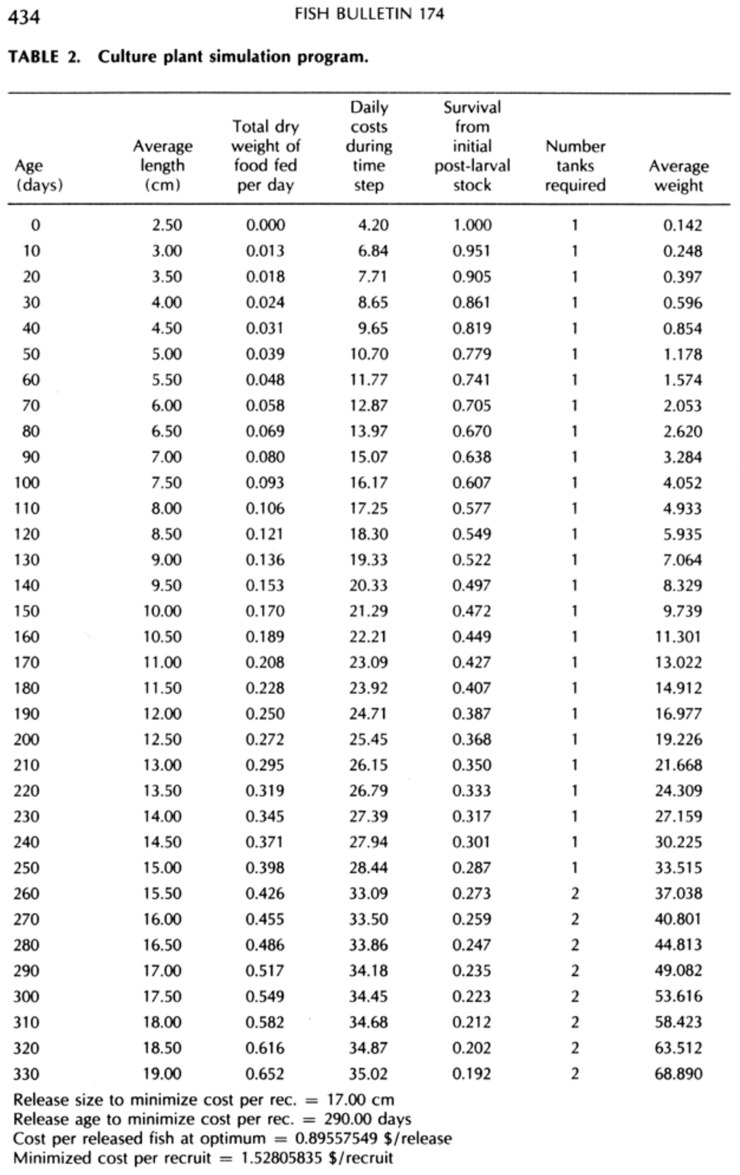

TABLE 2. Culture plant simulation program.

Age (days)	Average length (cm)	Total dry weight of food fed per day	Daily costs during time step	Survival from initial post-larval stock	Number tanks required	Average weight
0	2.50	0.000	4.20	1.000	1	0.142
10	3.00	0.013	6.84	0.951	1	0.248
20	3.50	0.018	7.71	0.905	1	0.397
30	4.00	0.024	8.65	0.861	1	0.596
40	4.50	0.031	9.65	0.819	1	0.854
50	5.00	0.039	10.70	0.779	1	1.178
60	5.50	0.048	11.77	0.741	1	1.574
70	6.00	0.058	12.87	0.705	1	2.053
80	6.50	0.069	13.97	0.670	1	2.620
90	7.00	0.080	15.07	0.638	1	3.284
100	7.50	0.093	16.17	0.607	1	4.052
110	8.00	0.106	17.25	0.577	1	4.933
120	8.50	0.121	18.30	0.549	1	5.935
130	9.00	0.136	19.33	0.522	1	7.064
140	9.50	0.153	20.33	0.497	1	8.329
150	10.00	0.170	21.29	0.472	1	9.739
160	10.50	0.189	22.21	0.449	1	11.301
170	11.00	0.208	23.09	0.427	1	13.022
180	11.50	0.228	23.92	0.407	1	14.912
190	12.00	0.250	24.71	0.387	1	16.977
200	12.50	0.272	25.45	0.368	1	19.226
210	13.00	0.295	26.15	0.350	1	21.668
220	13.50	0.319	26.79	0.333	1	24.309
230	14.00	0.345	27.39	0.317	1	27.159
240	14.50	0.371	27.94	0.301	1	30.225
250	15.00	0.398	28.44	0.287	1	33.515
260	15.50	0.426	33.09	0.273	2	37.038
270	16.00	0.455	33.50	0.259	2	40.801
280	16.50	0.486	33.86	0.247	2	44.813
290	17.00	0.517	34.18	0.235	2	49.082
300	17.50	0.549	34.45	0.223	2	53.616
310	18.00	0.582	34.68	0.212	2	58.423
320	18.50	0.616	34.87	0.202	2	63.512
330	19.00	0.652	35.02	0.192	2	68.890

Release size to minimize cost per rec. = 17.00 cm
Release age to minimize cost per rec. = 290.00 days
Cost per released fish at optimum = 0.89557549 $/release
Minimized cost per recruit = 1.52805835 $/recruit

TABLE 2. ***Culture plant simulation program.***

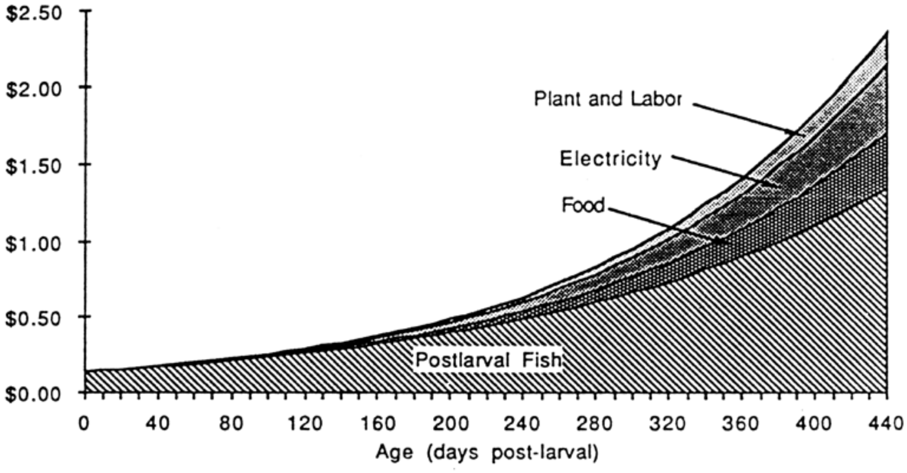

FIGURE 3. Distribution of costs per released fish by age at release in terms of actual value.

FIGURE 3. Distribution of costs per released fish by age at release in terms of actual value

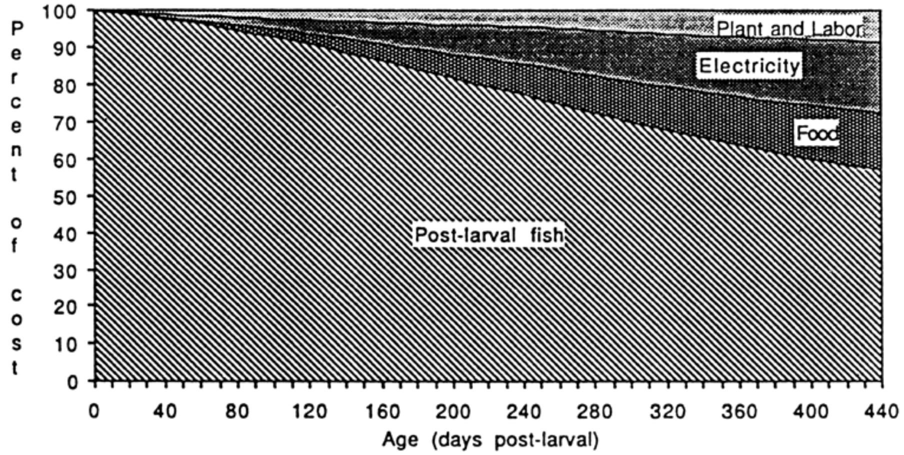

FIGURE 4. Distribution of costs per released fish by age at release as a proportion of total cost.

FIGURE 4. Distribution of costs per released fish by age at release as a proportion of total cost

recruit, the cultured fish should be released after about 290 d of culture. The value of optimal release is sensitive to both the initial cost of post-larval fish and to the post-release survival rates.

Graphical Analysis of Sensitivity

Because of the preliminary nature of the research into culture of the post-larval fish, there is a great deal of uncertainty regarding the food characteristics and the culture units (tanks) necessary. Also, the growth rates observed in the culture system are lower than those observed in the wild population. We have therefore evaluated the sensitivity of culture-system performance to these parameter values. This is most easily done graphically.

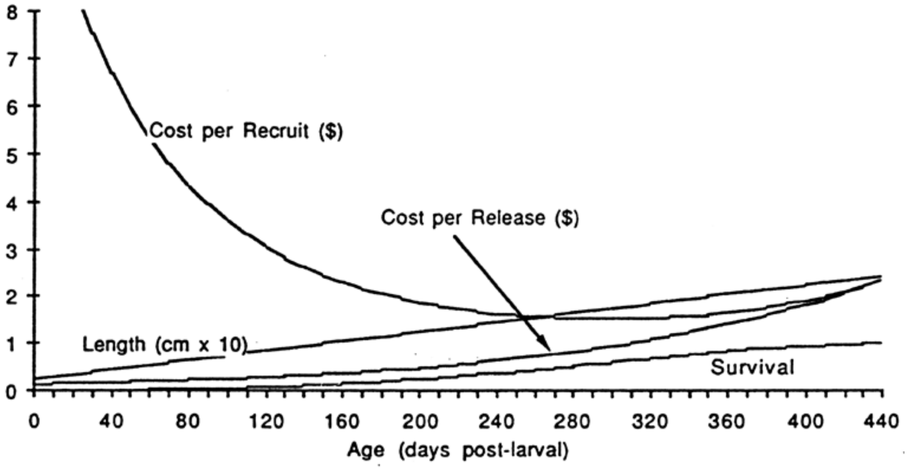

FIGURE 5. Cost per recruit (at 24 cm) if released from culture at the age on the horizontal axis. Other lines are the components of this cost (Equation 23).

FIGURE 5. Cost per recruit (at 24 cm) if released from culture at the age on the horizontal axis. Other lines are the components of this cost (Equation 23)

Culture costs and operation of the culture system are sensitive to growth rate. We compare cost per recruit for six different values of growth rate in the culture plant (Figure 6). These lines are the same as the cost-per-recruit line in Figure 5 for different values of individual growth rate. Note that both the optimal time of release and the resulting cost per recruit are sensitive to this parameter. Little benefit would be gained by culturing the fish at growth rates less than 0.02 cm/d, and at rates as low as 0.01 cm/d continuing culture beyond the post-larval phase would increase the cost per recruit. Recall 0.025 cm/d is the highest observed laboratory growth rate and 0.05 cm/d is the estimated wild growth rate. This figure shows that for both of these values culture beyond the post-larval phase is optimal, but that the cost per recruit is high (e.g. for the former value, cost per recruit is near $5.00).

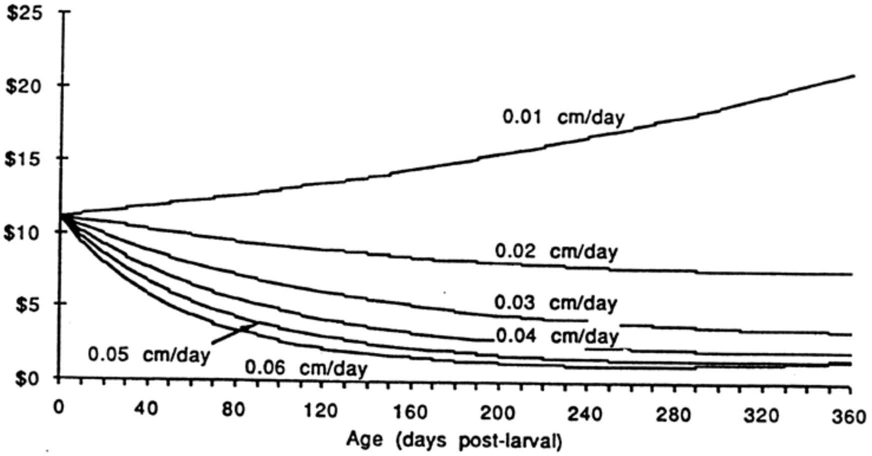

FIGURE 6. Cost per recruit as in Figure 5 for several different values of growth rate in culture.

FIGURE 6. Cost per recruit as in Figure 5 for several different values of growth rate in culture

Daily food costs and culture tank costs increase as the fish grow. Increases in the price of each of these has a significant affect on both the optimal release age and the cost per recruit (Figures 7 and 8). As food costs increase, cost per recruit increases, and the optimal release time decreases. The cost of tanks has a similar effect. Gadomski et al (1990) state that they have not been able to find a prepared food that post-larval halibut will utilize. Live food either collected or cultured is generally more expensive than prepared foods. Increased food costs would result in a younger optimum release age and a higher cost per recruit, but culturing beyond the post-larval phase is still cost effective in the sense that cost per recruit is less (but still expensive). A similar result occurs when cost per culture unit is varied.

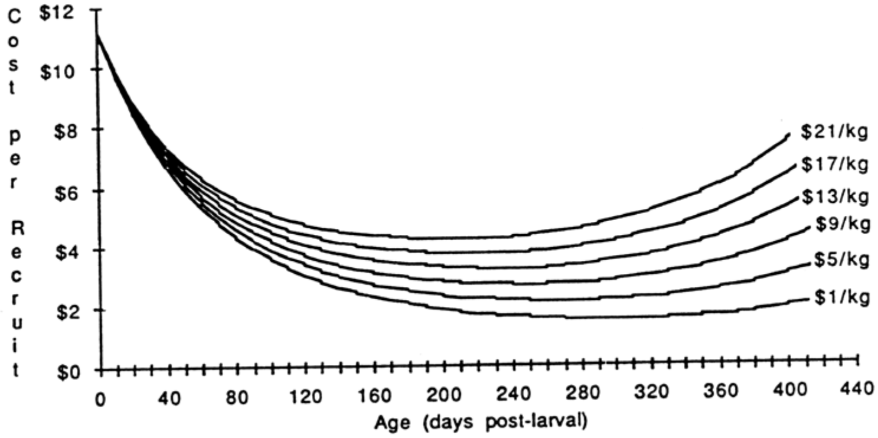

FIGURE 7. Cost per recruit for different food prices.

FIGURE 7. Cost per recruit for different food prices

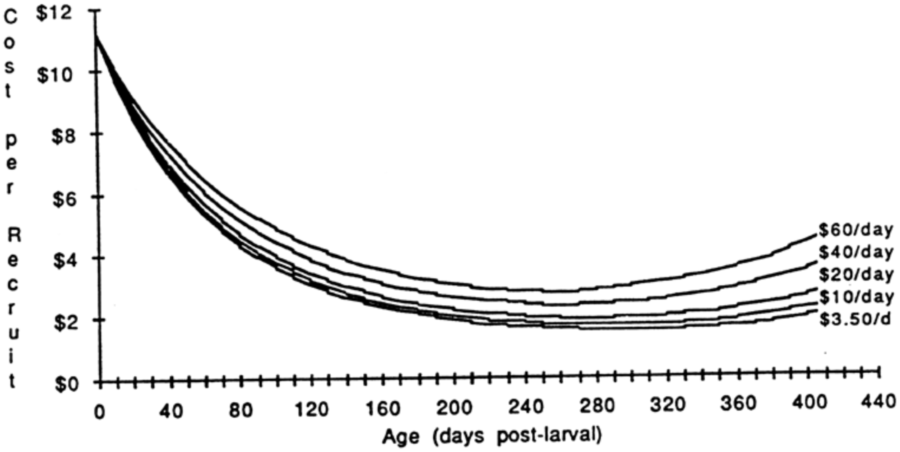

FIGURE 8. Cost per recruit for different costs of culture space.

FIGURE 8. Cost per recruit for different costs of culture space

Using increased food price as a typical increase in culture costs, we can examine the interaction of growth rate and culture costs (Figure 9), Even at high daily culture costs (food price of $50.00/kg) the optimal release age is greater than zero when the growth rate is greater than 0.02 cm/d. Minimized cost per recruit when compared for the same values of growth rates and food prices indicates that at growth rates above 0.02 cm/d the minimized cost per recruit is sensitive to food price (Figure 10). For lower growth rates no further culture of postlarvae is warranted even at very low food prices, so minimized cost per recruit is the cost of stocking postlarvae. Expensive culture practices may be cost effective if they increase the growth rate significantly. For example, food that cost $30.00/kg but increased the growth rate to 0.06 cm/d would result in a slight savings over $1.00/kg food that resulted in a growth rate of 0.025 cm/d, and a food that cost $10.00/kg with a potential growth rate over 0.04 cm/d would cut the minimized cost per recruit in half. Finally it should be noted that large increases in culture costs (e.g. 50-fold increase in food price) do not result in equivalent increases in minimized cost per recruit (approximately five fold), because a compensatory decrease occurs in optimal release age (Figures 9 and 10).

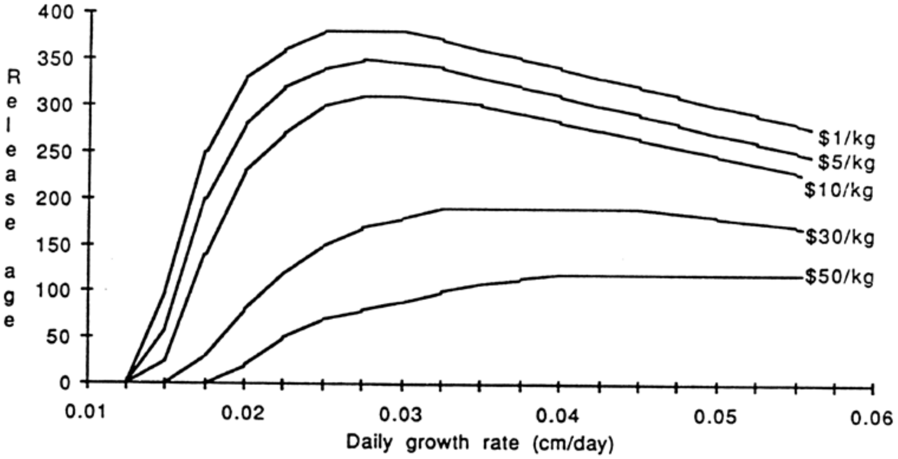

FIGURE 9. Optimal release age as both the cost of food and one of the potential effects of different foods, growth rate, vary.

FIGURE 9. Optimal release age as both the cost of food and one of the potential effects of different foods, growth rate, vary

Post-release mortality rates are also poorly known. In the model the post-release mortality parameter with the greatest uncertainty is the mortality of a post-larval fish (recall that post-release mortality rate is size dependent and decreases linearly from the post-larval size to recruit size, hence this is the value at lower end of this size range). Optimal release size, age, and cost, and the resulting cost per recruit, all increase with this parameter (Figure 11). The optimal values of these variables are those that correspond to the release age at which cost per recruit is minimized. The value of mortality rate used in the

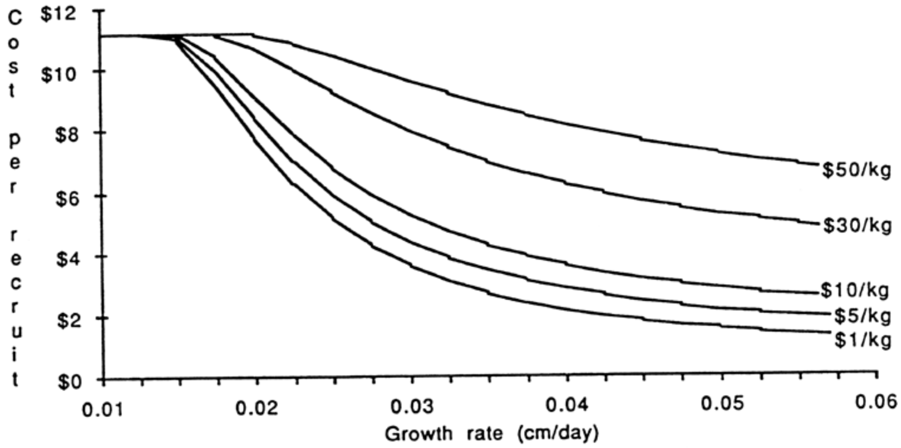

FIGURE 10. Cost per recruit (at 24 cm) as both the cost of food and growth rate vary.

FIGURE 10. Cost per recruit (at 24 cm) as both the cost of food and growth rate vary

baseline model is an instantaneous yearly rate of 7.0/year which would result in 1.3% survival from the post-larval size of 2.5 cm to the recruitment size of 24 cm. It is somewhat surprising to note that the cost per recruit varies relatively little (from $1.30 to $1.72) when the mortality rate is varied by a factor of two (from 5.0/year to 10.0/year or survival of 4.4% to 0.2% respectively). The cost per released fish varies by a factor of two (from $0.64 to $1.25), so the relative insensitivity of the cost-per-recruit variable results from an adjustment of the optimal release age (240 d to 340 d) that partly compensates for the variation in mortality rate.

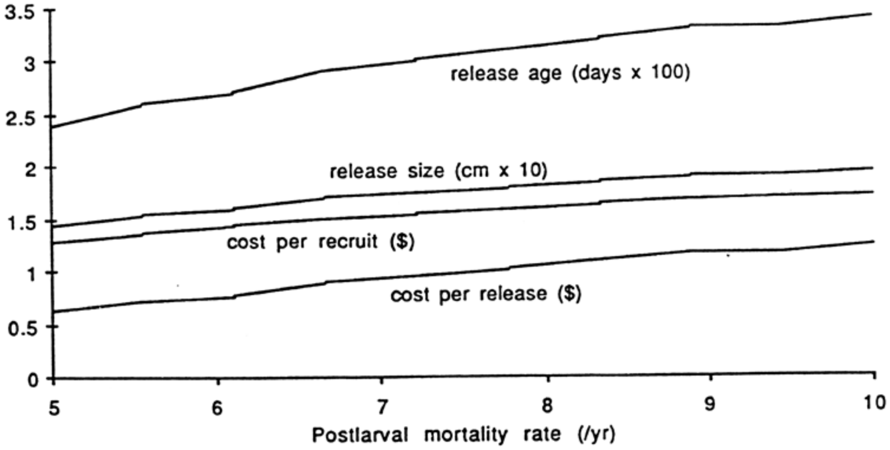

FIGURE 11. Optimal release age and size, and the associated cost per released fish and cost per recruit (at 24 cm) as the early natural mortality rate of juveniles is varied.

FIGURE 11. Optimal release age and size, and the associated cost per released fish and cost per recruit (at 24 cm) as the early natural mortality rate of juveniles is varied

One question that would arise from Figure 11 is how sensitive cost per recruit is to changes in both parameters of the post-release mortality rate (i.e. both the post-larval value and the pre-recruit value). Even when both parameters are varied, one by a factor of two and the other by a factor of six, the cost per recruit varies only from $1.19 to $1.84 (Figure 12).

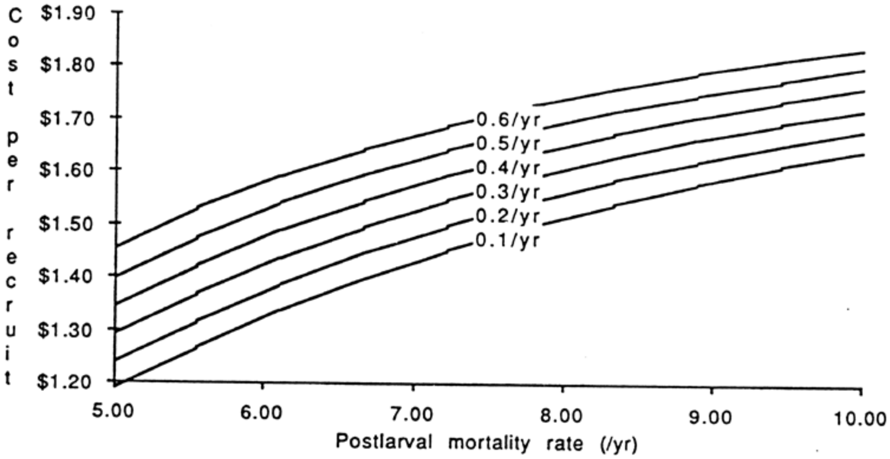

FIGURE 12. Cost per recruit as both the post-larval mortality rate (horizontal axis) and pre-recruitment mortality rate (individual lines) are varied.

FIGURE 12. Cost per recruit as both the post-larval mortality rate (horizontal axis) and pre-recruitment mortality rate (individual lines) are varied

Post-Recruitment

Direct, short-term impacts of the stocking program are evaluated here in four different ways. Parameter values used are shown in Table 3. These results are presented for a range of lower size limits and fishing mortality rates so that both the sensitivity of results to poorly known fishing mortality rates and the possible effects of changes in fishery policy can be evaluated.

The fraction of recruited, stocked fish that ends up being caught increases with the amount of fishing (i.e. the fishing mortality rate) because fewer fish survive long enough to die from natural mortality (Figure 13). It also increases as the size limit is lowered because fewer fish die from natural causes before reaching legal size. To get an idea of what would result from current management, we can look at the current size limit of 55.9 cm and assume a total fishing mortality rate including both sport and commercial fishing of 0.25/year; the fraction caught would be 0.22. This depends critically on stocked fish having the same survival rate as that estimated for natural fish (see Table 3).

Biomass caught accounts for the fact that fish grow larger with age while the fraction caught declines. The catch in the fishery in terms of biomass per recruited, stocked fish is higher at higher fishing rates and at intermediate size limits (Figure 14). Near 55.9 cm and 0.25/year it is relatively flat, indicating that little would be gained by a change in fishery policy and that, even if our

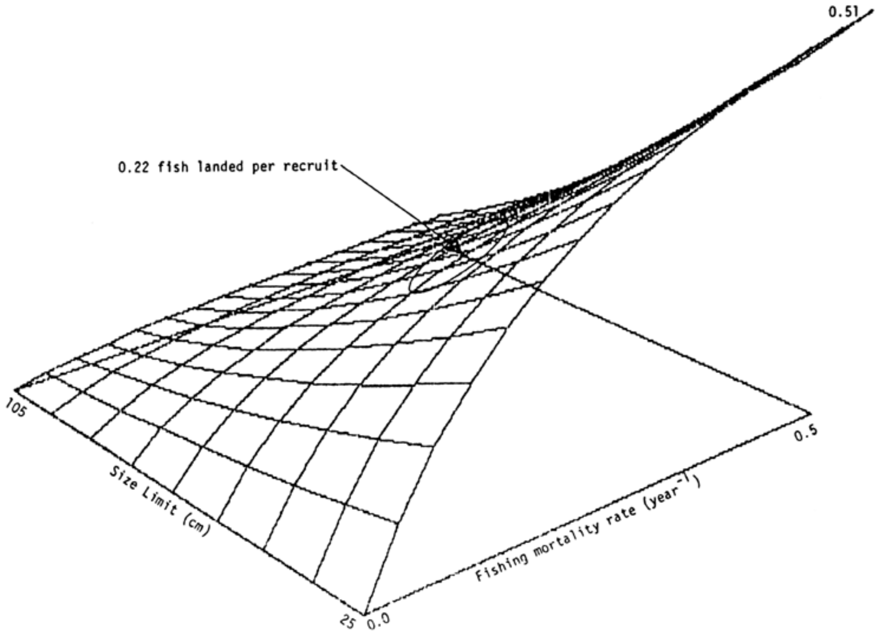

FIGURE 13. Fish landed per California halibut recruit as size limit and fishing mortaility rate are varied. The area marked corresponds to the present fishery.

FIGURE 13. Fish landed per California halibut recruit as size limit and fishing mortaility rate are varied. The area marked corresponds to the present fishery

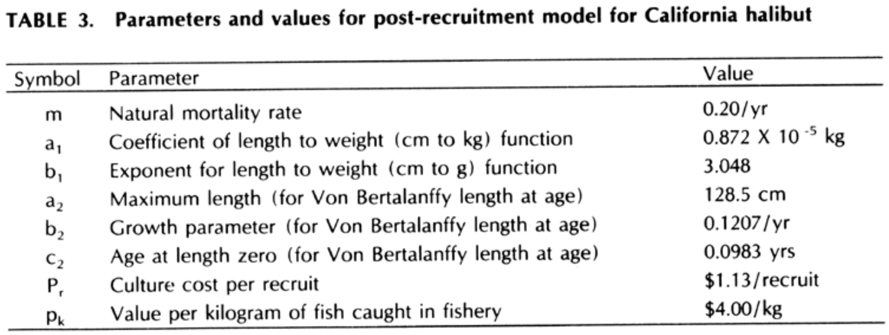

TABLE 3. Parameters and values for post-recruitment model for California halibut

Symbol	Parameter	Value
m	Natural mortality rate	0.20/yr
a_1	Coefficient of length to weight (cm to kg) function	0.872 X 10^{-5} kg
b_1	Exponent for length to weight (cm to g) function	3.048
a_2	Maximum length (for Von Bertalanffy length at age)	128.5 cm
b_2	Growth parameter (for Von Bertalanffy length at age)	0.1207/yr
c_2	Age at length zero (for Von Bertalanffy length at age)	0.0983 yrs
P_r	Culture cost per recruit	$1.13/recruit
p_k	Value per kilogram of fish caught in fishery	$4.00/kg

TABLE 3. ***Parameters and values for post-recruitment model for California halibut***

estimates of fishing mortality rate are off a bit, our projected biomass yield will not be far off. The value at that point is approximately 0.93 kg.

The two criteria evaluated thus far do not include the costs of stocking. The cost per stocked fish caught for California halibut is shown for various values of fishing rate and size limit in Figure 15. For low fishing rates and high size limits, this criterion is high (because few fish are caught). However, near the current operating point the cost is about $5.05 for a landed fish that would average 4.2 kg (yield per recruit / fraction caught). This cost could be reduced by lowering the size limit, but that would lead to smaller fish in the catch.

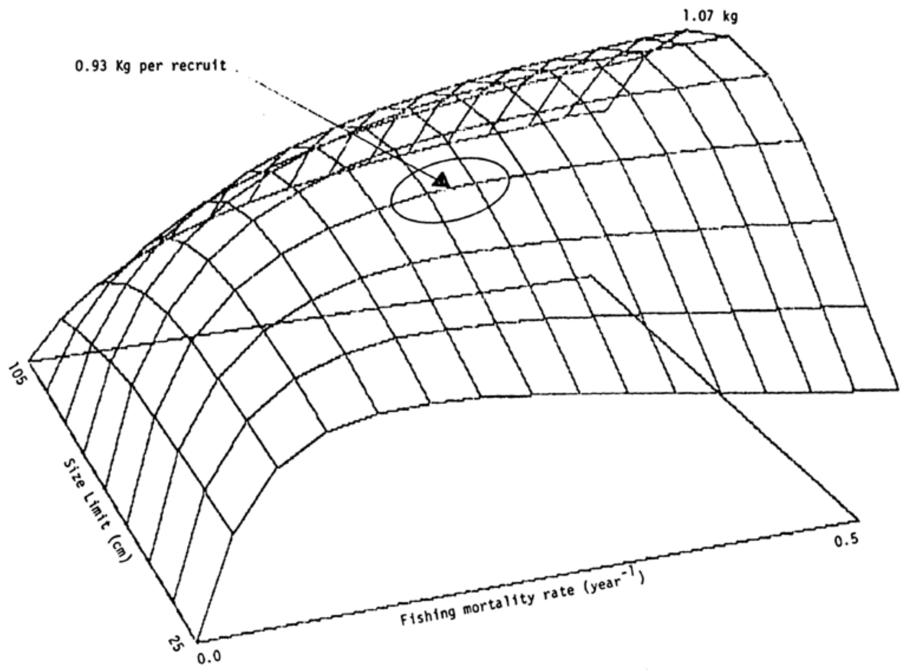

FIGURE 14. Biomass yield per California halibut recruit as size limit and fishing mortality rate are varied. The area marked corresponds to the present fishery.

FIGURE 14. Biomass yield per California halibut recruit as size limit and fishing mortality rate are varied. The area marked corresponds to the present fishery

A way of including the size of the fish in an economic criterion is to compute the difference between value to the fisherman (assuming it is proportional to weight) and the cost of culturing the fish. Net benefit is shown in Figure 16 for a value of $4.00/kg. This increases with fishing rate then decreases slightly and is a maximum for intermediate size limits. At the current operating point the net benefit is about $2.84 per recruit. The curve is fairly flat in the vicinity of this point.

A characteristic common to all of the four criteria is that they are sensitive to the assumed value of natural mortality rate. As one moves from a low estimate of 0.1/year to a high estimate of 0.3/year, biomass yield per recruit declines from 2.40 kg to about 0.43 kg (Figure 17) and the cost per stocked recruit caught increases from $2.50 to about $10.00 (Figure 18).

CONCLUSIONS FROM ANALYSES TO DATE

The analyses, thus far, raise some important issues that are worthy of attention. With regard to the culture phase, the fact that the cost of post-larval fish may dominate costs is important. For the analyses described here, we used a price ($0.15) which is less that the cost of commercially produced postlarvae of striped bass, Morone saxatilis, (for which females are also captured, and

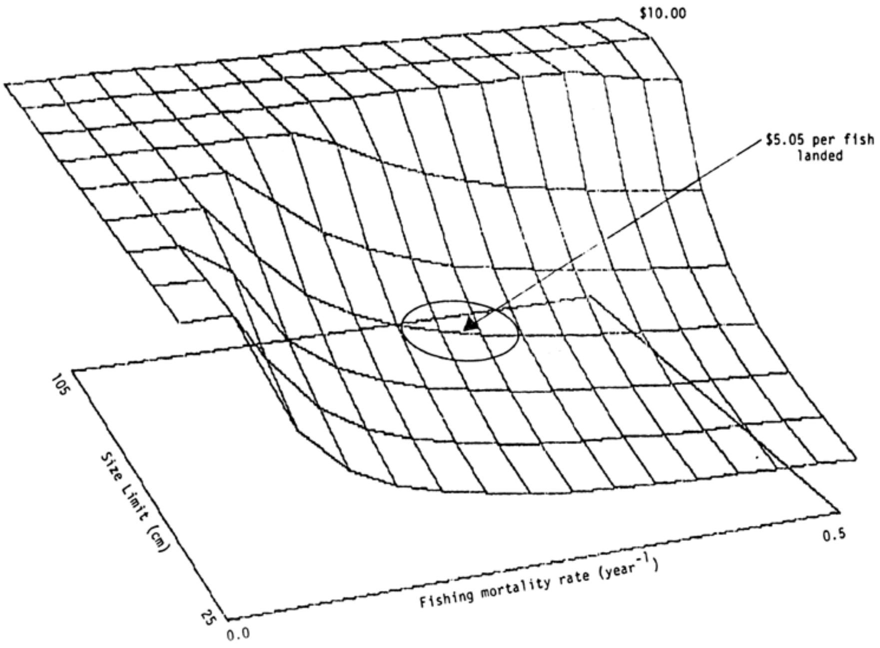

FIGURE 15. Average cost per stocked California halibut recruit as size limit and fishing mortality rate are varied. The area marked coresponds to the present fishery.

FIGURE 15. Average cost per stocked California halibut recruit as size limit and fishing mortality rate are varied. The area marked coresponds to the present fishery

postlarvae are also reared from eggs). Using this value, costs of postlarvae are a major part of culture costs. This would imply that more attention should be paid to reducing this cost. Also, an accurate estimate of these costs is necessary because of its effect on the decision regarding optimal time of release.

A graph such as Figure 5 is the best single summary of how the culture/stocking scheme works. The variation in cost per recruit as time of release from culture increases, indicates the optimal time of release, as well as the penalty for early or late release. It is somewhat surprising that cost per recruit is relatively insensitive to post-release mortality (Figure 11, 12). However, this result assumes that we know the post-release mortality rates, and can release the cultured fish at the optimal release time. It will be advisable to monitor survival during the post-release/pre-recruit period, and to continue to refine optimal release time, even after the project begins releasing cultured fish.

Figure 5 can be used to evaluate some of the recent conclusions by the halibut culture researchers. For example, the annual progress report for 1987–88 for California halibut (Stephens et al. 1988) stated that the best release age was 6 to 7 weeks, primarily because of lack of an available food and space limitations in culturing a bottom dwelling fish. However, modeling results described here indicate the cost per recruit at this age would be about $6.00 per fish (Figure 5). Thus, it appears that release at this age is not economically feasible, and that further research isrequired to develop the capability of

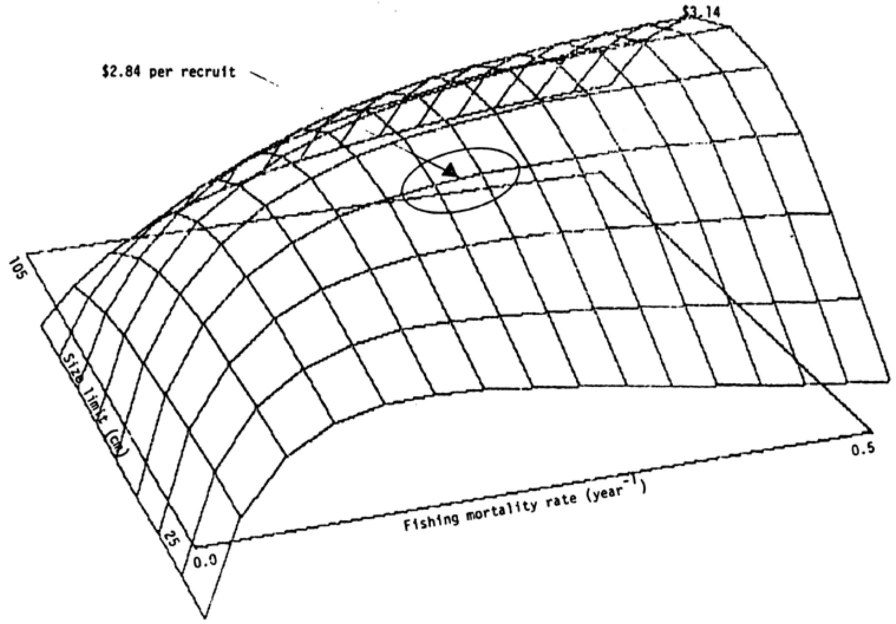

FIGURE 16. Net benefit per stocked California halibut recruit as size limit and fishing mortality rate are varied. The area marked corresponds to the present fishery.

FIGURE 16. Net benefit per stocked California halibut recruit as size limit and fishing mortality rate are varied. The are marked corresponds to the present fishery

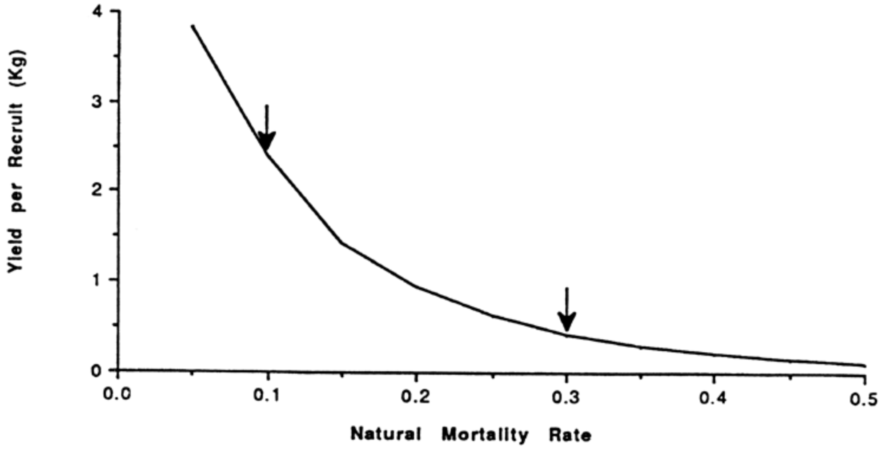

FIGURE 17. Biomass yield per California halibut recruit as natural mortality rate is varied. Arrows indicate recent low and high estimates of natural mortality rates.

FIGURE 17. Biomass yield per California halibut recruit as natural mortality rate is varied. Arrows indicate recent low and high estimates of natural mortality rates

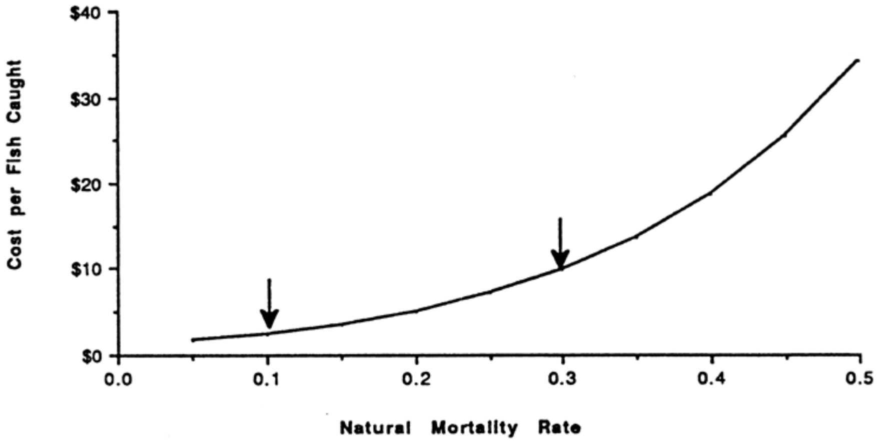

FIGURE 18. Average cost per stocked California halibut recruit caught in the fishery as natural mortality rate is varied. Arrows indicate recent low and high estimates of natural mortality rates.

FIGURE 18. Average cost per stocked California halibut recruit caught in the fishery as natural mortality rate is varied. Arrows indicate recent low and high estimates of natural mortality rates

culturing these fish to older ages. The economic analysis indicates that costs for food and culture space can be much higher than our baseline estimates and still result in substantial savings with culturing to an older release age (Figures 7 and 8). Other flatfish species have been cultured to larger sizes (Bardach et al. 1972).

Figure 6 reflects the implications of the current halibut growth rate. If growth rates are less than 0.02 cm/d, culture is not optimal (i.e. the optimal age of release is zero). If the growth rate is about 0.025 cm/d, the cost per recruit is about $8.00. A growth rate approximating the wild growth rate (0.05 cm/d) is required to bring the cost per recruit down to about $1.50.

The post-recruitment analysis provides an understanding of the economics of the culture/stocking system in terms of the fishery. We do not yet have the data necessary to confidently estimate culture costs, but the results illuminate sensitivity to various parameters. For example, they emphasize the importance of natural mortality rates. All criterion were sensitive to the value of that parameter. For California halibut the value probably lies between 0.1/year and 0.3/year, but this limited range allows a large uncertainty in the feasibility analysis. Because of the difficulty in estimating mortality rates in natural populations (Vetter 1988), some uncertainty will always be present in evaluations of the feasibility of the culture/stocking scheme.

Implications of current model results for feasibility of the culture/stocking concept are not straightforward. Cost and benefit projections appear high (about $5 per fish caught and a net benefit of $3 per fish if their value is $4/kg). However, these are based on growth at a rate near the natural rate to optimal release size. This growth rate is greater than current rates in culture and the optimal release size is far beyond the size to which researchers have thus far been able to grow this fish. If released at that size, cost per fish caught would be about $18, a value that is probably too high.

Overall evaluation of feasibility would also include consideration of less tangible effects of culture that are not included in our analysis. One example is the contribution of cultured fish to future recruitment. This would presumably be positive; however, there might be negative effects on genetic variability. Another less tangible effect is the negative effect that culture might have on the ability to protect habitat in the future. Some might assume that because fish could be cultured, there was less reason to protect natural spawning habitat.

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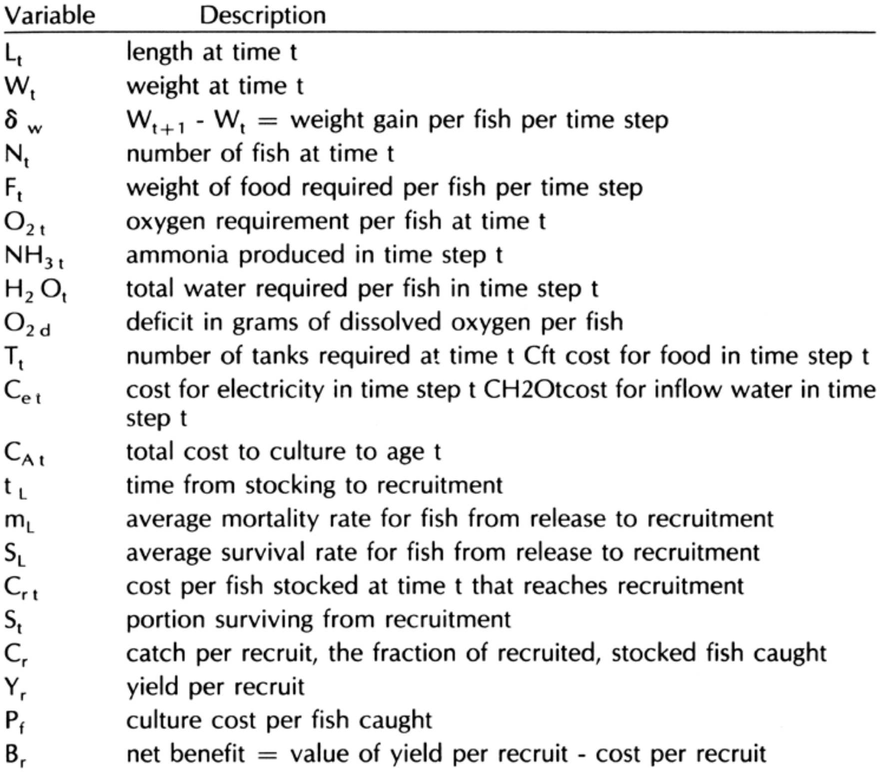
APPENDIX A



Variable	Description
L_t	length at time t
W_t	weight at time t
δ_w	W_{t+1} - W_t = weight gain per fish per time step
N_t	number of fish at time t
F_t	weight of food required per fish per time step
O_{2t}	oxygen requirement per fish at time t
NH_{3t}	ammonia produced in time step t
H_2O_t	total water required per fish in time step t
O_{2d}	deficit in grams of dissolved oxygen per fish
T_t	number of tanks required at time t Cft cost for food in time step t
C_{et}	cost for electricity in time step t CH2Otcost for inflow water in time step t
C_{At}	total cost to culture to age t
t_L	time from stocking to recruitment
m_L	average mortality rate for fish from release to recruitment
S_L	average survival rate for fish from release to recruitment
C_{rt}	cost per fish stocked at time t that reaches recruitment
S_t	portion surviving from recruitment
C_r	catch per recruit, the fraction of recruited, stocked fish caught
Y_r	yield per recruit
P_f	culture cost per fish caught
B_r	net benefit = value of yield per recruit - cost per recruit

APPENDIX A

APPENDIX B

The computer programs used in both the cost estimates and the sensitivity analysis have been developed for distribution and can be obtained by writing the authors. The programs are written in TURBO Pascal to run on IBM-compatible personal computers. The programs make use of a graphics package that is specific to the graphics system on the computer. Information on the graphics environment, in which the programs will be run, should be included with the request.

WHERE WE SHOULD GO WITH RESEARCH AND MANAGEMENT AS IT RELATES TO THE CALIFORNIA HALIBUT: A PANEL DISCUSSION

MARTIN F. GOLDEN[1] , Convener
U.S. Department of Interior
Minerals Management Service Pacific Outer Continental Shelf Region
Camarillo, CA 93010

INTRODUCTION

This symposium on the California halibut grew out of a need to help fisheries managers better understand the status of current research on the California halibut so as to update management strategies and to identify areas where additional research is needed. To optimize the results of the symposium, a general call for papers was made inviting anyone involved with research on the California halibut to participate. Additionally, a panel discussion was organized to involve user groups and the academic community in providing their perspectives on "Where we should go with research and management as it relates to the California halibut."

The concept for the Symposium was developed by the California Department of Fish and Game (CDFG) and administered by the Symposium Committee under the direction of John S. Sunada (CDFG), the Symposium Coordinator. The Symposium was truly a team effort with sponsorship including:

California Department of Fish and Game,
American Institute of Fishery Research Biologists,
Cabrillo Marine Museum, and
National Marine Fisheries Service.

Through the efforts of all these organizations a very successful symposium was held May 23 and 24, 1989 at the Cabrillo Marine Museum in San Pedro, California. The symposium attracted approximately 150 people and included 25 papers.

PANEL DISCUSSION

Panelists

Mr.Marty Golden, Convener and panel moderator
Director, Southern California Chapter
American Institute of Fishery Research Biologists, and
U.S. Department of Interior (MMS)
Pacific OCS Region, Camarillo, California

Mr. Al Petrovich, Chief
Marine Resources Division

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[1] Present address: NationalMarine Fisheries Service, Southwest Region, 300 South Ferry Street, Terminal Island, CA 90731

California Department of Fish and Game
Sacramento, California

Dr. John Stevens, Director
VANTUNA Research Group
Occidental College, Los Angeles, California

Dr. Louis Botsford
Fisheries population biologist
University of California, Davis, California

Mr. Mike McCorkle
Commercial fisherman
Santa Barbara, California

Mr.Dan Frumkes
Biostatistician, Owner of Commercial Sport Fishing Boat, and Member of the
Southern California Nearshore Ichthyologists Coordinating Committee on Research
Malibu, California

Mr. Golden:

I have asked each panelist to make a short presentation or comment about their thoughts on: Where we should go with research and management as it relates to the California halibut.

After their presentations we will have a short period of questions and answers between the panel members and then open it up to questions from the floor. I would like to start with Al Petrovich from the California Department of Fish and Game.

Mr. Petrovich:

Well first of all I want to thank the organizing committee for inviting me to participate although at this point in time I feel, like John Stephens, that our panel is anticlimactic to what preceded. I think that we all suspected that there was a lot of work going on with respect to California halibut but no one was sure of the magnitude of the research and management activities that were going on. This was one of the driving forces of the symposium and I, for one, want to pass out kudos to those who put it together because I think it was a real success and I think one of the finest symposiums I've been to. The symposium certainly has given me food for thought as to where the Department should go with respect to California halibut research and management in the future. I came into this symposium with a very open mind, in fact I had no preview of the presentations by Department employees or what their conclusions were other than what I had picked up prior to this symposium. So I have two views. I have one that I call Before Symposium or BS and then I have another view that would be After Symposium or AS. I'll be very brief because you've seen the kind of activities the Department of Fish and Game is involved in based on the presentations. We are involved in a gill net observer program, a market sampling program, and a commercial passenger fishing vessel sampling program. We are now once again participating in the marine recreational fisheries statistics survey. We are involved with alternative gear development. We have been involved with the ocean resource enhancement and hatchery program.

Where do we go in the future? Based on what I've heard at this symposium we are going to develop an action plan, and not all of my staff is aware of this but they will be now. I'm going to ask them to put together an action plan based on the findings and the presentations here at the symposium as to where we go with respect to California halibut in future years. I want to do this because I want to strike while the irons are hot. I think that there has been a lot of interesting information brought forward here and I want us to proceed posthaste. With that I think that I'll throw it open to the next panel member.

Dr. Stephens:

As I mentioned from the floor, Jim Berkson said a lot of what I intended to say, especially in his last slide. The information that we have been collecting seems to support the idea that many of us have had for a long time, mainly that we have had a recruitment limited population. The population is being fished pretty hard and this is fraught with peril. We needed some sort of model that can tell us what might be going on in the future, and it looks like that model is being generated and I'm really, really happy to see that work being done. We know that we've had peaks and valleys in the population in the past. It's very possible that we are in a peak today, and if that's the case then we are going to need management to get us through what might happen in the future. So we need to move in that direction and we need to keep going with that work that Jim started. I hope that he can be free to continue that work until some of the alternative models that he was talking about can be run so that we can really see what other scenarios might be with the same sorts of basic model.

We've seen some very nice supportive data. We know things about larvae; we know things about grow out of juveniles. It's interesting that in all cases it seems to be these early settled larvae and juveniles that are the problem. We don't know what to do about them, but that's obviously the weak spot in this whole halibut life cycle. The rest of the animal seems to be relatively well understood. There's nothing that competes with adult halibut in southern California. Lizardfish? I doubt it—they may for a bit but then they get eaten by adult halibut. Certainly the young are vulnerable. The young are, as Jim Allen mentions, probably outcompeted by speckled sanddabs in the open coast. The young may not like it in the open coast even if they settle there because it's not warm enough and they seem to do much better with the warm water, high mycid food content of inner waters and in the bays, and it may well be that this is the basic recruitment limitation.

What I would like to stress then is that we know a lot, but we don't have all the answers yet. We're approaching the answers and for God's sake, let's not stop any of these programs. Particularly, I think that the gill net observer program is on the dock now; it's finishing up this year. I don't think that we can stop any of these programs. I think that these programs have to be ongoing programs. In order to look at a fishery, especially a fishery that is subject to extremely variable recruitment, variable management strategies may be required. And then we have got to continue our monitoring. So I hope that all the monitoring programs that are going right now stay intact or are expanded, and that we have people somehow integrated within this program so everybody knows what they and others are doing. If all elements of the halibut program stick together and we communicate with one an other, we may be able to develop a suitable management strategy. Thank you.

Dr. Botsford:

I'd first of all like to thank the committee organizers for inviting me. I'm happy to come and give my observations. I must preface them with the statement that I'm certainly not an expert on halibut, although I do know something about population dynamics. So some of the observations may be obvious, especially by this time, and some of my thoughts are also BS (Before Symposium), as Al pointed out. I see several problems that should be approached and one of the big ones is allocation, of course, but I'm not going to say anything about it because that's completely outside my area of expertise.

The first big problem that I am going to talk about is the dramatic fluctuations in abundance. I think that we have to understand these in order to really understand how the population works, and that's going to be necessary for good management. Whatever problems we have in allocation now are certainly going to be exacerbated if the population declines in several years as one would expect from the fluctuations in the past catch. There are several possible causes of these fluctuations. The basic questions are, "Are they caused by environmental forcing, some sort of density dependence, or some sort of effort dependence?" And the question that relates those to management is, "Can you control these?"

I believe we are going to require a deeper look at how management is influencing the population. So far we've evaluated management in terms of its effect on growth and recruitment through yield-per-recruit analysis, without too much specific regard for how fishing has affected recruitment. More attention to that sort of thing will allow us to answer questions that are open issues now. For example, in 1971 regulations changed and the population started increasing. Was that a result of regulations or was that simply fortuitous?

The second problem that I see is this issue of stocking. Rod talked this morning about economic feasibility of stocking. Stocking decisions involve considerable uncertainty, and we've pointed out that you need to know more about the natural history of the young. We phrase this in terms of mortality rates, but another way to look at it is that you have to know the age at which to stock individuals, if you're going to stock them. That's related to the first problem. If there were some sort of density dependence or environmental dependence in recruitment at a certain age, we don't want to be stocking the fish before this crunch comes. In other words you don't want to be stocking them before the point in the life history that is called the critical period. Another point with regard to stocking is that if you do engage in a stocking program, you want to be sure to have some sort of ability to verify its effect, both in terms of an increase in catch and in marked individuals.

The steps that I think that should be taken to solve these kinds of problems have been touched on thus far. I think that reproductive rates are pretty well known, mortality rates are relatively well known for adults, and very poorly known for juveniles. Even something as simple as sex ratio seems to have a lot of confusion associated with it; we should be able to figure that out. There seems to be very little known about any relationship between stock and recruitment.

I think that the first step is data analysis—better data analysis—some of the beginnings of which we've heard here. We're starting to collect data on age and size structure in the population, but thus far that information has not really been used in any sort of catch-age analysis or stock-synthesis analysis. I think that the path to take is to assemble a model that can be made to be consistent with all the existing data, not just size structure data, not just the catch data, but even data on larval production such as what Geoff Moser presented here. This could be Rick Methot's stock synthesis model, it could be others. Once that's done there is still going to be a certain amount of ambiguity; there will be a number of different ways that the population could work that would still be consistent with current data. To resolve some of the remaining inconsistencies between data and models will require further field and life history studies.

Another approach that people are talking about these days in fisheries management, particularly Carl Walters, is some sort of experimental management. One idea is that we should vary fishing policy not just for the purpose of increasing catch but also to learn more about the population at the same time. That can be done by managing different populations and different areas in different ways, as they are trying to do with Pacific Ocean perch on the Canada-U.S. border. We could also do stocking as a sort of experimental probe into population variability.

The other thing that I think should be done—and this is related to the topic just mentioned—is to establish some sort of plan of action or some sort of consensus and direction for where we are going to go from here. I think a conference such as this was a good idea, but I've been to conferences like this before where everybody goes away and nothing really happens. I've been to conferences in other groups where we did have good planning afterwards. The striped bass is the best example I can think of, and a lot of research came from those meetings in the early 80s, even though we still don't understand striped bass. I think this conference is very important and I think that the leaders are certainly to be congratulated. I think that there is going to be more of a consensus, and that by combining the approaches of people working in northern California with those being taken in southern California, people working on different parts of the data base will realize significant benefits from communicating with each other.

Mr. McCorkle:

I've been a commercial fisherman since 1956 full time, and I've been a gill-netter since 1958, and I've trawled for halibut since 1972. I've gillnetted from Point San Juanico in Mexico up as far as Point Buchon. I've trawled from Point Buchon down to Port Hueneme. I've fished for halibut within the halibut trawl grounds, and I've also fished outside the halibut trawl grounds which is in deeper water (25 fathoms); we fish out to 50 fathoms.

One of the questions that I have is that I see, or I think I see in my fishing, three different sizes or populations of halibut. I see a population of big halibut, 20–50 pounds; I see a population of legal, or just under legal, and up to 7, 8, or 10 pound halibut; and I see a big population of sublegal halibut. I think that the sublegal halibut and the just legal halibut mix together at times, but I don't think the big halibut have anything to do with those two populations. They are an independent population and I think they travel great distances and they appear out of nowhere and they disappear as fast as they appear. I feel that there are quite a number of big halibut around, mainly coming around during maybe a spawning season, or they follow the bait, and if there is a lot of feed around then the big halibut come around.

I would like to see more tagging of large halibut so we'd get some idea where these large halibut come to and go to and where they come from. I catch them in 30–40 fathoms of water, and I catch them at the islands in gill nets in 10 or 15 fathoms of water. They are there for a few days, then they are gone. In trawling nobody catches them inside of 200 fathoms when they're around. So they've either got to be really deep or they've gone up and down the coast. I feel that they go up and down the coast and they go really deep, but I don't know, it's my observation. So I'd like to see if it's possible to do some tagging on these larger halibut to see exactly what they do and get a better idea. The big fish are around; they are not around only when conditions are right for them to be around.

I think that there's a heck of a lot of fish of the sublegal size and the just-legal size that are in deeper water that I don't hear being talked about today. I hear the depth ranges seem to be shallower than when we catch them trawling. I think there are a lot of fish around that people don't realize are around. It would be good to also tag that size of fish more. The Morro Bay tagging was very interesting. I know a little about tagging in the Santa Barbara area in the late 50s where a fish was tagged in Santa Barbara and in 5 weeks recovered in Oceanside. That was around a 15-pound fish that was tagged at that time. I think that you would see a larger size fish taken in sport fishing if they fished in deeper waters. I think they are fishing in the nursery areas more, and if they would fish out farther, then they would have a larger size catch. I notice that they all tend to fish right along the beaches. In Santa Monica Bay they seem to fish fairly close in. If you go out on the Santa Monica Bank you will find some really nice large fish out there. But hardly anyone fishes out there sport fishing. The fish are there; some gill-netters fish there and catch some, and there were a couple of shrimp trawlers that were catching them out there in deep water. Therefore, you know the populations are there, and I think you would see the size of sport-caught fish go up if the sport fisherman somehow realized that they'd catch bigger fish if they fished in areas where bigger fish lived.

I'd also like to see in future management some emphasis put on the survival rate of released fish in sports fishing. There have been different theories about the survival rate, but I don't think anyone is quite sure what it is. I feel that it's important to know because it looks like a large quantity of fish are caught and released. I think we should try to make it so that if that continues to happen that the survival rates are as good as they can be. One of the ways I would recommend helping the survival rate is to outlaw the treble hook in the use of sports fishing. A lot of the treble hook setups are used to catch halibut. I grew up in the sport fishing business. I worked over there at Joe Martin's, at 22nd Street, when I was a kid, and we caught halibut. Most of the halibut I caught swallowed the hook, and they swallow those little treble hooks. If you leave the hooks in the fish, it's not so bad. But a lot of people when they are catching 20–30 small halibut a day don't want to leave them in, so they just reach down in there with their pliers and pull them out, and I don't know how this effects the survival rate. I just know that the treble hook is not a good thing for halibut fishing, myself.

One comment was made about the size of fish caught dragging. John thought that maybe the fish are smaller around in the Santa Barbara area, but I think that the size of the halibut caught dragging versus the size of halibut caught in gill nets depends on where you are fishing. I see that different areas have different size fish. John said that in the area that he had sampled the fish were smaller in gill nets than they were trawling. What about other areas? I see an awful lot of big fish, and on an average a lot of fish are bigger in trawling than they are in gill nets. Just basic information from my observation.

There was some talk about dividing up the population of some fish. How serious that is I don't know, but to me that's pretty difficult to do. And you've got to remember that in the state of California the fish belong to everyone. When we go to divide them up the commercial fishermen represent all the people that aren't out sport fishing. So how do we divide them up? Fifty, fifty? Twenty-five, seventy-five? It's something to really think about. Who's going to get the fair share, the people of California? the sport fishermen? I'd say that the commercial fishermen are the people of California. That's something that's a real can of worms, I think.

Most of all, what I'd like to see out of this whole thing is that different user groups would stop fighting over this resource and learn to work together a little more. I think there are enough fish for everyone out there, and it seems to me that there is a handful of people that seem to be stirring the pot all the time, maybe for a little personal gain, depending on what type of business they're in. I know that talking as a commercial fisherman, or I'll say representing commercial fishermen's feelings, that everyone of them would like to see this come to an end. Because it's a continual fight. It seems, not only in halibut but in anything a commercial fisherman catches, he is in a fight with other user groups. A lot of it is misinformation, I think, that is being passed out, in different publications and stuff, that is causing this problem, and people just aren't aware of the real facts. I'd like to see that stopped.

That's about all I have to say today. It's been real interesting being here and I'm going back with some good information that I didn't have when I came here. Thank you.

Mr. Frumkes:

First of all, I'm at risk in thanking you for sitting me up here. I'm not sure it's going to be as much fun at this end of the questions as it was asking them. I'm supposed to be representing the recreation industry and I participate in that industry now. I've also been a commercial fisherman for about 11 years. Most of all I think of myself as a scientist usually filling in gaps that I find in the data being presented by other people. I'm independent and in that respect I can risk saying what I choose.

I was very happy to hear the Reed and McCall paper referenced. It was a yield per recruit analysis and I will be referring to some excerpts from it.

I don't want to pass up an opportunity to agree with Mike. First of all I agree that I would really like to see tagging of the larger fish, too. I guess it's a matter of us paying $2.00 a pound to be able to do that. It's the only reason I can think of that we are not tagging them. We can tag the shorts because they are going back anyway; we're not tagging the larger fish for $2.00 a pound. I think that's ridiculous and yet I think it is typical of how our research gets somehow bogged down, and I would like to talk a little about research also. Personally, I also agree with Mike about the treble hook, but I think I'd be shot by a lot of boat operators for saying this.

As a matter of fact we are going to have to think a lot more about the halibut management coming closer to the way we have been managing salmon. I think the future of the management of the nearshore in general is probably going to, in our generation, be more like the management of lakes than the management of an infinite sea. That's the direction I think we'll be going because we have a limited resource and more and more pressure, and we're all fighting for our share of the resource.

So as a representative of the recreational industry, I'm supposed to say what I think that industry wants. I guess they want more. I think they want more halibut, I think they want more management, and I think they want more research. The first way to get more halibut is to have good recruitment. Elimination of impacts of the back bays is one factor that causes good recruitment.

Given that we have recruits, given that we've got halibut which are about 20 inches, the first thing we should do is make them useful. In recent years we've had an awful lot of fish entering the fisheries, and they survive for about 2 years. Look at the distribution of the fish caught in gill nets, trawls, or the recreational catch and you will see that they are not much different. You see a couple of years of fish and then there is just a drop off. That is not a natural population, that's a population which has essentially been cropped of large adults. We are growth overfishing halibut. I'm quoting John Stephens.

The Department cooperated with McCall of the National Marine Fisheries Service to put together a management scheme. The idea was that we would be making better use of the resources if we waited until the fish were 26 inches. One year increases the body weight about 50 percent. The data I have seen was that the fish were entering the fishery at 4 years of age; apparently they are entering at 5 years. Anyway, now we are waiting 5 years. One more year can give a 50 percent increase in the weight of that fish. Now, it's a top predator; it's not likely to die of its own accord, so if it doesn't make it through that year it's probably going to be due to fishing mortality. The way to reduce the fishing mortality is 1) get a larger mesh gill net and a larger mesh trawl to allow the escape of the fish between 22 and 26 inches, and 2) reduce the recreational mortality associated with those fish. I guess you could have a small incidental take of fish under 26 inches in both the commercial and recreational catches. If we did that we would have a substantially larger biomass. There would be more for everybody. All we have to do is allow that one year. So that has nothing to do with taking from anyone; it's just making more use of the fish we've got.

This management methodology will, however, require a reduction in fishing effort, because the problem with waiting that year is that the fish have such a high probability of being caught. The McCall paper says that the recreational halibut industry has been preempted by commercial fishing. They say that the fishing effort has to be reduced. It's presently about twice optimum level. We have to increase the mesh size and maybe remove the suspenders, too. We also have to reduce the number of nets. The number of nets has exploded with the introduction of monofilament in the 70s. We want to return to the level of fishing effort in the early 70s. With that we can have more halibut to go around.

Next I would say that the recreational industry would like to see the halibut caught in ways that have the least negative side effects. Minimize the bycatch. In general, that's by using less efficient gear. Maybe you take away the suspenders, and don't use nets in areas where you are likely to catch fish that you don't want to catch. Maybe you can do it without nets. Maybe it can be done by just trolling because of the higher population. There used to be a successful trolling fishery. The work that has been done up until now has said that trolling has been promising, but we haven't done much more work on it. The Department of Fish and Game, in managing the fishery, should be able to observe anything that it wants to. It should be able to go on a sport boat and look in the sacks, and it should be able to go on a commercial boat and look. It should be able to have a net pulled. It's a privilege to fish, and we have to allow the Department to measure what it wants to measure and to do designed experiments. Again the gill net study is a flawed study because they ask permission. They go out when they can and they tell what they see. It would be better, cheaper, and more effective if more studies were designed. I would like to see studies done in general more as they are in the community I am used to. I come from a medical community and there we have to develop the study design very carefully. We send them out to our peers for review, and we learn an awful lot from what our peers return. We end up with a designed study.

OPEN DISCUSSION

Mr. Golden:

We are going to have questions and answers for about 20 minutes. First I'm going to ask the panel members if they have any questions for each other, then I will open the discussion to all symposium attendees.

Note: Low tape quality precluded a direct transcript of the question and answer session; however, the list below serves to summarize some of the key points made during the question and answer session, as well the panel discussion. There are many other issues, conclusions, and recommendations coming from this symposium, which may be located in the text of the papers presented over the course of the entire symposium.

1. There was a concern that an increased minimum size of 26 inches might only apply to commercial fishermen. Mr. Frumkes indicated that the recommendation to go to 26 inches (from 22 inches) should apply to both fishing groups.

2. How would sex ratio change with population density? Is this an area that is in need of additional research?

3. Additional studies related to spawning behavior and spawning habitat should be conducted.

4. Habitat improvement policies and initiatives for bays and estuaries should be given high priority.
5. Mr. Frumkes indicated that his group has made a start on dealing with items 3 and 4 above with their "Bay-Estuary-Nearshore Ecosystem Study.
6. Mr. McCorkle suggested that the interactions of halibut populations between Mexico and California be studied, and to consider some tagging studies to look for deep water populations of halibut.
7. Continue to work on population modeling and the collection of the kind of data necessary for the models to reach a higher level of credibility.
8. Elimination of treble hooks in the fishery should be considered as a way to increase survivability of short fish.
9. Make a concerted effort to understand how management influences the halibut population.
10. Stocking programs should be based upon research which clearly indicates a need, and then only if the ability to verify the effect of the stocking is designed into the program.

PANEL DISCUSSION CLOSING REMARKS

Mr. Golden:

In the time remaining, I would like to highlight some of the remarks made during the panel discussion. First, I would like to emphasize the importance of the issue of wetlands protection and enhancement, as it relates to fish stocks. Sharon Kramer's presentation yesterday and ongoing work by Larry G. Allen (California State University, Northridge) and M. James Allen (MBC Applied Environmental Sciences) are an important beginning in documenting the role that wetlands and nearshore habitat play with respect to halibut stocks.

Many issues brought up today on how to increase halibut stocks are met with disagreement by one or more interests; but preserving, enhancing, restoring, and keeping our wetlands functioning should be a common goal of the commercial fishermen, recreational fishermen, and all of the resource agencies that are interested in the California halibut. To be successful we cannot limit ourselves to the science of the issue, but we must get involved with the politics as well, since it is quite often the politics of the issue that becomes the deciding factor.

Second, I would like to complement Al Petrovich (CDFG) for coming up with the idea of an action plan based upon the papers and issues brought forth today. As Dr. Botsford mentioned, all too often we leave meetings such as this with a lot of good information that is not acted upon in any organized and specific manner. I am looking forward to seeing a draft action plan which is made available to interested parties outside of the California Department of Fish and Game for comment and review. Bringing together the expertise of the academic community, scientists from other agencies, organizations such as the American Institute of Fishery Research Biologists (AIFRB), and user groups can only improve on what I believe can be the most important accomplishment of this symposium.

Finally, wearing the hat of the Director of the Southern California Chapter of the AIFRB, I would like to thank the people that helped organize and handle the logistics of the meeting, especially AIFRB members Ann Brierton, Steve Caddell, Pete Haaker, Jim Allen, Mark Helvey, Kevin Herbinson, and several Department of Fish and Game personnel.

SYMPOSIUM CLOSING REMARKS

Mr. Sunada, Symposium coordinator:

A lot of people have come up to tell me what a difficult job it must have been for me to conduct this symposium. To be honest, it was not that bad, since of the 28 papers scheduled only three were no-shows, indicating the high degree of professionalism and dedication of all the people involved.

I would also like to extend accolades to the American Institute of Fishery Research Biologists, and particularly their Director, Marty Golden, for providing most of the logistic support and front money for putting on the Symposium. Also, accolades to Dr. Susanne Lawrenz-Miller and staff of the Cabrillo Marine Museum for the use of their facilities and audiovisual support. of course in the trenches were the members of the Symposium Committee which included Pete Haaker, Steve Crooke, John Hunter, Geoff Moser, Jim Berkson, Jim Hardwick, Marija Vojkovich, Rick Klingbeil, Christine Pattison, Cheryl Avants, Marty Golden, and Rhonda Reed. Also Liz Cardin and Patty Velez helped with registration.

Thank you, Bob Fletcher, for the Keynote Presentation and also to the panelists for giving their views and insight into the issues we have talked about today. Last but not least, this symposium would not have been possible without the support of my supervisor, Rick Klingbeil; the Program Manager, Rolf Mall; and our Division Chief, Al Petrovich.

Thank you to the audience for your support. You all deserve a hardy round of applause.

I hereby adjourn this Symposium. Have a safe trip home.

ADDENDUM
A SYNOPSIS OF CALIFORNIA HALIBUT LAWS AND REGULATIONS

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INTRODUCTION

Before presenting a list of California halibut laws and regulations, it may be helpful to review the evolution of California's fish and game laws and regulations, and the origin of existing management authority. Until 1933, California laws regulating the take of fish and shellfish were typically included in the California Penal Code and the Political Code (first published as Revised Laws of the State of California in Four Volumes: Political, Civil, Civil Procedures, and Penal in 1871), or were the result of other earlier separate Acts adopted by the California Legislature.

The Fish and Game Commission (FGC), known as the State Board of Fish and Game Commissioners prior to 1927, and Board of Fish Commissioners prior to 1909, annually or bi-annually compiled fish and game-related statutes into a volume variously entitled Laws Relating to Fish and Game and Fish and Game Laws. This volume served as a reference guide and, in this respect, served the same general purpose as today's Fish and Game Code (FG Code) and Title 14 of the California Code of Regulations (CCR—entitled the California Administrative Code prior to 1988).

In 1927 the Division of Fish and Game was established within the Department of Natural Resources. The new Division assumed many of the administrative duties formerly performed by the Commission, while the Commission retained its policy and regulatory authority. The regulatory powers of the Fish and Game Commission were broadened considerably in 1945, when the Legislature (through a constitutional amendment) delegated to the Commission authority for regulating sport fishing and hunting. Also in 1945, regulations of the Fish and Game Commission were first incorporated into Division I of Title 14, of the California Administrative Code.

The Fish and Game Code was created in 1933 with the transfer of Penal Code sections and other sections regarding the take of fish and game. Following an intensive review during the mid-1950s by the California Law Revision Commission, the Fish and Game Code was repealed in its entirety, reorganized and readopted in 1957 in its present general form.

Some of the earliest laws directed at marine species appear to be those encouraging the cultivation of oysters (enacted 1851), and licensing of commercial fishermen (enacted 1887). Laws directed at other marine shellfish species such as abalone, crab, crawfish (lobster), and shrimp; and anadromous species such as salmon, shad, steelhead, striped bass, and sturgeon were enacted during the 1890s. It was not until 1909 that the first law directed specifically at the take of wholly-marine species of fin fish was enacted. This law (Section 628 of the Penal Code) made it a misdemeanor to take, catch, or kill any "California whiting" (California corbina) also termed "surf-fish" or any "yellow-fin" or "spot-fin" croaker, except with hook-and-line.

In 1913, the Anglers License Act made it a misdemeanor for any person over 18 years of age to take, catch, or kill any "game fish" for any purpose other than profit, without first purchasing a license. For purposes of the Act, "game fishes" did not include California halibut, but did include "tuna, yellowtail, giant sea bass, albacore, barracuda, bonito, rock bass (kelp bass), California whiting, also known as corbina and surf-fish, yellowfin croaker, spotfin croaker, salmon, steelhead, and other trout, charr, white-fish (mountain whitefish), striped bass and black bass". Beginning in 1947 a "sporting fishing license" was required by persons over the age of 16 to take any fish (including California halibut) for any purpose other than profit.

Laws and regulations affecting California halibut can perhaps best be categorized as those which directly refer to California halibut and those which, though not directly referring to California halibut, affect some aspect of the fisheries for that species, such as gear restrictions or gear construction standards (mesh size, etc.). The term "regulation" is often popularly applied to both provisions enacted by the Legislature and those adopted by boards and commission. However, the convention typically followed by lawmakers and other regulatory bodies is that the Legislature enacts laws (statutes), while boards and commissions (the Fish and Game Commission, in this case) adopt orders, rules, and regulations under authority provided to them by the Legislature.

In this regard, Table 1 includes laws and Table 2 regulations directly referring to California halibut. Table 1 includes the chapter number and date of the legislation adding or amending a Code section (where available), while Table 2 includes the Register number and date associated with the filing of a new or revised Fish and Game Commission regulation. In most cases, legislation becomes effective on January 1 of the year following its enactment. However, legislation may specify another effective date after January 1 (for part or all of the provisions in the bill). Also, when legislation is enacted on an emergency basis, the provisions typically become effective immediately upon filing with the Secretary of State.

Laws and regulations which do not directly refer to California halibut, but may have a significant effect upon the fisheries for California halibut are briefly discussed below.

CALIFORNIA HALIBUT COMMERCIAL FISHING LAWS

Perhaps the first and most descriptive account of the early commercial fisheries for, and laws related to the taking of, California Halibut is contained in an early report entitled, The California Halibut (Paralichthys californicus) and an Analysis of the Boat Catches (Clark 1931). Clark's account of the trammel and trawl net provisions in effect prior to 1930 follows.

“"Aside from the geographical separations of fishing areas, the California halibut fishery can be segregated into two divisions: the trammel net and the trawl net fisheries.” “"Trammel nets are, and have been, legal ocean fishing gear since 1915 from the northern boundary of Mendocino County to the California-Mexican boundary line, with the exception of Monterey Bay. Previous to 1915, the use of trammel nets was prohibited in the State in 1911, but in 1913 trammel nets could be legally fished in the coastal waters of the State one mile from shore. In 1919, regulations were made for the use of trammel nets in the Sacramento River and San Francisco Bay districts.” “"Trawl or drag nets were first prohibited in southern California in 1911, when what was then known as district 6 (coastal waters from the northern boundary of Ventura County to the Mexican line) was closed to trawl net fishing. In 1915, new fish and game districts were created so that the coastal waters from the northern boundary of Santa Barbara County to the Mexican line became district 19, in which possession of trawl nets was prohibited. In this year, the entire State waters were closed to the use of trawl nets, but possession was only prohibited in district 19, so that trawling could be carried on outside of the three-mile limit. In 1917, it became lawful to use trawls in the coastal waters from the Oregon line to the southern boundary of Mendocino County (districts 5, 6 and 7) and from Point Carmel in Monterey County to the northern boundary of Santa Barbara County (district 18). It also became lawful to use drag nets in district 13 for shrimps. District 19 was closed to fishing with trawl nets.” “"The law enacted in 1915, prohibiting the possession of trawls in district 19 remained on the statutes until 1923, but could not be enforced because the later law passed in 1917 superseded it until 1923. In 1919, the use of drag nets for catching shrimps was permitted in district 12; and the bays in district 18 (Point Carmel to Santa Barbara, northern county line) were closed to trawl net operations. This last act was passed because it was believed that the waters close to shore and in the bays were nurseries for young fish. No new trawl net legislation was enacted until 1923, at which time the possession of drag nets was prohibited in district 19 (coastal waters from northern Santa Barbara County line to Mexican line), in land district 4 (southern Ventura County line to Mexican line), in districts 20 and 20A (Catalina Island and water around the island), and in district 21 (San Diego Bay). This last law was a great help to the enforcement agents of the State in controlling trawl nets in district 19. In order to aid the trawl net fishermen, who maintain they never fished close to shore or took small fish in their nets, Santa Barbara County was taken out of district 19 and placed in district 18 in 1925. The rest of the regulations remained as before. In 1927, after the courts had decided that Monterey Bay and three miles beyond was State territory, it became lawful to fish with trawls in Monterey Bay provided fishing was confined to waters of 25 fathoms or more in depth. In addition, district 2 in the Sacramento River was opened to trawl nets for shrimp fishing. The other regulations remained as they were the previous year. No change in the trawl net law has occurred since 1927."”

Since this account relatively little has been published regarding the commercial or recreational fisheries for California halibut.

The most recently published account of California halibut laws and regulations (Methot 1983) provides insights into the reasons for regulatory changes occurring from 1960 until 1983 and are reproduced here in part. “"Two regulations historically have affected the commercial halibut fishery: exclusion of trawls from the region nearshore of three miles and a four-pound size limit. Because the preferred habitat of halibut is shallow sandy bottoms, much of the stock was unavailable to the trawl fishery. During the low catch period of the late 1900's, there was interest in increasing short-term catches while allowing gradual improvement of the resource. In 1971, the California Assembly attempted to improve catches by establishing a special inshore halibut trawl ground that extended to one mile off shore at the Santa Barbara area.” “"To allow gradual improvement of the stock, special regulations were placed on trawling in this region. The season was closed from March 15 to June 15 and a minimum mesh size of 7.5 inches was required in the cod end of the trawls. The closed season was designed to protect the nearshore fish during the spawning season. The mesh-size limitation was designed to permit undersized fish to escape through the mesh. At the same time, a 22-inch size limit was established for the recreational fishery to balance the regulatory impact between the commercial and recreational fisheries. The biological impact of opening the nearshore region to trawling was balanced against the increased protection of the young fish.” “"The legislation that established the halibut trawl grounds also required that the effect of the legislation be evaluated. [It was] found that the mesh-size regulation was effective in greatly reducing retention by trawls of fish less than 22 inches (about four pounds). Compliance with the recreational size limit initially was poor, but now is improving. In 1975 to 1976 greater than 43% of the halibut landed by the independent sport fishery were smaller than legal size but, by 1981, this figure had declined to less than 29%. Although an attempt to detect a recovery in the stock was inconclusive, the commercial catch increased greatly in 1981 after the report [to the Legislature] was prepared."”

Since 1980, changes in laws and regulations affecting the commercial fisheries for California halibut have focused primarily upon further limitations on the use of gill and trammel nets, gear modifications, and the area encompassed by the California halibut trawl grounds (Table 1). These changes include: 1) The establishment of a revocable nontransferable permit for the use of gill and trammel nets (commonly referred to as the general gill and trammel net permit) (Ch. 316, Stats. 1980; Ch. 1002, Stats. 1985; Ch. 436, Stats. 1985; Ch. 1242, Stats. 1989); 2) Several area and season closures for the use of gill and trammel nets to protect seabirds, marine mammals, and nearshore kelp bed resources (Ch. 316, Stats. 1982; Ch. 206, Stats. 1984; Ch. 50, Stats. 1985; Ch. 854, Stats. 1985; Ch.910, Stats. 1986; Ch. 1298, Stats. 1987; Ch. 702, Stats. 1987; Ch. 979, Stats. 1987); 3) Increasing the mesh size and limiting the length of gill and trammel nets, and reducing the tolerance of undersized California halibut allowed to be taken by gill and trammel net fishermen (Ch. 1002, Stats. 1985; Ch. 1031, Stats. 1988); and 4) Increasing the area of the California halibut trawl grounds (Ch. 353, Stats. 1988).

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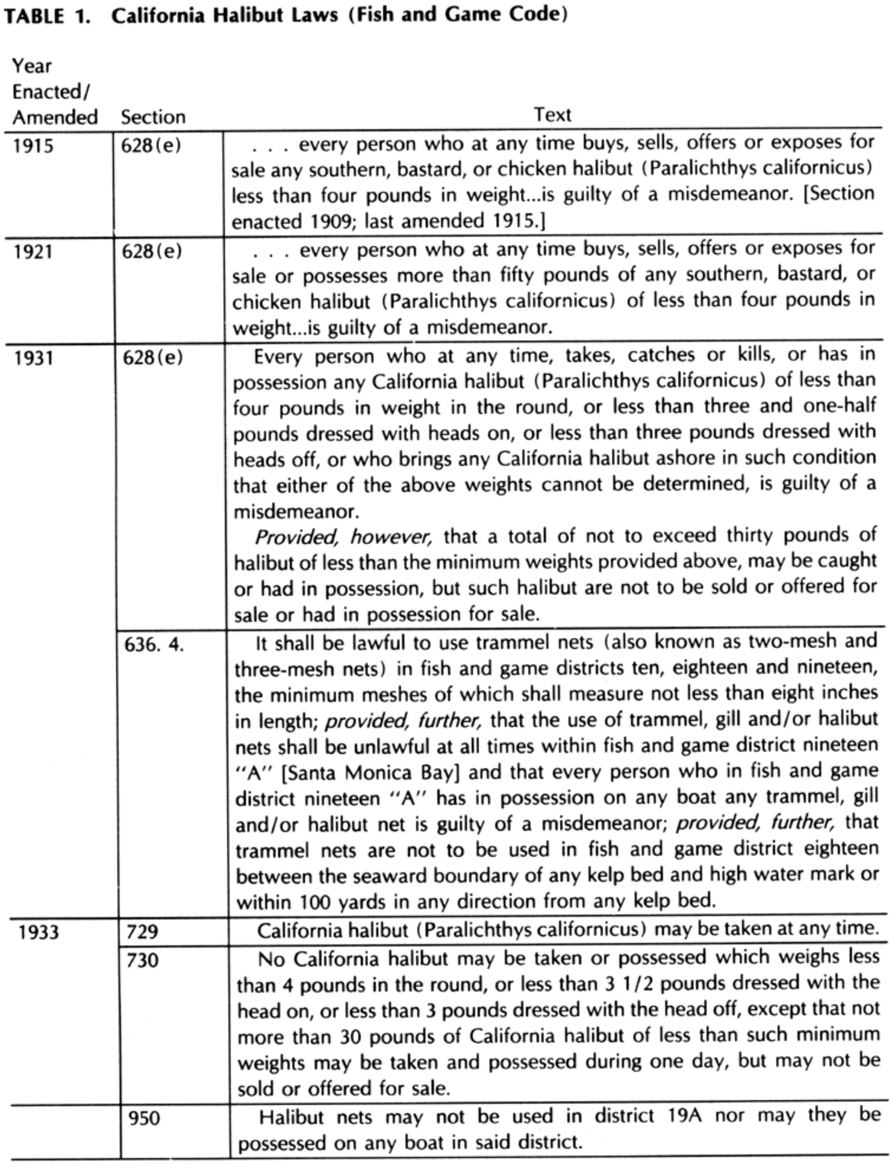
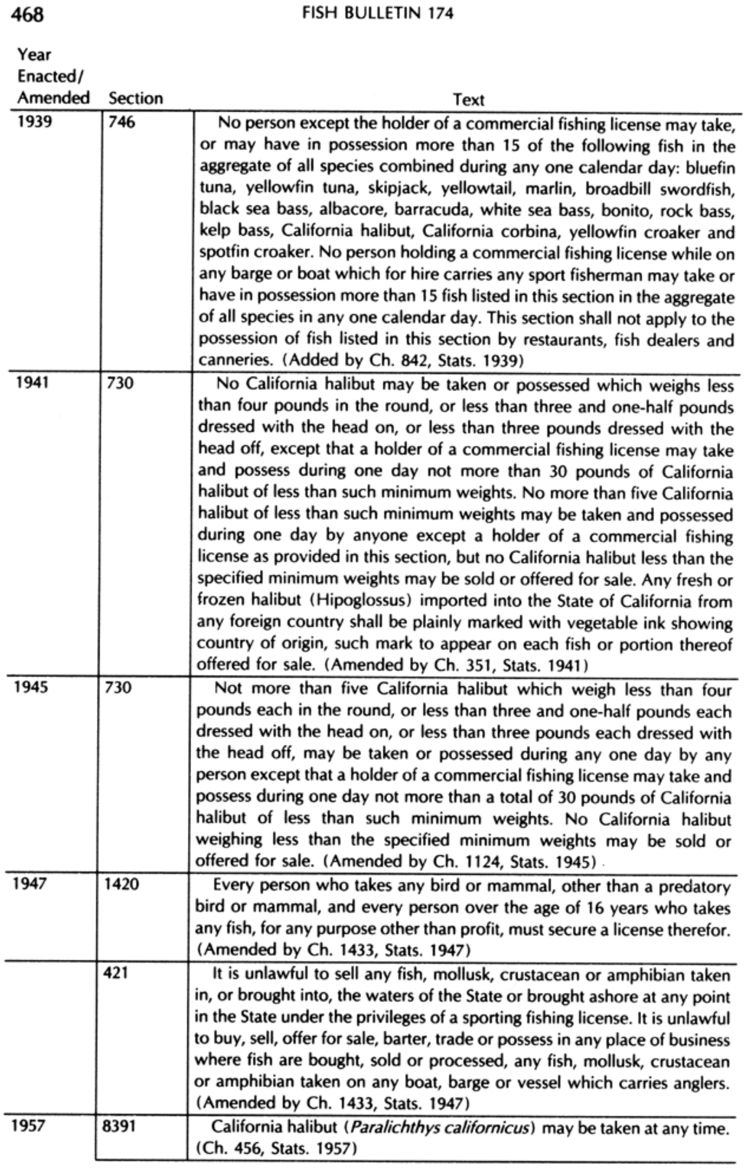


TABLE 1. California Halibut Laws (Fish and Game Code)

Year Enacted/ Amended	Section	Text
1915	628(e)	. . . every person who at any time buys, sells, offers or exposes for sale any southern, bastard, or chicken halibut (Paralichthys californicus) less than four pounds in weight...is guilty of a misdemeanor. [Section enacted 1909; last amended 1915.]
1921	628(e)	. . . every person who at any time buys, sells, offers or exposes for sale or possesses more than fifty pounds of any southern, bastard, or chicken halibut (Paralichthys californicus) of less than four pounds in weight...is guilty of a misdemeanor.
1931	628(e)	Every person who at any time, takes, catches or kills, or has in possession any California halibut (Paralichthys californicus) of less than four pounds in weight in the round, or less than three and one-half pounds dressed with heads on, or less than three pounds dressed with heads off, or who brings any California halibut ashore in such condition that either of the above weights cannot be determined, is guilty of a misdemeanor. *Provided, however,* that a total of not to exceed thirty pounds of halibut of less than the minimum weights provided above, may be caught or had in possession, but such halibut are not to be sold or offered for sale or had in possession for sale.
	636. 4.	It shall be lawful to use trammel nets (also known as two-mesh and three-mesh nets) in fish and game districts ten, eighteen and nineteen, the minimum meshes of which shall measure not less than eight inches in length; *provided, further,* that the use of trammel, gill and/or halibut nets shall be unlawful at all times within fish and game district nineteen ''A'' [Santa Monica Bay] and that every person who in fish and game district nineteen ''A'' has in possession on any boat any trammel, gill and/or halibut net is guilty of a misdemeanor; *provided, further,* that trammel nets are not to be used in fish and game district eighteen between the seaward boundary of any kelp bed and high water mark or within 100 yards in any direction from any kelp bed.
1933	729	California halibut (Paralichthys californicus) may be taken at any time.
	730	No California halibut may be taken or possessed which weighs less than 4 pounds in the round, or less than 3 1/2 pounds dressed with the head on, or less than 3 pounds dressed with the head off, except that not more than 30 pounds of California halibut of less than such minimum weights may be taken and possessed during one day, but may not be sold or offered for sale.
	950	Halibut nets may not be used in district 19A nor may they be possessed on any boat in said district.

TABLE 1. ***California Halibut Laws (Fish and Game Code)***



Year Enacted/ Amended	Section	Text
1939	746	No person except the holder of a commercial fishing license may take, or may have in possession more than 15 of the following fish in the aggregate of all species combined during any one calendar day: bluefin tuna, yellowfin tuna, skipjack, yellowtail, marlin, broadbill swordfish, black sea bass, albacore, barracuda, white sea bass, bonito, rock bass, kelp bass, California halibut, California corbina, yellowfin croaker and spotfin croaker. No person holding a commercial fishing license while on any barge or boat which for hire carries any sport fisherman may take or have in possession more than 15 fish listed in this section in the aggregate of all species in any one calendar day. This section shall not apply to the possession of fish listed in this section by restaurants, fish dealers and canneries. (Added by Ch. 842, Stats. 1939)
1941	730	No California halibut may be taken or possessed which weighs less than four pounds in the round, or less than three and one-half pounds dressed with the head on, or less than three pounds dressed with the head off, except that a holder of a commercial fishing license may take and possess during one day not more than 30 pounds of California halibut of less than such minimum weights. No more than five California halibut of less than such minimum weights may be taken and possessed during one day by anyone except a holder of a commercial fishing license as provided in this section, but no California halibut less than the specified minimum weights may be sold or offered for sale. Any fresh or frozen halibut (Hipoglossus) imported into the State of California from any foreign country shall be plainly marked with vegetable ink showing country of origin, such mark to appear on each fish or portion thereof offered for sale. (Amended by Ch. 351, Stats. 1941)
1945	730	Not more than five California halibut which weigh less than four pounds each in the round, or less than three and one-half pounds each dressed with the head on, or less than three pounds each dressed with the head off, may be taken or possessed during any one day by any person except that a holder of a commercial fishing license may take and possess during one day not more than a total of 30 pounds of California halibut of less than such minimum weights. No California halibut weighing less than the specified minimum weights may be sold or offered for sale. (Amended by Ch. 1124, Stats. 1945)
1947	1420	Every person who takes any bird or mammal, other than a predatory bird or mammal, and every person over the age of 16 years who takes any fish, for any purpose other than profit, must secure a license therefor. (Amended by Ch. 1433, Stats. 1947)
	421	It is unlawful to sell any fish, mollusk, crustacean or amphibian taken in, or brought into, the waters of the State or brought ashore at any point in the State under the privileges of a sporting fishing license. It is unlawful to buy, sell, offer for sale, barter, trade or possess in any place of business where fish are bought, sold or processed, any fish, mollusk, crustacean or amphibian taken on any boat, barge or vessel which carries anglers. (Amended by Ch. 1433, Stats. 1947)
1957	8391	California halibut (*Paralichthys californicus*) may be taken at any time. (Ch. 456, Stats. 1957)

TABLE 1—Cont'd.

Year Enacted/ Amended	Section	Text
	8392	No California halibut which weighs less than 4 pounds each in the round, or less than 3 1/2 pounds each dressed with the head on, or less than three pounds each dressed with the head off, may be taken, possessed, or sold. The holder of a commercial fishing license may possess during one day for noncommercial use not more than a total of 30 pounds of California halibut of less than such minimum weights if taken incidentally in commercial fishing. (Amended by Ch. 456, Stats. 1957)
1957	8385	No person holding a commercial fishing license while on any barge or boat which for hire carries any sport fisherman may take or have in his possession in any one day more than the aggregate number of the following kinds of fish permitted in the case of sport fishing: bluefin tuna, yellowfin tuna, skipjack, yellowtail, marlin, broadbill swordfish, black seabass, albacore, barracuda, white seabass, bonito, rock bass, kelp bass, California halibut, California corbina, yellowfin croaker, and spotfin croaker. (Amended by Ch. 456, Stats. 1957)
1971	8495	The following areas are designated as the California halibut trawl grounds: Those portions of District 18, 19, and 118.5 adjacent to the mainland shore in waters not more than 25 fathoms deep and not less than one nautical mile from the mainland shore lying south and east of a line runninng due west (270° true) from Point Arguello and north and west of a line running due south (180° true) from Point Mugu. (Added by Ch. 1341, Stats. 1971)
	8496	Within the California halibut trawl grounds the following requirements shall apply to the use of trawl nets: (a) Open season shall be June 1 through January 30. (b) No California halibut which weighs less than four pounds each in the round may be possessed aboard trawl vessels. (c) Not more than 500 pounds of fish other than California halibut may be possessed. (d) It is unlawful to operate a trawl net in such a way as to damage or destroy other types of fishing gear which is buoyed or otherwise visibly marked. (e) Sections 8392, 8833, and 8836 do not apply to trawl nets when used or possessed on such California halibut trawl grounds. (Added by Ch. 1341, Stats. 1971)
	8497	If the director determines that the California halibut resource, or existing fishing operations, within the designated California halibut trawl grounds are in danger of irreparable injury, he may order the closure of the area, or portions thereof, to trawl net fishing or further restrict the nets that may be used in the area, or portions thereof. Any such closure or restriction order shall be adopted by emergency regulation in accordance with Chapter 4.5 (commencing with section 11371), Part 1, Division 3, Title 2 of the Government Code. The department shall bring to the attention of the Legislature within 30 calendar days after commencement of the next succeeding regular session of the Legislature any regulation adopted pursuant to the section. (Added by Ch. 1341, Stats. 1971)

TABLE 1—Cont'd.

Year Enacted/ Amended	Section	Text
1972	8496	Within the California halibut trawl grounds the following requirements shall apply to the use of trawl nets: (a) Open season shall be June 16 through March 14. (b) No California halibut which weighs less than four pounds each in the round may be possessed aboard trawl vessels. (c) Not more than 500 pounds of fish other than California halibut may be possessed. (d) It is unlawful to operate a trawl net in such a way as to damage or destroy other types of fishing gear which is buoyed or otherwise visibly marked. (e) Sections 8392, 8833, and 8836 do not apply to trawl nets when used or possessed on such California halibut trawl grounds. (Amended by Ch. 985, Stats. 1972)
1979	8392	(a) No California halibut which measures less than 22 inches in total length may be taken, possessed, or sold. (b) Total length means the shortest distance between the tip of the jaw or snout, whichever extends farthest while the mouth is closed, and the tip of the longest lobe of the tail, measured while the halibut is lying flat in natural repose, without resort to any force. (c) The holder of a commercial fishing license may possess during one day for noncommercial use not more than a total of 30 pounds of California halibut of less than 22 inches in total length if taken incidentally in commercial fishing. (Amended by Ch. 154, Stats. 1979)
	8496	Within the California halibut trawl grounds the following requirements shall apply to the use of trawl nets: (a) Open season shall be June 16 through March 14. (b) California halibut shall only be taken pursuant to Section 8392. (c) Not more than 500 pounds of fish other than California halibut may be possessed, except that any amount of sharks, skates, or rays may be taken or possessed. (d) It is unlawful to operate a trawl net in such a way as to damage or destroy other types of fishing gear which is buoyed or otherwise visibly marked. (e) Sections 8833, and 8836 do not apply to trawl nets when used or possessed on such California halibut trawl grounds. (Amended by Ch. 154, Stats. 1979)
1981	8392	(a) No California halibut may be taken, possessed, or sold which measures less than 22 inches in total length, unless it weighs four pounds or more in the round, three and one-half pounds or more dressed with the head on, or three pounds or more dressed with the head off. Total length means the shortest distance between the tip of the jaw or snout, whichever extends farthest while the mouth is closed, and the tip of the longest lobe of the tail, measured while the halibut is lying flat in natural repose, without resort to any force. (b) The holder of a commercial fishing license may possess during one day for noncommercial use not more than a total of 30 pounds of California halibut of less than 22 inches in total length or less than the minimum weights specified in subdivision (a) if taken incidentally in commercial fishing. (Amended by Ch. 448, Stats. 1981)

TABLE 1—Cont'd.

Year Enacted/ Amended	Section	Text
1985	8392	(a) No California halibut may be taken, possessed, or sold which measures less than 22 inches in total length, unless it weighs four pounds or more in the round, three and one-half pounds or more dressed with the head on, or three pounds or more dressed with the head off. Total length means the shortest distance between the tip of the jaw or snout, whichever extends farthest while the mouth is closed, and the tip of the longest lobe of the tail, measured while the halibut is lying flat in natural repose, without resort to any force. (b) The holder of a commercial fishing license may possess during one day for noncommercial use not more than four California halibut of less than 22 inches in total length or less than the minimum weights specified in subdivision (a) if taken incidentally in commercial fishing. (Amended by Ch. 1002, Stats. 1985)
	8624	(a) Set gill nets and trammel nets with mesh size of not less than 8 1/2 inches may be used to take California halibut in ocean waters between a line extending due west magnetic from Ragged Point in San Luis Obispo County, and a line extending due west magnetic from Point Dume in Los Angeles County. (b) No permittee operating under a gill net or trammel net permit issued pursuant to Section 8681 shall fish, in combination each day, more than 1,000 fathoms (6,000 feet) of set gill or trammel nets for California halibut in ocean waters between a line extending due west magnetic from Ragged Point in San Luis Obispo County and a line extending due west magnetic from Point Dume in Los Angeles County. (c) This section shall become operative on August 15, 1986. (Added by Ch. 1002, Stats. 1985)
1987	8392	(a) No California halibut may be taken, possessed, or sold which measures less than 22 inches in total length, unless it weighs four pounds or more in the round, three and one-half pounds or more dressed with the head on, or three pounds or more dressed with the head off. Total length means the shortest distance between the tip of the jaw or snout, whichever extends farthest while the mouth is closed, and the tip of the longest lobe of the tail measured while the halibut is lying flat in natural repose, without resort to any force other than the swinging or fanning of the tail. (b) The holder of a commercial fishing license may possess during one day for noncommercial use not more than four California halibut of less than 22 inches in total length or less than the minimum weights specified in subdivision (a) if taken incidentally in commercial fishing. (Amended by Ch. 1002, Stats 1985; Ch. 817, Stats. 1986)

TABLE 1—Cont'd.

Year Enacted/ Amended	Section	Text
1988	8624	(a) Set gill nets and trammel nets with mesh size of not less than 8 1/2 inches may be used to take California halibut in ocean waters between a line extending due west magnetic from Ragged Point in San Luis Obispo County and a line extending due west magnetic from Point Dume in Los Angeles County. (b) No permittee operating under a gill net or trammel net permit issued pursuant to Section 8681 shall fish, in combination each day, more than 1,000 fathoms (6,000 feet) of set gill or trammel nets for California halibut in ocean waters between a line extendng due west magnetic from Ragged Point in San Luis Obispo County and a line extending due west magnetic from Point Dume in Los Angeles County. (c) This section shall become operative on August 15, 1989, and, as of January 1, 1990, is repealed, unless a later enacted statute, which becomes effective on or before January 1, 1990, deletes or extends the dates on which it becomes inoperative and is repealed. (Amended by Ch. 1031, Stats 1988)
	8626	(a) Notwithstanding Section 8625, and where consistent with the determination made pursuant to subdivisions (b) and (c), the director may reduce the minimum mesh size permitted for gill and trammel nets used to take California halibut from 8 1/2 inches to not less than 8 inches in any or all areas south of a line extending 240 degrees magnetic from the boundary line between the Counties of Los Angeles and Ventura. (b) If, on or before October 1, 1990, the department determines that commercial landings of California halibut taken south of the line extending 240 degrees magnetic from the boundary line between the Counties of Los Angeles and Ventura in the period between September 1, 1989, and August 31, 1990, decline by 10 percent or more compared with landings of California halibut taken in this area during the period between September 1, 1988, and August 31, 1989, the department shall assess the impact of the 8 1/2 inch minimum mesh size restriction on the California halibut fishery in the area described in subdivision (a). The assessment shall include, but is not limited to, an analysis of landing data, including landings of California halibut in Los Angeles, Orange, and San Diego Counties, the age and size composition of the catch, and the department's monitoring at sea of the gill and trammel net fishery. (c) If the department determines that the 8 1/2 inch minimum mesh size, established pursuant to Section 8625 has directly resulted in a decline of 10 percent or more in landings of California halibut south of the line extending 240 degrees magnetic from the boundary between the Counties of Los Angeles and Ventura, the director shall hold a public hearing in the area affected to make findings and take public testimony prior to taking any action pursuant to subdivision (a). (d) This section shall become operative on August 15, 1989. (Added by Ch. 1031, Stats. 1988)

TABLE 1—Cont'd.

TABLE 2. California Halibut Regulations (Title 14 CCR)

Year Enacted/ Amended	Section Number	Text
1949	5 (q)	Various Salt Water Varieties. Not more than 10 bluefin tuna, yellowfin tuna, skipjack, yellowtail, marlin, broadbill swordfish, black sea bass, albacore, barracuda, white sea bass, bonito, rock bass, kelp bass, California halibut, California corbina, yellowfin croaker, spotfin croaker, lingcod and cabezone, in the aggregate of such fish, may be taken or possessed by any person during any one day, provided that not more than 2 of such fish shall be marlin, broadbill swordfish, or black sea bass. This order modifies Section 746 and all other sections of the Fish and Game Code or orders of the Commission inconsistent herewith. (*Register 15, No. 3, 2/2/49)
1951	5 (o)	Various Salt Water Varieties. Not more than 15 bluefin tuna, yellowfin tuna, skipjack, yellowtail, marlin, broadbill swordfish, black sea bass, albacore, barracuda, white sea bass, bonito, rock bass, kelp bass, California halibut, California corbina, yellowfin croaker, spotfin croaker, lingcod and cabezone, in the aggregate of such fish may be taken or possessed by any person during any one day, provided that not more than 10 of any one species of such fish shall be taken or possessed. This order modifies Section 746 and all other sections of the Fish and Game Code and orders of the commission inconsistent herewith. (Register 23, No. 3, 2/10/51). [This section apparently was intended to correct the inconsistency in bag limits between the Fish and Game Code and Title 14, California Administrative Code.]
1956	5.3 (f)	Various Salt Water Fishes. Not more than 15 bluefin tuna, yellowfin tuna, skipjack, yellowtail, albacore, barracuda, white sea bass, bonito, kelp bass, sand bass, spotted bass, California halibut, California corbina, yellowfin croaker, spotfin croaker, lingcod and cabezone, in the aggregate of such fish may be taken or possessed by any person during any one day, provided that not more than 10 of any one species of such fish shall be taken or possessed during any one day, and provided further, that not more than two each of marlin, swordfish or black sea bass, may be taken or possessed in any one day. No kelp bass, sand bass or spotted bass less than 10 1/2 inches in length may be taken. No more than five each of barracuda, white sea bass or yellowtail less than 28 inches in length, or five California halibut of less than four pounds round weight, may be taken or possessed during any one day. Except for the species enumerated in Section 5, paragraphs (a), (b), (g) and (j), and in Section 5.3, there are no bag limits, size limits or closed seasons for salt water fishes. (Register 56, No. 19, 10/20/56)

* Changes in sport fishing regulations typically become effective on March 1 of each year. The Register date shown is the date the regulation is first published following the Commission's action to adopt or amend the regulation, and typically falls within a few months of March 1.

TABLE 2. **California Halibut Regulations (Title 14 CCR)**

Year Enacted/ Amended	Section Number	Text
1957	5.3	(f) Various Salt Water Fishes. Not more than 15 bluefin tuna, yellowfin tuna, skipjack, yellowtail, albacore, barracuda, white sea bass, bonito, kelp bass, sand bass, spotted bass, California halibut, California corbina, yellowfin croaker, spotfin croaker, lingcod and cabezone, in the aggregate of such fish may be taken or possessed by any person during any one day, provided that not more than 10 of any one species of such fish shall be taken or possessed during any one day, and provided further, that not more than two each of marlin, swordfish or black sea bass may be taken or possessed during any one day. No kelp bass, sand bass or spotted bass less than 11 inches in length may be taken. No more than two each of barracuda or white sea bass less than 28 inches in length, nor more than five yellowtail less than 28 inches in length, nor more than two California halibut less than 22 inches in length, may be taken or possessed during any one day. Except for the species enumerated in Section 5, paragraphs (a), (b), (g) and (j), and in Section 5.3, there are no bag limits, size limits or closed seasons for salt water fishes. (Register 57, No. 4, 3/9/57)
1959	73.5	Halibut, California. Limit: Two halibut. (Register 59, No. 5, 3/21/59)
1963	73.5	Halibut, California. Limit: Five halibut. (Register 63, No. 1, 1/19/63)
1966	61.3.	Hook Limitation, Certain Ocean Waters. (a) No hook with more than one point may be used while trolling in ocean waters between Tomales Point in Marin County and Yankee Point in Monterey County. This section does not include San Francisco Bay and tributaries between the Golden Gate Bridge and the west Carquinez Bridge. (Register 66, No. 1, 1/19/66) (b) Not more than one hook may be used to take halibut in Tomales Bay and that portion of Bodega Bay inshore from a line drawn between Tomales Bluff and the southernmost point of Bodega Head. (Register 66, No. 1, 1/19/66).
1971	67.	California and Pacific Halibut. (a) Daily bag and possession limit: Five. Minimum size: 22 inches total length. (Register 70, No. 52, 12/26/70).
	78.	General. Except as provided in this article, fin fish may be taken only on hook and line or with the hands. Any number of hooks and lines may be used in all ocean water and bays except San Francisco Bay between the Golden Gate Bridge and the west Carquinez Bridge, where only one line with not more than three hooks may be used. (Supercedes former section 61.3)
1972	67.	California and Pacific Halibut. Daily bag and possession limit: Five (5) except three (3) in Tomales Bay and Bodega Bay easterly of a line running northeasterly from Tomales Point to the Whistle Buoy, thence to the Gong buoy (S.E. of Bodega Rock) thence to the westerly side of Bodega Head. Minimum size: 22 inches total length. (Register 72, No. 1, 1/1/72)

TABLE 2—Cont'd.

Year Enacted/ Amended	Section Number	Text
1974	28.	California and Pacific Halibut. (a) Limit: Five, except three in Tomales Bay and Bodega Bay easterly of a line running northeasterly from Tomales Point to the Whistle buoy, then to the gong buoy (S.E. of Bodega Rock) then to the westerly side of Bodega Head. (b) Minimum size: Twenty-two inches total length.
1975	28.15	Halibut, California. (a) Limit Five, except three in Tomales Bay and Bodega Bay easterly of a line running northeasterly from Tomales point to the whistle buoy, then to the bell buoy (S.E. of Bodega Rock) then to the westerly side of Bodega Head. (b) Minimum size: Twenty-two inches total length. (Change in Section number only)

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TABLE 2—Cont'd.