Title

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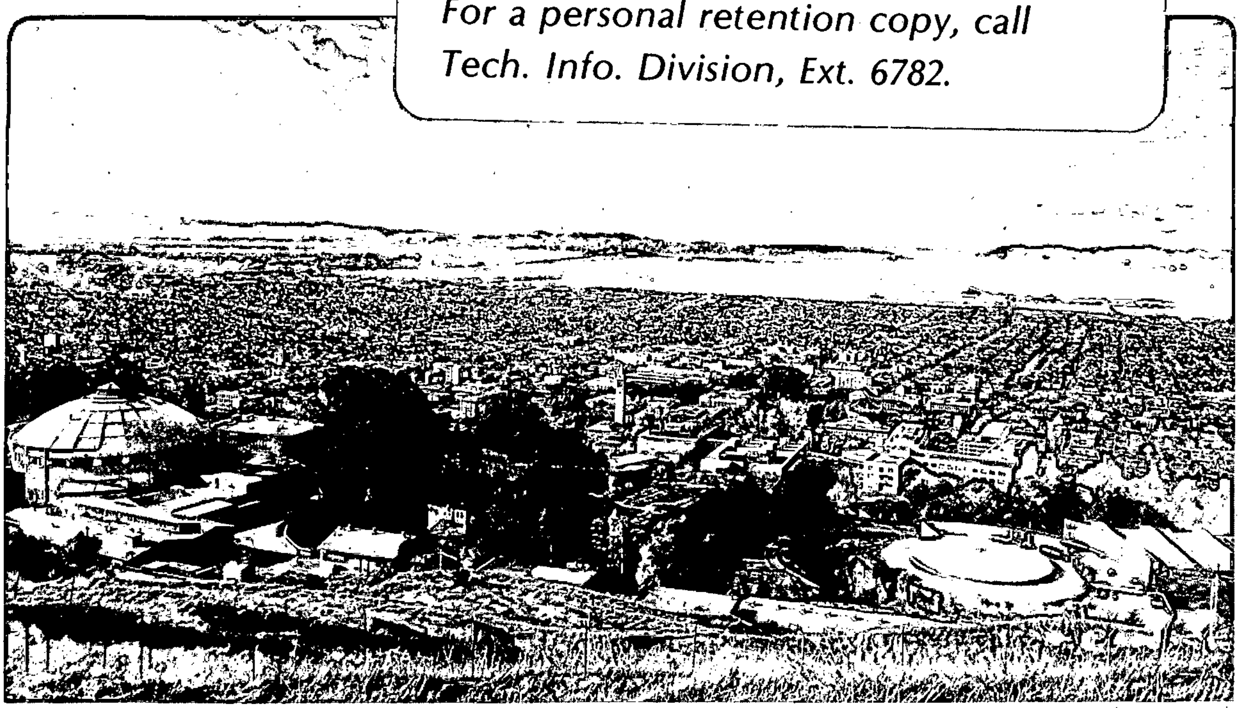

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THE ECOLOGY OF HAWAIIAN MARINE MAMMALS EMPHASIZING THE IMPACT OF OCEAN THERMAL ENERGY CONVERSION (OTEC) ON ENDANGERED SPECIES

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ABSTRACT

Twenty-two marine mammal species including 2 baleen whales, 20 toothed whales, and one pinniped occur in Hawaiian waters. Among these are two endangered species, the migratory humpback whale (Megaptera novaengliae) around the main islands, and the non-migratory Hawaiian monk seal (Monachus schauinslandi) in the extreme northwestern island chain. The endangered species are among those most commonly sighted, while spinner dolphins (Stenella spp.), bottle-nosed dolphins (Tursiops sp.), and false killer whales Pseudorca crassidens) are sighted less frequently. Most Hawaiian cetacean species are Odontoceti, or toothed whales, and feed on fish and squid. The Mysteceti or baleen whales feed on plankton, however the endangered humpback whale, which migrates to Hawaii to breed and calve, presumably does not feed there. The endangered monk seal feeds on cephalopods and fish. The impact of OTEC on endangered and non-endangered marine mammals results from several direct and indirect effects and are discussed in the text. Careful siting of OTEC plants away from humpback breeding areas and monk seal breeding and feeding areas will avoid adverse effects on these populations.

INTRODUCTION

The ecology of marine mammals in Hawaiian waters and the impact of Ocean Thermal Energy Conversion (OTEC) power plants on these mammals is the subject of this paper. Particular attention is given to the effect of OTEC on endangered marine mammal species.

The distribution of whales, dolphins, and porpoises (order Cetacea) depends on the presence and quantity of food available; water temperature is of lesser importance (Marcuzzi and Pilleri 1971). The toothed whales (suborder Odontoceti) are generally ichthyophagous and are found in temperate or tropical waters. The planktophagous baleen whales (suborder Mysteceti) are more often found in Arctic and Antarctic waters where there are seasonally high standing crops of phytoplankton and euphausid shrimp (Gulland 1974). In Hawaiian waters, which have low phytoplankton standing crops, only two species of Mystecetes are found, while 19 species of Odontocetes occur.

One pinniped, the endemic Hawaiian monk seal, completes the list of Hawaiian marine mammal fauna (see Table 1). Of these 22 species, the humpback whale (*Megaptera novaengliae*) and the monk seal (*Monachus schauinslandi*) are endangered species and thus protected under the Endangered Species Act of 1973. In addition, all marine mammal species are protected within the United States under the Marine Mammal Protection Act of 1972.

ENDANGERED SPECIES

Megaptera novaengliae (Humpback Whale)

Distribution and Status

~~The humpback whale is the most abundant large Cetacean in Hawaii.~~ The humpback whale is a cosmopolitan coastal species which has undergone a vast reduction in numbers due to early exploitation by commercial whalers. It has received complete protection since being placed on the Endangered Species List in 1970. The estimated worldwide population of humpbacks is 5200-7000, 1200 of which are found in the north Pacific, and no more than a few hundred of these east of 140^{o}W (Jurasz and Wolman 1977).

Migrations

Humpback whales exhibit the typical Mystecete migration pattern, feeding in colder temperate and sub-polar waters during the summer, and migrating to tropical waters to breed during the winter. Tropical coastal conditions with water temperatures near 25^{o} C are required for breeding (Dawbin 1966). In the eastern north Pacific, four main areas of winter concentration exist; the west coast of Baja California, the mainland coast of west-central Mexico, the offshore Islas Revillagigedo, and Hawaii (Rice 1974). Humpback whale migrations in the Antarctic and Southern Atlantic have been studied (Dawbin 1966), but it is not known where the Hawaii-wintering stock spends the summer.

Hardy and Gunther (1935) suggest the number of baleen whales in Antarctic waters is related to the concentration of phosphates, nitrates and plankton. Dawbin (1966) believes that humpbacks do not feed while in tropical waters. He states that their migration routes "show no consistent relationship to plankton distribution or to chemical and physical properties of the waters traversed." Evidence from New Zealand suggests that migration cannot be directly correlated to currents or water masses, or to water depth or bottom topography (Dawbin 1966).

During humpback migrations from the feeding grounds, lactating females arrive in the tropics first and remain the longest, followed by immature whales of both sexes, mature males and resting females, and lastly by late-pregnancy females. Differential susceptibility to a changing photo-period may initiate migration. Humpback whale migration rates have been calculated to be 15^{o} per month (Dawbin 1966).

The Hawaiian Population

The population of humpback whales that winters in Hawaii may have begun to inhabit this area only within the past 200 years (Herman 1979). A yearly census of the Hawaiian humpback population began in 1976. Jurasz and Wolman (1977) conducted the first census by vessel, and observed 373 whales. The greatest areas of concentration were Penguin Bank, Niihau, Molokai, Maui, the east side of Lanai, and the north side of Kahoolaw (see Figure 1). They are found more often on lee than windward sides of the islands, and most frequently in waters less than 100 meters deep. 75% of the whales observed by Jurasz and Wolman (1977) were single or in pairs, and no groups of more than five animals were observed. Although feeding was not observed, defecation did occur.

In the 1977 survey conducted by Rice and Wolman (1978), a total of 411 humpback whales were counted. The probable number of whales was estimated to be 550 in 1977 and 450 in 1976. During the 1977 survey 78 whales were seen near the big island of Hawaii. All whales were over banks of less than 180 m depth, and more were on the leeward than windward sides of the islands. Almost half the whales were observed in groups of 2, and most of the remainder in groups of 3 or solitary. In both 1976 and 1977 some humpback whales were seen in association with schools of 40-50 pygmy killer whales (Feresa attenuata). The 1978 and 1979 aerial census showed an inverse relationship between humpback and human population density or offshore activities (Herman 1979).

Calving occurs in 5 shallow sand-bottomed areas in Hawaii: Maui (Kihei-Maalea); Lanai (Shipwreck Point); Kauai, Niihau; and Hawaii (Kailua-Kona) (Norris and Reeves 1978). Four calving sites are shown in Figure 1. Hawaii surface water temperatures are between 24°C and 25°C in December and April, a breeding requirement for humpbacks (Herman 1979).

The humpback whales arrive in Hawaii in October/November and remain through May/June (Forestell and Herman 1977). Sightings are scarce in December, and peak in February/March, decreasing again through April and May (Soares et al. 1977). Humpbacks are found more frequently in areas with little human disturbance, and show defensive responses (disperse if an all-adult pod; coalesce around calf if one is present) to a plane or ship (Forestell and Herman 1977).

Hawaiian humpback whales may leave or become more difficult to approach in areas of human activity (Shallenberger 1977, Herman 1979). Limiting boat traffic, direct human contact, and construction in certain areas may be necessary to protect this population (Shallenberger 1977).

Hawaii represents an important breeding ground for a species sensitive to the effects of human presence. Of the estimated worldwide humpback whale population of 6000 and the estimated North Pacific population of 1,200, five hundred breed in Hawaii. More information on humpback feeding ecology and migration routes and the effect of human activity on their behavior is needed.

Monachus schauinslandi (Hawaiian Monk Seal)

The endemic Hawaiian monk seal is the sole pinniped found in Hawaii; and is a member of the rare pinniped genus Monachus which includes the now extinct Caribbean monk seal (M. tropicalus) and the Mediterranean monk seal (M. monachus), an extremely rare species. The Hawaiian monk seal is an endangered species, today restricted to breeding areas in the extreme northwestern Hawaiian Islands (see Figure 3).

Hawaiian monk seals breed on Kure, Pearl, Lisianski, Laysan, and French Frigate Shoals atolls. Breeding occurs from late December through mid-August, and most pups are born between March and May (Kenyon 1973). The pups remain on shore for five weeks, then leave the island while the females remain (Wirtz 1968). Wirtz postulates that the pups spend "much of their first few years at sea, perhaps spending little time ashore until they are of breeding age." The seals are very sensitive to human disturbance, and such disturbance during nursing, along with predation by sharks, leads to mortality (Kenyon 1973).

The Hawaiian monk seal population is considered to be nonmigratory (DeLong and Brownell 1977). Individuals may "straggle" as far as the big island of Hawaii (Rice 1960), and Kenyon (1973) reports that the seals frequently travel long distances from the breeding atolls, up to 1165 km.

Hawaiian monk seals feed in lagoons and shoals. They are bottom-feeders whose diet consists of coral-reef and shallow-water cephalopods and fish (Rice 1960). During the nursing period, the females fast.

The Hawaiian monk seal population is declining and has recently been placed on the Endangered Species list. The 1973 population estimate was 700-1000 individuals (Kenyon 1973).

OTHER MARINE MAMMALS

Large Cetaceans

Balaenoptera (Rorquals)

The Bryde's whale, *B. edeni*, is a non-migratory, coastal, tropical and sub-tropical species which is found between 40°N and 40°S (Marcuzzi and Pilleri 1971). It has been sighted in Hawaii (22°23'N, 162°32'W) by DeLong and Brownell (1977). Although most likely of the rorquals (genus *Balaenoptera*) to be found near Hawaii, the scanty data suggests that its presence is not common. The primary food of Bryde's whale is herring but it also feeds on plankton (Marcuzzi and Pilleri 1971).

Other members of the genus *Balaenoptera* may occur near Hawaii as occasional migrants. The blue whale, *B. musculus*, and the fin whale, *B. physalus*, are cosmopolitan, pelagic species which migrate from their Arctic and Antarctic feeding grounds towards the equator to breed during the winter months. The blue whale ranges farther north and south than the fin whale. Neither may be expected near Hawaii in large numbers. The blue whale is planktophagous, while the fin whale also feeds on fish (Marcuzzi and Pilleri 1971). The minke whale, B. acutorostrata inhabits colder waters than the blue or fin, and the sei whale, B. borealis, is found in warmer waters during the winter.

Physeter catodon (= macrocephalus) (Sperm Whale)

The sperm whale, largest of the toothed whales, is found in all oceans except polar ice-fields (Rice 1977). They are found most often in tropical, sub-tropical, and very warm currents, and prefer deep water (Marcuzzi and Pilleri 1971). Sperm whale distribution, as noted from catch data, coincides with areas of major upwelling. Large males are found in temperate and subpolar waters, while the rest of the population is found in tropical and subtropical waters. As all members of the population apparently eat the same food item, this segregation is probably related more to social factors than to food (Gulland 1974). Migrations of sperm whales depend on water temperature, the abundance of cephalopods, and the presence or absence of harem schools or solitary males (Slijper 1962). Females do not migrate as far north and south as males, remaining between 40°N and 40°S latitude.

North Pacific catch records for sperm whales show that they are found near Hawaii in the summer but more frequently in winter (Rice 1974). Sperm whale populations have decreased as a result of whaling.

Sperm whales are at the apex of their food chain, feeding on giant squid, a second or third level predator (Gulland 1974). Cephalopods occur in large numbers where warm and cold currents meet, coinciding with higher sperm whale density. In an area near the Kurile Islands, Japan, squid were found in 80% of the stomachs examined (Caldwell et al. 1966). A prevalence of deeper dwelling squid species was noted.

Various authors (reported in Caldwell et al. 1966) have found fish species in sperm whale stomachs including blue shark, rock cod, scorpaenids, anglerfish, snapper, barracudas, sardines, skates, ragfish, albacore and rattails. Among the invertebrates found were spiny lobsters, crayfish, crabs, jellyfish, sponges, and tunicates (Caldwell et al. 1966).

Gaskin and Cawthorn (1967) examined the stomach contents of 133 male sperm whales in New Zealand waters. Squid were the primary food source, while fish were of secondary importance. Fish species recorded frequently included Ploypiron oxygeneois, Genypterus blacodes, Hoplostethus sp., and Jordanidia solandri. Squid species consumed and their percentages by occurrence and by weight are given in Table 2.

Feeding and diving behavior was also observed by Gaskin and Cawthorn (1972). Of the 117 animals sighted, most were in waters of from 400 - 1800 m in depth. Of these 11 were feeding, and 7 of the feeding whales were observed at depths of 800 - 1600 m.

SMALL CETACEANS

Seventeen species of dolphins or smaller whales occur in Hawaiian waters. Among the most numerous genera are Stenella and Tursiops. Cetacean observations incidental to a monk seal survey in the Hawaiian Islands were recorded by DeLong and Brownell (1977). The species sighted with greatest frequency were Stenella longirostris (ca. 400 sighted), followed by Tursiops truncatus (ca. 60 sighted) and Pseudorca crassidens (15 sighted). Unidentified dolphins were noted 90 times. These figures may give some indication of which dolphin species are most abundant in Hawaii, if not their actual distributions or relative abundances.

Stenella sp. (Spinner, Spotted and Striped Dolphins)

There are three main groups of dolphins in the genus Stenella: the spinner dolphins, the spotted or bridled dolphins, and the striped dolphins (Rice 1977). Differences in snout length and color pattern distinguish these groups. All three of these types are found near Hawaii (see Figure 2 for sightings of the spinner dolphins).

The spinner dolphin, S. longirostris, is found in the tropical Atlantic Indian and Pacific Oceans. Marked gropraphical variation occurs within the species, and three races are recognized in the Eastern Tropical Pacific (Perrin 1975); the eastern whitebelly, Costa Rican, and Hawaiian races.

The spotted dolphin, S. attenuata (= graffmani, dubia) is found in the Indian and Pacific Oceans, the South China Sea, the Sea of Japan, and Hawaii (Marcuzzi and Pilleri 1971). A tropical species, it occurs most often near coastal areas and islands. Like the spinner dolphin, the spotted dolphin species is also made up of defineable geographic races in the Eastern Tropical Pacific; the coastal, offshore, and Hawaiian races (Perrin 1975).

The striped dolphin, S. coeruleopalba, occurs in the Atlantic and North Pacific Oceans, and is a pelagic species in temperate and tropical waters (Marcuzzi and Pilleri 1971, Nishiwaki 1975). A specimen from

Hawaii has been recorded (Hubbs et al. 1973). Stenella sp. are frequently encountered in large schools, up to several hundred, in close association with yellowfin tuna (Thunnus albacares) schools. The reason for the tight association is not well understood, but its usefulness to tuna fishermen in locating tuna schools is well known. In the years since implementation of the purse-seine method of tuna fishing, up to several hundred thousand dolphins have died each year in the tuna nets. Tighter regulations have recently begun to alleviate the problem; however, the dolphin population decline has been great.

Food habit studies of the spinner dolphin (S. longirostris) and spotted dolphin (S. attenuata) have been carried out in conjunction with studies of the tuna-porpoise association. Stomach-content analysis of 140 spotted porpoise and 46 spinner porpoise taken in tuna net hauls was performed by Perrin et al. (1973). 46 spinner dolphin stomachs from 3 net hauls were examined. In one haul, all 19 stomachs were empty. Of the stomachs from the 2 hauls which did contain food, squid and fish, mostly myctophids, each made up approximately one half of the contents. An ommastrephid squid, probably Doscidius gigas, was the predominant squid species. Benthosema panamense, Diogenichthys sp., Vinciguierra sp. and Bregmaceros sp. were important fish species found in the spinner dolphin stomachs (see Table 3).

140 spotted dolphin stomachs from six net hauls were examined in this same study. In four of six hauls, squid predominates, especially Symplectoteuthis sp. (Table 3). In two of the net hauls ommastrephid squid made up over 85% of the food content by number. Onycoteuthid squid, especially Onykis sp., were also found. Small mesopelagic fishes

are apparently a much less significant food source for the spotted dolphin as compared with the spinner dolphin. Of the fish present, Oxyporhampus micropterus, Diogenichthys sp., and Bregmaceros sp. were found most often.

In a study of the fish component of Stenella stomach contents, Fitch and Brownell (1968) examined fish otoliths from the stomachs of 5 spinner dolphins and 3 spotted dolphins. (Note that the taxonomy of the spotted dolphins is still being worked out; S. graffmani = S. attenuatai). In the spinner dolphin (S. longirostris), two myctophid species comprised over 50% of the piscivorous diet; Benthosema panamense and Lampanyctus parcivauda. Both of these species were also present in the spinner dolphin stomachs examined by Perrin, et al. (1973). Fitch and Brownell (1968) conclude that the spinner dolphins had fed at 100-250 m depth, and 16 kinds of fish were eaten. The spotted dolphin stomachs also contained otoliths of Benthosema panamense as an important component. They had apparently fed at the surface in waters 30 m deep or less, and seven kinds of fish were eaten (see Table 4).

The stomach contents of a spotted dolphin from Hawaii were analyzed by Shomura and Hida (1965). The results are in general similar to those of Perrin et al. (1973), with cephalopods (squids) predominating in volume (86%) and number (see Table 5). This dolphin was caught 3 miles west of Oahu, about 360 m in depth. The animal may have fed before dawn when the squids and predominant fish, the myctophids, were near the surface. Squid species found were Abralia astrostica and Ommastrephis hawaiiensis. Fish families found included Paralepididae, Alepsauridae, Gemplyidae, Bramidae, and Myctophidae. Except for the myctophids, none of the other fish are reported as common in Hawaiian waters. All organisms found in the dolphin's stomach were pelagic forms.

Miyazaki et al. (1973) report different results for the striped dolphin, S. coeruleoalba, in a food-habits study from western Pacific waters. Twenty-seven stomachs of dolphins captured off Japan were examined. Fish represented 59% of the total food, with squid and shrimp also present. Of the fish species present, myctophids represented 64%. Some of the species present were Argentina semifasciata (Argentinidae), Polyiprius spinosus, Diaphus coeruleus, and D. eleucens (Mycotophidae). Squid species included Todarodes pacificus and Symplectoteuthis luminosa. Shrimp species included Benthogennema borealis, representing 85% of the total shrimp found.

In summary, the spinner dolphin and spotted dolphin apparently have different prey items and feed at different times of day. Spotted dolphins feed at the surface and largely on epipelagic prey; mesopelagic fish in the family Exocoetidae (e.i., Oxyporhampus) are especially common. The spinner dolphin feeds in deeper water and mainly on mesopelagic ommastrephid squid; of fish species which were present, those in the family Myctophidae are most common (Table 3).

The behavior of the Hawaiian spinner dolphin, Stenella longirostris has been studied by Norris and Dohl (1978, 1980). Behavioral observations concentrated on the Kealakekua Bay population of 70 animals, but included stightings of Stenella throughout the island chain (see Figure 2). A population of 200-500 animals was observed to occur at Keahole Point.

The distribution of spinner dolphins in Hawaii was heterogeneous, with concentrated areas of congregation as well as stretches where the animals are not seen. The spinner population feeds at night, approaches shore in the morning, rests in "rest areas" (the areas of congregation) until midday and travels to deeper feeding areas at night. Rest areas are shallow flats less than 50 m in depth, and close to deep water areas of greater than 500 m depth. At Keahole Point, the animals move offshore to waters of 2000 m depth.

The population of each rest area is not a cohesive resident school; rather, several subgroups make up a school and the subgroups may remain in a certain area for days or weeks. Ranges of movement of individuals are not precisely known. Intermixing between the various schools may be common.

The spinner dolphins are nocturnal feeders which feed upon the deep scattering-layer fish, squid and shrimp that approach the surface at night. Possible feeding dives were observed by Norris and Dohl (1980) beginning as early as dusk when the scattering layer was quite deep. Their evidence suggests that the feeding schools patrol breaks in the island slope and come inshore over shallow water as morning approaches. Feeding dives were observed to last an average of 3.5 minutes.

Stomach-content analysis by Norris and Dohl confirm Fitch and Brownell's (1968) findings (see above), but also show that sergestid crustaceans are an important component of the diet. The epipelagic squid which are common in Hawaiian waters were not found. The deep-water forms Abralia astrosticta and A. trigonura were found although they are not well known in squid collections from Hawaiian waters. The squid A.

trigonura, a vertical migrant from 500 m during the day to 100 m at night, was the most common species in the stomachs analyzed. Spinner dolphins commonly show scars from shark attacks. The sharks scoop out disc-shaped pieces of blubber which heal and form disc-shaped scars.

Tursiops sp. (Bottlenosed Dolphin)

The bottlenosed dolphin, *T. truncatus*, (DeLong and Brownell 1977) is found throughout both the leeward and main Hawaiian islands; it is the second most frequently observed cetacean in the leeward chain. It is widely distributed in temperate and tropical waters, found close to shore, near islands, and over shallow banks (Rice 1977). Geographic variation within the species occurs. *T. gilli*, a closely related species, is found in the North Pacific from Japan to Hawaii, and California and Mexico (Hershkovitch 1966). The size of the Hawaiian *Tursiops* population, not including the leeward chain, is estimated at 500-1000 individuals. No migration patterns are known; the animals apparently stay near the islands, and travel in groups of 5-20 animals (Orr 1978).

Pseudorca crassidens (False Killer whale)

The false killer whale is found in all temperate and tropical seas, and is a pelagic and oceanic species (Rice 1977, Marcuzzi and Pilleri 1971). It is described by Brown et al. (1966) as "a very social form," as evidenced by the sighting of large herds at sea and the occurrence of mass strandings. It has been observed feeding off of California on bonito, *Sarda lineolata*; and off the Kona Coast of the big island of Hawaii on dolphin-fish, *Coryphaena*. It is a frequent predator on large pelagic fishes, which are broken up into small chunks before eating. Captive

Pseudorca also feed on dead squid and small fish, but seemed to prefer large live fish.

Delphinus delphis (Common Dolphin, Saddleback Dolphin)

The common dolphin is widely distributerd in warm temperate and tropical waters of all oceans, and geographic variation within the species exists (Rice 1977). This pelagic species is a migrant, following the migrations of its food source, especially sprat, (Clupea sprattus) and anchovy (Engraulis encrasicholus) (Marcuzzi and Pilleri 1971).

In the Eastern Tropical Pacific, this species, like Stenella, is also found in association with yellowfin tuna. Two stomachs of D. delphis captured off of southern California were examined for fish remains (Fitch and Brownell 1968). One stomach contained the remains of six species in six families, all of which would have been caught at or near the bottom (200-250 m). The other dolphin, stranded alive, contained the remains of four fish in three families. The Pacific saury, Colabais saira was taken at the surface, while the other species were probably captured 200 m beneath the surface. (Table 6).

Feresa attenuata (Pygmy Killer Whale)

The pygmy killer whale, one of the least known cetaceans, occurs in the tropical and warm temperate waters of the Atlantic, Indian and Pacific Oceans. This species is considered a regular resident of the Hawaiian Islands (Pryor et al. 1965). Most captures and strandings of Feresa have occurred in areas with little or no continental shelf in moderately deep waters. (Caldwell and Caldwell 1971), Steno bredanensis (Roughtoothed Dolphin)

The roughtoothed dolphin is a tropical inhabitant of the Atlantic, Indian and Pacific Oceans and the Mediterranean and Caribbean Seas. It is fairly common in Hawaiian waters (Norris 1974, Tomich 1969). A pelagic species which inhabits deep water (Slijper 1962) it has been reported for the Eastern Tropical Pacific by Perrin and Walker (1975).

Other Delphinidae

Little literature exists on the other members of the family Delphinidae listed in Table 1. All are tropical species which are expected to occur in Hawaiian waters. Globicephala macrorhyncus, the shortfin pilot whale, is found in tropical and warm temperate waters in the Atlantic, Indian, and Pacific Oceans. Grampus griseus, Risso's dolphin, is a cosmopolitan, pelagic species found in all temperate and tropical seas. Lagenodelphis hosei, the short snouted, whitebelly dolphin, is an inhabitant of tropical and warm temperate waters in the Indian and Pacific Oceans. The little blackfish, Peponocephala electra, is a tropical species found in the Atlantic, Indian, and Pacific Oceans.

Kogia breviceps (Pygmy Sperm Whale)

The pygmy sperm whale is a little-known, relatively uncommon relative of the sperm whale. The species is distributed world wide in tropical and warm temperate waters. Traveling singly or in small groups, pygmy sperm whales feed on squid, crabs, and shrimp (Handley 1966). Like other marine mammals, they are parasitized internally by nematodes and cestodes, and externally by crustaceans. The species is of little commercial importance, and thus has probably not experienced a population decline due to exploitation. They are ocasionally taken in the Japanese porpoise fishery.

Kogia simus (Dwarf Sperm Whale)

The dwarf sperm whale is a tropical species found in the seas adjacent to South Africa, Indian, Ceylon, Japan, California, Baja California, and the eastern United States (Rice 1977). It is not known whether Kogia sp. migrates. Like the pygmy sperm whale, it is a little-known species. The same habits regarding social structure, feeding, and parasitism apply.

The stomach contents of three K. simus harpooned off of Japan were examined for fish remains by Fitch and Brownell (1968). Eighteen fish species in seven families were represented. Caphalopod beaks and crustacean remains were also found. Only 3 of the 18 fish species were eaten by all of the dwarf sperm whales examined, but these constituted 43% of the fish otoliths found. Table 7 contains a list of the kinds and numbers of otoliths found in this study.

Mesoplodon densirostris (Densebeak Whale)

The densebeak whale is an inhabitant of tropical and warm temperate waters on both sides of the equator. It is widely but sparsely distributed (Marcuzzi and Pilleri 1971). A sighting in Hawaii has been reported by Moore and Gilmore (1967).

Ziphius cavirostris (Goosebeak Whale)

The goosebeak whale is distributed in all temperature and tropical seas (Rice 1977). A cosmopolitan, pelagic species, it undertakes long migrations (Marcuzzi and Pilleri 1971), which are not well known.

POSSIBLE EFFECTS OF AN OTEC PLANT ON HAWAII'S MARINE MAMMALS

The operation of an OTEC plant off of Hawaii may have several environmental effects which could affect marine mammals. These include:

(1) Discharge of biocides (e.g. chlorinated compounds) used in cleaning heat exchangers.

(2) Accidental spillage of working fluid (e.g. ammonia) from storage tanks or heat exchanger leaks.

(3) A possible petroleum spill due to increased boat traffic at the site.

(4) Release of waste effluents.

(5) Redistribution of cold, deep, nutrient-rich seawater and warm, nutrient-poor, surface seawater to intermediate depths.

(6) Effects due to the physical presence of an OTEC plant.

(7) Noise effects due to OTEC operation and increased numbers of other vessels (fishing, supply) in the area.

The direct effect of the discharge, spillage and release of chemicals and waste effluents on marine mammals would be to cause injury, disease or increase mortality. Disease or injury may result in behavioral changes affecting migration, communication, feeding and breeding. Another direct effect would be the attraction to or avoidance of an area due to a chemotactic response. Such responses are not known for marine mammals but very little is known of their behavior.

The indirect effects of chemicals and waste effluents plus the redistribution of deep nutrient-rich seawater into the photoic zone would be a consequence of effects to other organisms. If the planktonic and nektonic prey of marine mammals are effected by these releases the effect may be passed through to the mammal. The effect may be stimulatory, such as an increase in prey biomass due to nutrient inputs, or inhibitory, such as the retention of halogenated organics ingested with prey organisms due to the use of chlorine as a biocide.

The presence and operation of an OTEC plant and other vessels may also affect marine mammals. The effects are a consequence of the physical presence of the OTEC structure and the noise produced during OTEC operation and the operation of other vessels. Norris and Dohl (1978) have found that spinner dolphins (Stenella longirostris) avoided any strange object for some days before habituating to its presence. These objects were small, such as buoys and boats, and placed in the resting cove. They report that the animals display a fear of strange objects. Location of an OTEC plant in one of their feeding areas may cause them to desert the area, especially if construciton is prolonged. They may become habituated to its presence after some time, or even be attracted to it.

THE ENDANGERED SPECIES AND OTEC EFFECTS

The Hawaiian Islands are a critical habitat area for two endangered marine mammals, the Hawaiian monk seal and the humpback whale. Because of the importance of the habitat to these species, adverse environmental effects may be more detrimental to them, and they will be considered in this separate section.

The monk seal is an endemic pinniped found in the extreme northwestern Hawaiian islands (Figure 3). As the monk seal is nonmigratory proper siting of OTEC plants would alleviate adverse impacts to the monk seal population.

Possible effects on the humpback whale are more important. The humpback whales are sensitive to human presence and activities during their breeding period in Hawaii, and such activities have been on the increase in recent years. A 1977 workshop on humpback-human interactions in Hawaii (Norris and Reeves 1978) defined two main types of harrassment to humpback whales; long-term effects reducing the biological fitness of the population and short-term direct effects.

Observations made during operation of the OTEC-1 experiment off Kawaihae, Hawaii showed that migrating humpback whales (Megaptera novaeangliae) did not avoid the area. In fact, on several occasions groups of one to three whales were seen to come towards the OTEC-1 platform and remain in the vicinity for an hour or more before leaving. The same behavior was also noted for several unidentified species of dolphins.

The effect of the physical presence of the OTEC-1 plant did not induce stress-related avoidance behavior; humpback whales apparently are not disturbed by boat and ship traffic not oriented towards them. To avoid adverse impacts to humpback whales setting of the OTEC structure and the initial deployment of the OTEC plant would best be done out of whale season, which lasts from November to May. The OTEC site should also be distant to breeding and calving areas.

The conclusion of the 1977 humpback workshop was that the whales probably experience a great deal of harrassment, and management recommendations for reducing such harrassment were presented. Establishment of a federal, state or county "humpback park," a sanctuary under the Maine Sanctuaries Act, or the designation of humpback whale "critical habitat" under the Endangered Species Act are possible options. Those operating an OTEC plant should consider these possibilities and locate the plant in an area that will not conflict with the goal of reducing harrassment to and protection of the Hawaiian humpback whales on their wintering grounds.

SUMMARY

Twenty-two marine mammal species occur in Hawaiian waters, including 2 baleen whales and 19 toothed whales, and one pinniped or seal. The humpback whale (*Megaptera novaengliae*) and monk seal (*Monachus schauinslandi*) are endangered species. The endangered blue whale and fin whale may occur occasionally as migrants. Humpback whales occur at their Hawaiian breeding grounds from November to May, and calving occurs during the first months of the year. The humpback whale, the only large cetacean which occurs frequently in Hawaii, does not feed there, but lives on fat reserves gained by feeding on plankton in polar waters during the summer months.

Among the smaller cetaceans, dolphins in the genus *Stenella* are most abundant. They are often found in close association with yellowfin tuna (Thunnus ablacares) and because of this their food habits have been studied more often than the other cetacean species. Squid and several deep-dwelling pelagic fish are major food items. The bottlenosed dolphin (tursiops truncatus) and false killer whales (Pseudorca crassidens) are also fairly common.

About 1000 rare, endemic monk seals breed on islands in the extreme northwestern part of Hawaii, and have been occasionally seen on or near beaches of the larger islands. The monk seal lives in shallow lagoons and shoals, feeding on littoral fishes and cephalopods.

Environmental effects of an OTEC plant which may affect marine mammals include structure effects, noise, effluent release, redistribution of seawater, accidental spillage of working fluid, biocide release, or a petroleum spill. We conclude that properly selected OTEC sites in the main islands will have no effect on monk seal populations. Deleterious effects on the humpback whale could occur, but may be overcome by careful siting of the OTEC plant out of breeding and calving areas and seasons. The adverse enviromental effects listed are unlikely to cause important problems for marine mammals; however, there is little information on the response of mammals to typical pollutants; e.g. ammonia or total residual oxidant. This contrasts with a good deal of such information for fish, zooplankton, and algae.

Experience gained during the deployment and operation of OTEC-1 off the Island of Hawaii indicated that the presence and operation of the OTEC plant plus the presence and operation of numerous smaller vessels did not cause avoidance behavior in the humpback whales passing through the area. The possibility of unanticipated adverse effects of Hawaiian cetaceans should be studied during future OTEC investigations. Even for those species that are comparatively well-studied, little literature exists concerning trophic relationships and ecology. For others, almost no literature exists, and further study is certainly needed before an understanding of their ecology and potential effects of OTEC operation emerges.

Acknowledgment

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Literature Cited

Brown, D.H., M.C. Caldwell & D.K. Caldwell. 1966. Observations on the behavior of wild and captive false killer whales, with notes on associatd behavior of other genera of captive delphinids, L.A. Co. Mus. Contrib. Sci. 95:1-32.

Caldwell, D.K., and M.C. Caldwell. 1971. The Pygmy killer whale, Feresa attenuata, in the western Atlantic, with a summary of world records. J. Mammal. 52:206-209.

Caldwell, D.K., M.C. Caldwell, and D.W. Rice. 1966. Behavior of the sperm whale, Physeter catodon Linnaeus. In: Norris, K.S., ed. Whales, Dolphins and Porpoises. UC Press.

Dawbin, W.H. 1966. The seasonal migrating cycle of humpback whales. Pages 145-190 In: Norris, K.S., ed. Whales, Dolphins & Porpoises, UC Press.

DeLong, R.L., and R.L. Brownell. 1977. Hawaiian monk seal (Monachus schauinslandi) habitat and population survey in the northwestern (leeward) Hawaiian Islands, April 1977, NMFS, NW & Alaska Fish. Cent., Seattle, Wa. Unpubl. 1-30.

Fitch J.E. and R.L. Brownell, Jr. 1968. Fish otoliths in cetacean stomachs and their importance in interpreting feeding habits. J. Fish. Res. Bd. Canada 25:2561-2574.

Forestell, P. and L.M. Herman. 1977. The Hawaiian humpback whale: behaviors. Atstr. of paper presented at 2nd Conf. on Biol. Mar. Mammals, Dec. 1977.

Gaskin, D.E. and M.W. Cawthorn. 1967. Diet and feeding habits of the sperm whale (Physeter catodon) in the Cook Strait region of New Zealand. N.Z. J. Mar. Freshwater Res. 2:156-79.

Gulland, J.A. 1974. Distribution and abundance of whales in relation to basic productivity. Pages 27-52 In: Schevill, W.E., ed. The Whale Problem, Harvard Univ. Press.

Handley, C.O., Jr. 1966. A synopsis of the genus Kogia (Pygmy sperm whales). In: Norris, K.S., ed. Whales, Dolphins and Porpoises, UC Press.

Hardy, A.C. and R.E. Gunther. 1935. The plankton of the South Georgia whaling grounds and adjacent waters, 1926-27. Discovery Reports 11:1-456.

Herman, L.M. 1979. Humpback whales in Hawaiian waters: a study in historical ecology. Pac. Sci. 33:1-15.

Hershkovitz, P. 1966. Catalog of living whales, Bull. U.S. Mus., Smithsonian Inst., Wash. D.C. 246: 1-259.

Hubbs, C.L., W.F. Perrin, and K.C. Balcomb. 1973. Stenella coenleoabla in the eastern and central tropical Pacific. J. Mammal. 54:549-552.

Jurasz, C.M. and A.A. Wolamn. 1977. Humpback whales in Hawaii: vessel census 1976. Mar. Fish. Rev. paper 1254. vol. 39, no. 7, July 1977.

Kenyon, D.W. 1973. The Hawaiian monk seal. Pages 88-97 In: Seals, Proc. workshop of seal specialists on threatened and depleted seals of the world, 18-19 Aug. 1972, Guelph, Canada. IUCN (World Wildlife Fund., publ.) Switzerland.

Marcuzzi, G. and G. Pilleri. 1971. On the zoogeography of Cetacea. Pages 101-170 In: Pilleri, G., ed. Investigations on Cetacea, Vol. 3.

Miyazaki, N., T. Kusaka and M. Nishiwaki. 1973. Food of Stenella coeruleoalba. Sci. Rep. Whales Res. Inst. Tokyo 25:265-275.

Moore, J.C. and R.M. Gilmore. 1967. A beaked whale new to the western hemisphere. Nature 205: 1239-1240.

Nishiwaki, M. 1975. Ecological aspects of smaller cetaceans, with emphasis on the striped dolphin (Stenella coeruleoalba). J. Fish. Res. Board Canada 32:1069-1072.

Norris, K.S. 1974. The porpoise watcher. W.W. Norton & Co. NY 250 pages.

Norris, K.S. and T.P. Dohl. 1978. The behavior of the Hawaiian spinner porpoise, Stenella longirostris (Schlegel, 1841), Center for Coastal Marine Studies, U.C.S.C. Ms.

Norris, K.S. and R.R. Reeves, ed. 1978. Report on a workshop on problems related to humpback whales (Megaptera novaengliae) in Hawaii, Oct. 1977. Final report to U.S. Marine Mammal Commission, Contract MM7AC018.

Norris, K.S. and T.P. Dohl. 1980. Behavior of the Hawaiian spinner dolphin Stenella longirostris. Fish. Bull. 77:821-849.

Orr, J.M. 1978. A survey of Tursiops populations in the coastal United States, Hawaii, and territorial waters. Prepared for the U.S. Marine Mammal Commission, Requisition no. PL 92-522.

Perrin, W.F. 1975. Variation of spotted and spinner porpoise (genus Stenella) in the eastern Pacific and Hawaii. Bull. Scripps Inst. Oceanogr. 21.

Perrin, W.F. and W.A. Walker. 1975. The rough-toothed porpoise, Steno bredanensis, in the Eastern Tropical Pacific. J. Mammal. 56:905-907.

Perrin, W.F., R.R. Warner, C.H. Fiscus and D.B. Holts. 1973. Stomach contents of porpoises, Stenella sp., and yellowfin tuna (Thunnus albacares) in mixed-species aggregations. Fish. Bull. 71:1077-1092

USFWS.

Pryor, T.K. Pryor and K.S. Norris. 1965. Observations on a pygmy killer whale (Geresa attenuata Gray) from Hawaii. J. Mammal. 46:450-461.

Rice, D.W. 1960. Population dynamics of the Hawaiian monk seal; J. Mammal. 41::376-385.

Rice, D.W. 1974. Whales and whale research in the Eastern North Pacific. Pages 170-195 In: Schevill, W.E., ed., The Whale Problem, 1974.

Rice, D.W. 1977. A list of the marine mammals of the world (3rd ed.) N.O.A.A. Tech. Rept. NMFS SSRF-711, Apr. 1977.

Rice, D.W. and A.A. Wolman 1978. Humpback whale census in Hawaiian waters -- Fed. 1977. In: Norris and Reeves, eds. Report on a workshop on problems related to humpback whales in Hawaii, Marine Mammal Commission contract MM7AC018.

Shallenberger, E.W. 1977. The effect of human-generated activities on the Hawaiian humpback whale. Abstract, 2nd Conf. on Biol. Marine Mammals, San Diego, Dec. 1977.

Shomura, R.S. and T.S. Hida. 1965. Stomach contents of a dolphin caught in Hawaiian waters. J. Mammal. 46:500-501.

Slijper, E.J. 1962. Whales. Hutchinson, London, 475 pages.

Soares, M., E. Shallenberger and R. Antinoja. 1977. The Hawaiian humpback whale: population characteristics. Abstr., 2nd Conf. Biol. Mar. Mammals, San Diego, Dec. 1977.

Tomich, P.O. 1969. Mammals in Hawaii. Bishop Mus. Press, Honolulu, Special Publication 57:1-238.

Wirtz, W.D. 1968. Reproduction, growth and development, and juvenile mortality in the Hawaiian monk seal. J. Mammal. 49:229-238.

LIST OF TABLES

Table 1: Marine mammals which may occur near Hawaii.

Order Carnivora, Suborder Pinnipedia
Family Phocidae
1. Monachus schauinslandi, Hawaiian monk seal

Order Cetacea, Suborder Mysteceti
Family Balaenopteridae

2. Balaenoptera edeni, Bryde's Whale
3. Megaptera novaengleae, Humpback whale

Suborder Odontoceti
Family Delphinidae
4. Delphinus delphis, Common dolphin
5. Feresa attenuata, Pygmy killer whale
6. Globicephala macrorhyncus, Shortfin pilot whale
7. Grampus griseus, Gray grampus, Risso's dolphin
8. Lagenodelphis hosei, Shortsnouted whitebelly dolphin
9. Peponocephala electra, Little blackfish
10. Pseudorca crassidens, False killer whale
11. Stenella attenuata, Spotted dolphin, Bridled dolphin
12. S. coeruleoalba, Stripped dolphin
13. S. longirostris, Spinner dolphin
14. S. plagiodon, Spotted dolphin
15. Steno bredanensis, Rough toothed dolphin
16. Tursiops gilli, Pacific bottlenosed dolphin
17. T. truncatus, Bottlenosed dolphin

Family Physeteridae
18. Kogia breviceps, Pygmy sperm whale
19. Kogia simus, Dwarf sperm whale
20. Physeter catodon, Sperm whale

Family Ziphiidae
21. Mesoplodon densirostris, Densebeak whale
22. Ziphius cavirostrus, Goosebeak whale

Table 2: Squid Species from Sperm Whale (<u>Physeter catodon</u>) stomachs, New Zealand

Species	% by occurence	% by weight
Histioteuthis cookiana	13.3	1.0
Nototodarus sloanei	8.0	5.6
Moroteuthis sp.	46.6	74.8
Onychoteuthidae	24.1	14.9

from: Gaskin, D.E. and Cawthorn, M.W. 1967. N.Z. J. Mar. Freshwat. Res. 2:156-179.

Table 3: Summary of important fish and squid species from stomachs of *Stenella* sp. taken in the Eastern Tropical Pacific.

Modified from: Perrin, et.al. 1973. Fish. Bull. 71(4).

	Spotted *S. attenuata*	Spinner *S. longirostris*
Fishes:		
Oxyporhampus Micropterus	+ + + +	
Auxis Sp.	• • •	
Diogenicthys sp.	+ +	•
Benthosema panamense		+ •
Vinciguierra sp.	+	+ •
Bregmaceros sp.	+ +	•
Squids:		
Onykis sp.	+ •	+ •
Ommastrephid A (*Doscidius gigas*?)	• • • • •	• •
Ommastrephid B (*Symplectoteuthis*?)	+ + + • • •	
Abraliopsis affinus	+ + • •	
	6 hauls examined	2 hauls examined

+ = present in one haul

• = common in one haul

Table 4: Numbers and kinds of fish otoliths found in the stomachs of two species of *Stenella* from the eastern tropical Pacific.[a]
Modified from: Fitch and Brownell, 1968. J. Fish. Res. Bd. Canada 25(12) 2561-2574.

	No. of otoliths								
	Stenella Longirostris					*Stenella graffmani (= attenuata)*			
Kinds of fishes eaten	1	2	3	4	5	1	2	3	Fish habitat
Bathylagidae									
Bathylagus sp.	1	12			2				>200 m depth; no migration
Bregmacerotidae									
Bregmaceros bathymaster	11	76	6	89	61				Migrates to surface at night
Centrolophidae?									
Centrolophid?	2	16			5	45			Probably eaten nr. surface
Exocoetidae									
Oxyporhamphus micropterus						29			Surface inhabitant
Gonostomatidae									
Gonostomatid		7							
Vinciguerria lucetia	256	126	3	435	497		3		200-300 m days surface night
Myctophidae									
Benthosema panamense	1	241	234	6147	983	4	1235	2357	
Diaphus sp.	1								
Diogenichthys laternatus	949	97	60	302	15	4			Surface at night
Hygophum sp.	1	35		4	1				
Lampanyctus idostigma	13	1			12				
Lampanyctus parvicauda	1916	465	30	27	282				400 m day; 200 m night
Myctophum aurolaternatum	2	107		7	106	8			
Symbolophorus evermanni	3	13							
Unidentifiable myctophids	78	54	13						
Paralepididae									
Stemonosudis?					30				300-800 m
Scopelarchidae									
Benthalbella		1							250-300 m day; young surface at night
Unidentified		2			1	1			
Total	3234	1253	346	7011	1995	91	1238	2357	

[a]Capture data (all specimens netted with tuna; M-numbers are accession numbers of Cetacean Research Laboratory, Little Company of Mary Hospital, Torrance, Calif.). *Stenella longirostris*: (1) M-57-66, about 350 miles (>550 km) SW of Manzanillo, Mex., in early 1966; (2) M-33-67, same general area as (1), but March 1967; (3) M-20-68, 12°N lat, 92°W long, February 21, 1968; (4) M-60-68, 13°N lat, 99°22' W long. April 16, 1968; (5) M-60-68, ca. 350 miles (±550 km) SW of Acapulco, Mex., April 1968. *Stenella graffmani*: (1) M-32-67, ca. 350 miles (>550 km) SW of Manzanillo, Mex., March 1967; (2) 150 miles off Acapulco, Mex., November 1959; (3) off Costa Rica, January 1963, Jules Crane data.

Table 5: Stomach contents of dolphin, Stenella attentuata caught in Hawaiian waters on 18 August 1962

ITEM	NUMBER	DISPLACEMENT VOLUME (cc)	% VOLUME	SIZE RANGE (cm)
Squids				
Abralia astrostica	258	656	51.5	2.3-3.7 mantle length
Onmastrephes Hanaiiensis	3	435	34.1	11-19 " "
Squid beaks	2			
Fishes				
Paralepididae	7	20	1.6	13-15
Alepisauridae	3	28	2.2	15 (est. avg.)
Gempylidae	3	10	0.8	12 (" ")
Bramidae	8	55	4.3	5-10
Myctophidae	16	70	5.5	6-10
Others				
Nemertean worms	4			
Crab larvae	3			

from: Shomura, S.H. and Hida, T.S. 1965. J. Mammal. 46(3):500-501.

Table 6: Number and kinds of fish otoliths found in Delphinus delphis stomachs from Southern California

	No. of otoliths	
	Delphinus delphis	
Kinds of fishes eaten	M-02-68[a]	RLB 69[b]
Argentinidae		
Argentina sialis		3
Bathylagidae		
Bathyalagus sp.		1
Batrachoididae		
Porichthys notatus		3
Centrolophidae		
Icichthys lockingtoni		
Engraulidae		
Engraulis mordax	127	14
Melamphaidae		
Scopelogadus bispinosus		
Metlucciidae		
Merluccius productus		97
Myctophidae		
Diaphus cf. theta	1	
Lampadena urophaos		
Lampanyctus cf. ritteri		
Stenobrachius leucopsarus	3	
Triphuturus mexicanus		
Unidentifiable myctophids		
Ophidiidae		
Otophidium taylori		1
Sciaenidae		
Seriphus politus		
Scomberesocidae		
Cololabis saira	2	
Total	133	119

*Accession number of Cetacean Research Laboratory, Little Company of Mary Hospital, Torrance, California.
[1]R.I. Brownell field number.

from: Fitch, J.E. and Brownell, R.L. 1968. J. Fish. Res. Bd. Canada, 25(12): 2561-2574

Table 7: Numbers and kinds of fish otoliths found in stomachs of three dwarf sperm Whales, kogia simus, captured off Taiji, Japan, during July 1967

	Whale identity and no. of otoliths			
Kind of fishes eaten	RI.B 392[a]	RI.B 397[a]	RI.B 400[a]	Fish habitat
Argentinidae				
Glossanodon sp.	3	5	2	>200 m
Nansenia sp.		2	2	
Congridae				
Congrid		2		Surface at night
Gonostomatid				
Gonostomatid			3	>300 m day, closer night
Ichthyococcus sp.	10		7	200-250 m night
Macrouridae				
Coelorhynchus?			4	
Macrourid #1	3	1	7	Bottom dwelling
Macrourid #2		14	9	
Moridae				
Morid #1	3	14		
Morid #2		1		200-450 m
Morid #3		3		
Myctophidae				
Diaphus #1			1	
Diaphus #2			2	
Hygophum ?			1	
Lampadena #1	19	12	14	
Lampadena #2			2	
Symbolophorus sp.		1	3	
Sternoptychidae				
Polyipnus sp.		2	1	200-250 m
Total	38	57	58	

[a]R.I. Brownell field numbers.

Modified from: Fitch, J.E., and Brownell, R.L. (1968) J. Fish. Res. Bd. Canada 25(12):2561-2574

LIST OF FIGURES

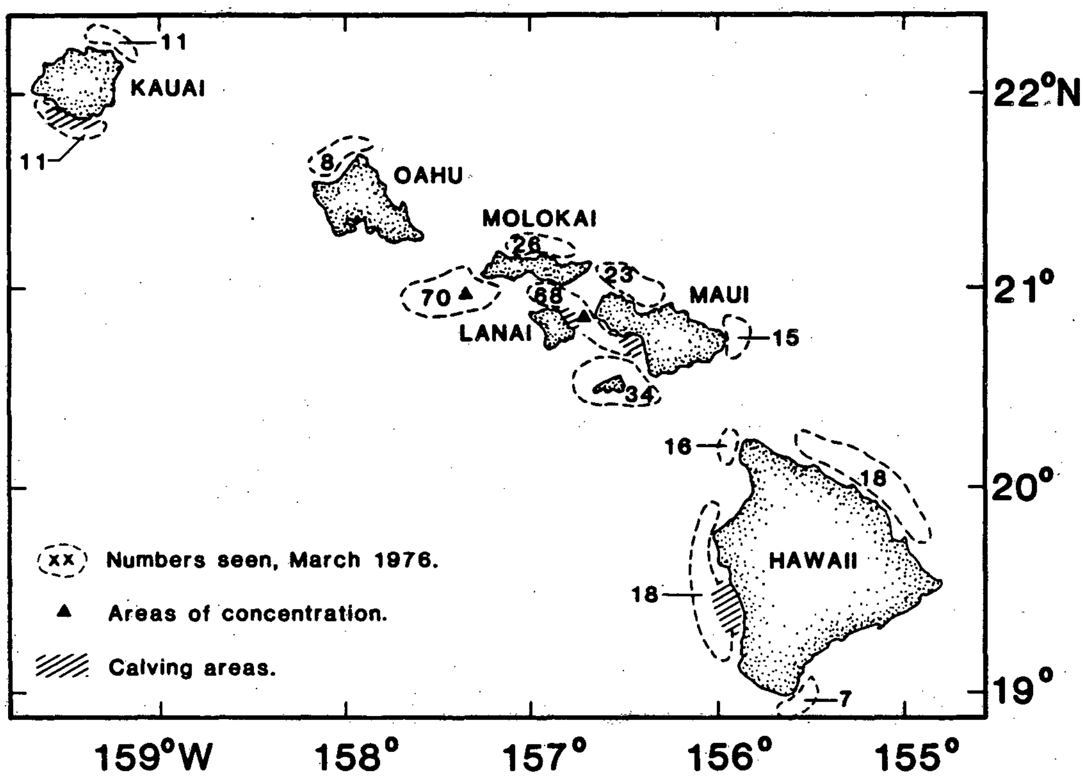

Figure 1: Humpback whale (Megaptera novaengliae) distribution in Hawaii

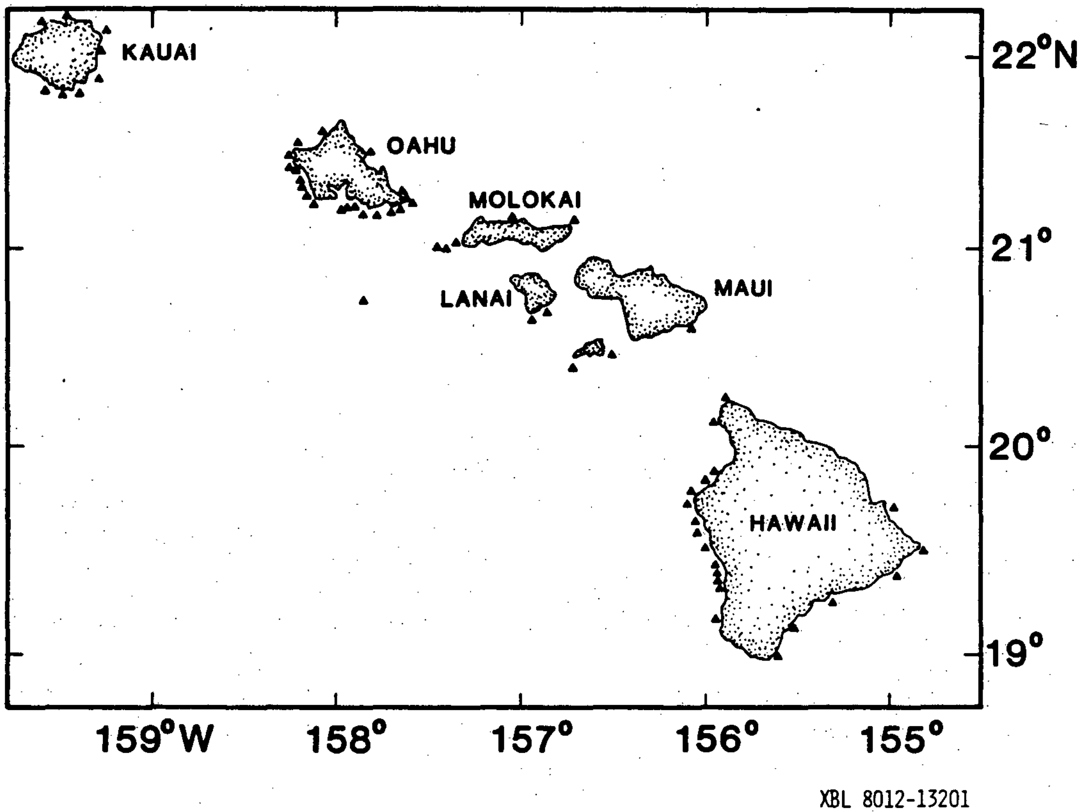

Figure 2: Sightings of spinner dolphins (Stenella longirostris) off Hawaii

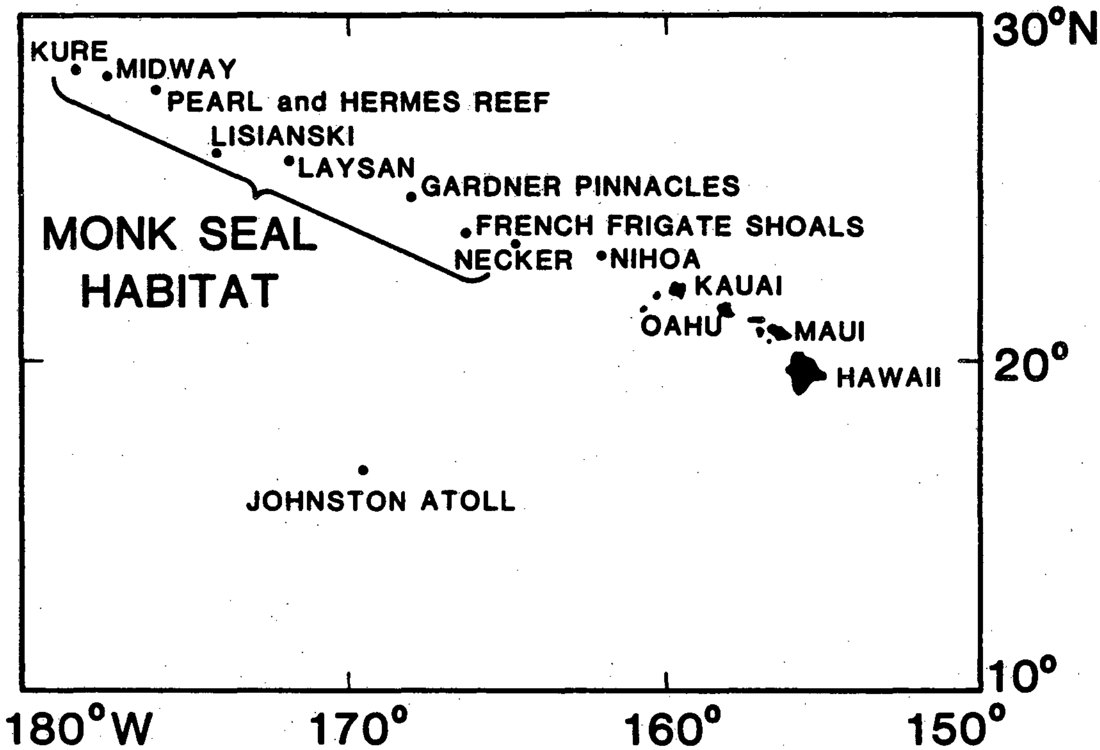

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Figure 3: Location of Hawaiian monk seal (Monachus schauinslandi) population

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