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Population Size, Mortality Rates, and Growth Rates of Northern California Ocean Shrimp, Pandalus jordani, 1965 Through 1968

by
Daniel W. Gotshall
Marine Resources Region

1972

Dedicated to Charles H. Turner, May 15, 1934–October 27, 1970. Senior Marine Biologist, California Department of Fish and Game.

"Whose dwelling is the lite of setting suns,
and the round ocean and the living air."

—*Wordsworth*

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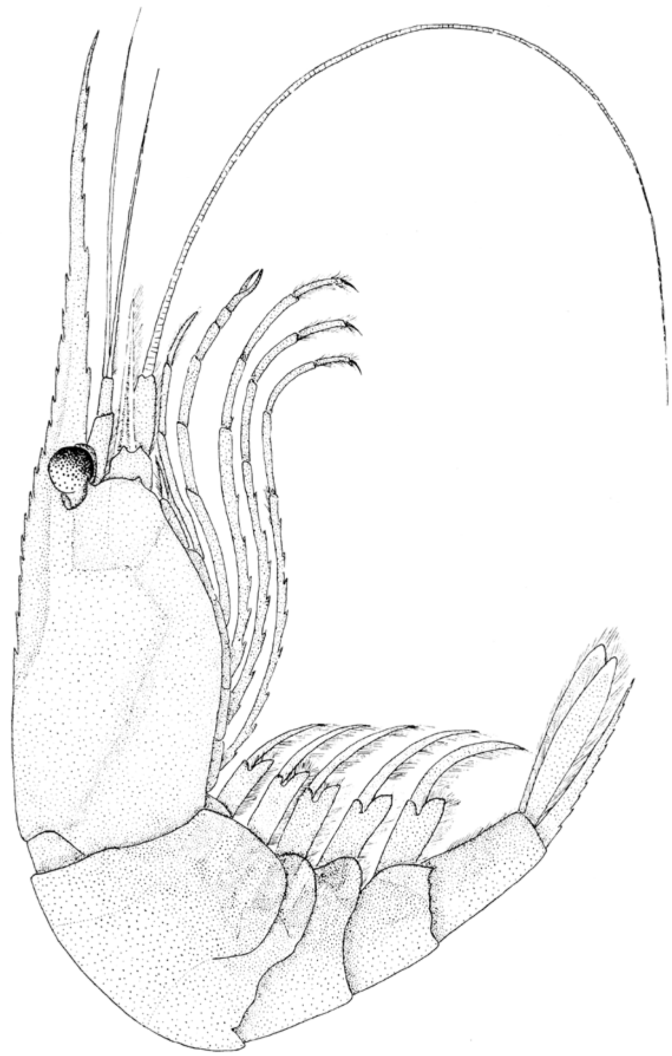

Ocean shrimp, *Pandalus jordani*. Drawing by Cathy Short.

ABSTRACT

Sea surveys were initiated in the spring of 1965 to obtain estimates of population size, mortality rates, and growth rates of the northern California ocean shrimp population. From March 1965 through September 1968, nine surveys were conducted in a 270-square-mile area from off Mad River, California, north to Smith River, California. Four surveys were conducted in a 105-square-mile area off southern Oregon during 1967 and 1968. Estimates of the California population ranged from a low of 2.2 million pounds in the fall of 1966 to a high of 8.1 million pounds in the fall of 1967.

Survival rates, derived from natural mortality rates for ocean shrimp during their second winter of life, for the 1964 and 1965 year classes were 0.68 and 0.55 respectively. Lowest survival rates were obtained from the 1963 and 1964 year classes during their third winter of life. The highest fishing mortality rates were observed for shrimp during their third summer in the fishery. Survey data indicate a relationship between annual fishing mortality rates and total trawling hours expended by shrimp fishermen. Limited data suggest a relationship also exists between the number of spawners and 1-year-old recruits as well as the existence of a density dependent relationship between population size and survival of the incoming year class.

The Von Bertalanffy growth equation was applied to mean carapace lengths of 1964 and 1965 year class shrimp. Values for the constants L and K were very close while the values to t_0 varied considerably.

I believe the spring and summer 1965 and fall 1966 surveys produced underestimates of abundance, possibly due in part to vertical migrations of shrimp during daylight in 1965 and a horizontal shift of the population north in 1966.

ACKNOWLEDGMENTS

The successful completion of this study required the assistance and advice of many people. I especially express my appreciation to the following: Norman Abramson for designing the survey methods and supplying the many equations and ideas for analyzing the data; Jo Ann Spaulding for designing the computer program for selecting trawl stations; Dave Hoopaugh, Mel Willis, and Steve Taylor who spent many hours at sea working up samples; Walt Dahlstrom for providing many insights into shrimp biology; and Dave Mackett and Timothy Farley for their assistance in data processing. Finally, this study could not have been undertaken and completed without the assistance and cooperation of Captains R. B. Mitchell and Kuljis and the crews of the research vessels N. B. SCOFIELD and ALASKA.

Daniel W. Gotshall
March 1971

1. INTRODUCTION

The California fishery for ocean shrimp, Pandalus jordani, has been managed by a quota system since its inception in 1952. In the early years this was based on harvesting one-quarter of the total calculated population. Population sizes were computed by using the size of the commercial fishing area and the average catch per hour (Dahlstrom, 1961). In the fall of 1960 a series of pre- and postseason cruises was initiated to determine the size and condition of the populations on each of the four California beds described by Dahlstrom.

Generally, the concentration of shrimp and the size of the population were determined by making random and nonrandom tows in the commercial fishing area. Tows were made at the outer limits of the known beds to determine their approximate perimeters. These surveys were presumed to yield data not only for calculating population size, but for determining mortality rates. These parameters could have been used to calculate a population model from which equilibrium yields could be estimated and fishing quotas recommended. By late 1964 it became apparent that the surveys were not fully satisfying either of these objectives.

A series of intensive sea surveys of California's northernmost ocean shrimp population was initiated in the spring of 1965 using a stratified two-stage sampling plan (Abramson, 1968). This probability sea survey plan was designed to yield unbiased estimates of abundance parameters and associated variances.

2. METHODS

Sampling procedures were those described by Abramson (1968); and the survey area (Figure 1) , sampling gear, and the procedure used in determining the ages of shrimp were those discussed by Gotshall (1969).

The 270-square-mile survey area located between the Oregon-California border and the mouth of Mad River was divided into 14 strata based on shrimp concentrations previously encountered by the commercial fleet and our research vessels from 1950 to 1964 (Figure 1). The random starting site for each trawl was selected by computer; however, known snag and reef areas were selectively deleted from consideration. A 41-ft head rope semi-balloon trawl with 1-inch stretch mesh and a 5-inch stretch mesh liner in the cod end with a net opening of 25 ft (based on one observation by scuba divers) was towed for 0.5 nautical mile. Thus, the total area swept was calculated to be 76,000 square feet. At the outset we decided upon the minimum number of trawls that could be completed on a single cruise. This number was based on vessel availability, loss of time due to equipment breakdowns, and unfishable weather conditions. The minimum number of trawls (39 trawls, April 1965 through September 1966; 51 trawls, March 1967 through October 1968) was divided amongst the 14 area strata. Each set of 51 trawls was defined as a "step." If a step was completed before the end of a cruise, then another step was undertaken. Usually at least three steps were completed on each survey.

After sorting the catch, the shrimp were placed in boxes containing 80 equal-size numbered compartments (Figures 2 , 3). Two compartments were selected using random number tables; these were our two samples.

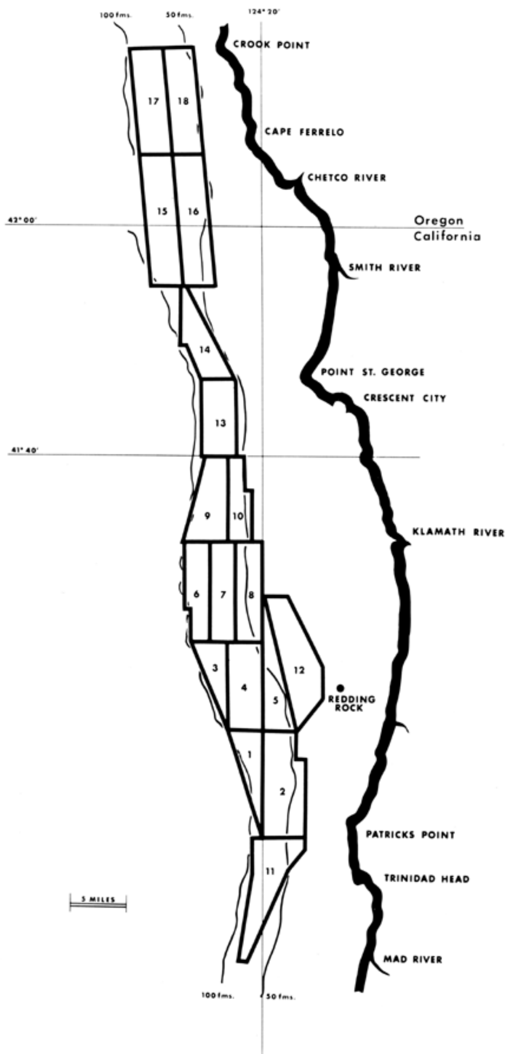

FIGURE 1 Northern California and southern Oregon ocean shrimp survey strata.

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FIGURE 2 Biologists and crew of N. B. SCOFIELD sorting out shrimp. Photo by Ted Hamilton.

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Shrimp in each sample were counted, sexed, measured (carapace length) to the nearest 0.2 mm, and then the entire sample weighed to the nearest gram (Figure 4) . All data were recorded on special forms for a storage and retrieval system (INFOL). All of the length frequencies for each step were combined and ages assigned. Once this was done, all cruise data were processed using procedures designed by Abramson (1968). The resulting estimate of catch per standard trawl by age and weight of shrimp was then used to calculate total population by multiplying weight or number of shrimp per standard trawl by total trawls that possibly could be made in the area with our net (Table 1).

In 1967 the survey area was increased to include a 105-square-mile area off southern Oregon (Figure 1) since we suspected these shrimp and those of northern California of belonging to one intermingling population. This new area was divided into four strata and assigned 14 trawls, thus the 14 California strata and 4 Oregon strata were subject to 51 trawls per step (Table 1). The estimating procedures remained the same as before.

FIGURE 3 **Biologist collecting shrimp sample for sexing and aging from random sample boxes. Photo by Daniel Gotshall.**

FIGURE 3 Biologist collecting shrimp sample for sexing and aging from random sample boxes. Photo by Daniel Gotshall.

The June 1968 survey was conducted by nine cooperating commercial shrimp trawlers using standard 57-ft head rope semi-balloon trawls with 1.5-inch stretch mesh net and with 0.5-inch stretch mesh liners in the cod end. The catch per unit of effort data were adjusted so they would be comparable to data from our smaller 41-ft head rope net.

The Von Bertalanffy growth equation was used to plot carapace length and age curve and derive the growth constants. A FORTRAN program written by the Department's Biometrical Analysis Unit was used to process the data.

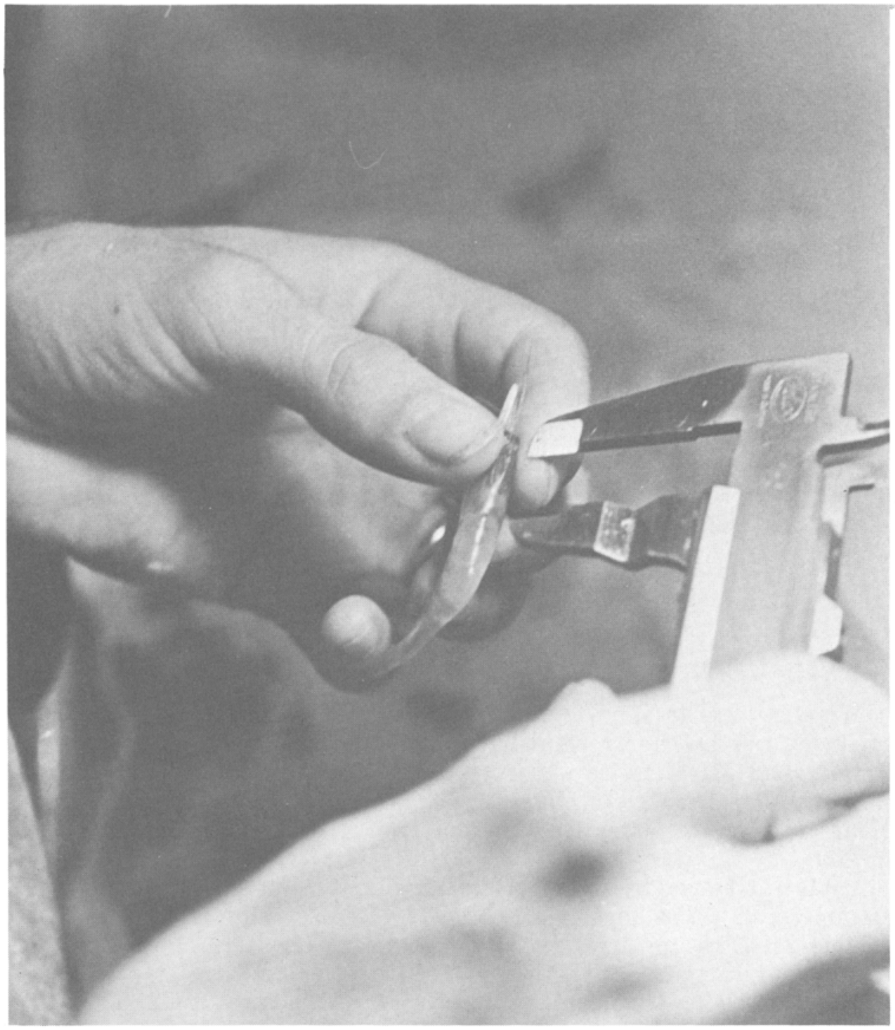

FIGURE 4 Measuring carapace length of ocean shrimp for aging. Photo by Ted Hamilton.

FIGURE 4 Measuring carapace length of ocean shrimp for aging. Photo by Ted Hamilton.

TABLE 1

Northern California Ocean Shrimp Survey Area, Size of Strata, and Number of Trawls per Stratum, April 1965–September 1967

Stratum number	Area (square miles)	Assigned number of trawls (April 1965–Sept. 1966)	Assigned number of trawls (March 1967–Sept. 1967)	Total possible trawls in area
California				
1	12.586	2	2	6,123
2	31.212	5	4	15,169
3	11.161	2	2	5,424
4	21.518	4	3	10,458
5	17.471	3	2	8,491
6	13.744	2	2	6,680
7	17.262	3	2	8,389
8	19.808	3	3	9,627
9	16.910	3	2	8,218
10	11.475	2	2	5,577
11	27.000	3	4	13,122
12	32.361	3	4	15,727
13	19.777	2	3	9,612
14	17.570	2	2	8,539
Subtotal	269.855	39	37	131,156*
Oregon				
15	28.875	--	4	14,037
16	28.875	--	4	14,037
17	23.625	--	3	11,485
18	23.625	--	3	11,485
Subtotal	105.000	--	14	51,044*
Total	374.855	39	51	182,200

* There were 107,607 trawls in California and 41,878 trawls in Oregon where commercial sized nets were used June 1968.

TABLE 1

Northern California Ocean Shrimp Survey Area, Size of Strata, and Number of Trawls per Stratum, April 1965–September 1967

3. RESULTS

3.1. Sea Surveys and Population Estimates

3.1.1. March 17–April 17, 1965, Survey

We were able to operate only 15 days during this spring survey due to strong northwesterly winds. A total of 4,955 pounds of shrimp was caught, and 210 samples were processed to determine sex, length, and weight. Catch per unit of effort ranged from 0 to 1,380 pounds per haul. Mean numbers of shrimp per pound from the trawls ranged from 54 to 262.

Total number and weight per standard trawl for the combined strata amounted to 6,754 shrimp and 14,776 g (32.5 pounds), respectively (Table 2). Stratum 3 produced the highest average catches (in numbers) and Stratum 10 the lowest (Figure 1, Table 3).

The population was composed of three year classes: 1962, 1963, and 1964. The 1964 year class made up the bulk of the catch both in numbers and weight (Table 4). I calculated the total population to be 886 million shrimp weighing 4.3 million pounds (Figure 5) . This population was composed of 89.8% 1964 year class shrimp, 8.6% 1963 year class shrimp, and 1.6% 1962 year class shrimp (Figure 6) . More than half (56.8%) of the 1963 year class, and 3.0% of the 1964 year class were females (Table 5).

TABLE 2

Number and Weight of Ocean Shrimp per Standard Trawl, March 1965–October 1968

Survey dates	Number of trawls	Number of shrimp in standard trawl	95 percent confidence interval	Weight of shrimp in standard trawl (g)	95 percent confidence interval
		California Strata			
1965					
Mar. 17–Apr. 17	125	6,754	±1,611	14,776	±3,277
June 5–June 27	117	7,858	±1,953	19,847	±4,628
Oct. 2–Oct. 21	117	5,291	±1,423	18,849	±5,125
1966					
Mar. 24–Apr. 25	117	6,990	±3,593	21,506	±11,367
Aug. 15–Sept. 10	156	4,077	±1,241	7,652	±2,415
1967					
Mar. 6–Apr. 12	105	7,485	±3,459	16,802	±7,052
Aug. 22–Sept. 10	111	8,323	±2,958	27,955	±8,633
1968					
June 18–June 20	65	6,023	±1,084	26,548	±4,973
Sept. 5–Oct. 3	111	13,221	±3,018	25,888	±5,768
		Oregon Strata			
1967					
Mar. 6–Apr. 12	28	19,223	±8,258	41,340	±49,919
Aug. 22–Sept. 10	42	6,312	±1,323	23,567	±5,100
1968					
June 18–June 20	16	298	±336	1,241	±1,357
Sept. 5–Oct. 3	42	2,989	±1,026	10,933	±3,750

TABLE 2

Number and Weight of Ocean Shrimp per Standard Trawl, March 1965–October 1968

3.1.2. June 5–June 27, 1965, Survey

This summer survey was conducted during the fishing season to serve as a check on our spring survey estimate. The total catch amounted to 5,735 pounds, and ranged from 0 to 3,336 pounds per haul.

We processed 219 samples containing 19,922 shrimp for sex and age determinations.

Catch per standard trawl was 7,858 shrimp and 19,847 g (43.7 pounds) for the combined 14 strata (Table 2).

The average number of shrimp per pound from trawls ranged from 70 to 205.

The highest concentration of shrimp occurred in Stratum 4; the lowest in Stratum 11 (Table 3).

The 1964 year class continued to dominate the population (Table 4). The size of this year class was calculated to be 961 million shrimp (Figure 6). Both its catch per standard trawl and population size were higher than the March survey values.

The total shrimp population (number and weight) also increased over the March figures (Figure 5), even though the catch per standard trawl values for the 1963 and 1962 year classes were less than March values (Table 4).

TABLE 3

Number and Weight of Ocean Shrimp per Standard Trawl by Strata off Northern California and Southern Oregon, 1965–1968

Stratum	March 1965		June 1965		October 1965		March 1966		August 1966		March 1967		August 1967		June 1968		September 1968	
	Numbers	Grams	Numbers	Grams	Numbers	Grams	Numbers	Grams	Numbers	Grams	Numbers	Grams	Numbers	Grams	Numbers	Grams	Numbers	Grams
1	14,912	29,808	5,194	14,580	7,364	29,826	5,376	22,007	2,542	5,696	1,654	3,722	136	722	4,409	24,590	6,814	14,112
2	6,999	18,794	2,436	6,535	1,724	5,869	15,087	41,997	1,017	3,228	885	2,841	6,832	19,602	2,309	10,828	9,240	25,179
3	17,631	31,526	21,909	48,434	8,837	21,733	3,564	7,820	827	460	8,813	26,846	7,212	23,814	7,823	36,423	4,144	7,419
4	15,637	34,660	23,307	57,585	13,072	46,677	2,871	7,614	4,112	9,918	5,689	13,226	17,534	38,961	28,272	127,022	22,616	74,396
5	8,298	18,267	17,766	43,549	7,240	24,164	20,278	65,017	645	2,128	8,192	18,480	9,603	35,437	288	1,380	12,525	15,258
6	4,675	13,477	4,598	14,356	12,187	48,217	2,227	6,966	20,193	38,266	25,658	58,033	12,982	43,934	6,031	28,229	27,631	50,023
7	13,304	28,792	10,352	26,052	6,125	17,484	365	1,546	15,711	32,509	15,912	27,860	30,273	101,392	17,630	68,931	20,038	19,210
8	11,160	22,781	3,737	9,047	596	1,783	624	1,306	962	612	8,416	18,919	3,796	14,515	6,226	22,972	19,674	33,222
9	1,394	3,242	12,895	34,108	7,456	24,930	10,242	37,104	9,879	12,859	1,189	3,151	4,144	16,145	1,159	6,261	14,183	21,867
10	0	0	5,755	14,817	5,326	18,317	1,745	5,280	265	460	840	2,732	6,142	22,254	1,032	4,551	12,558	11,995
11	755	2,002	285	986	1,386	5,030	7,930	27,480	1,074	5,163	386	1,154	324	721	4	23	3,861	7,087
12	4,004	8,172	7,295	17,980	1,021	3,296	12,467	35,173	272	292	2,223	6,074	3,579	13,998	0	0	13,171	29,827
13	410	1,027	3,283	9,998	7,938	30,812	757	3,087	6,850	6,249	34,502	74,038	6,004	24,775	4,350	20,013	10,056	12,961
14	2,375	4,650	798	2,758	4,295	15,006	756	2,905	923	2,411	1,084	3,510	9,256	36,119	9,584	43,425	11,806	26,445
15	--	--	--	--	--	--	--	--	--	--	47,317	101,528	5,611	21,315	742	3,420	3,634	14,694
16	--	--	--	--	--	--	--	--	--	--	12,555	27,690	8,410	31,486	344	1,093	5,335	18,544
17	--	--	--	--	--	--	--	--	--	--	28	31	3,498	12,745	0	0	1,112	3,580
18	--	--	--	--	--	--	--	--	--	--	12,228	25,771	7,418	27,463	0	0	1,209	4,388

TABLE 3
Number and Weight of Ocean Shrimp per Standard Trawl by Strata off Northern California and Southern Oregon, 1965–1968

TABLE 4

Number of 1962, 1963, 1964, 1965, 1966, 1967, and 1968 Year Class Ocean Shrimp per Standard Trawl, March 1965–October 1968

Survey	1962 year class		1963 year class		1964 year class		1965 year class		1966 year class		1967 year class		1968 year class	
	Number per standard trawl	95 percent confidence interval	Number per standard trawl	95 percent confidence interval	Number per standard trawl	95 percent confidence interval	Number per standard trawl	95 percent confidence interval	Number per standard trawl	95 percent confidence interval	Number per standard trawl	95 percent confidence interval	Number per standard trawl	95 percent confidence interval
							California Strata							
Spring 1965	108	±25	578	±154	6,068	±1,510								
Summer 1965	44	±14	486	±102	7,327	±1,877								
Fall 1965	58	±27	460	±143	4,162	±1,240	611	±173						
Spring 1966	--	--	187	±117	3,459	±1,887	3,344	±1,764						
Fall 1966	--	--	20	±12	610	±213	888	±329	2,559	±961				
Spring 1967	--	--	--	--	241	±100	549	±229	6,695	±3,254				
Fall 1967	--	--	--	--	28	±16	461	±133	7,078	±2,400	446	±265		
Summer 1968	--	--	--	--	--	--	69	±52	3,760	±1,509	2,194	±846		
Fall 1968	--	--	--	--	--	--	22	±10	1,962	±713	2,302	±1,236	8,935	±2,037
							Oregon Strata							
Spring 1967	--	--	--	--	388	±557	828	±937	18,006	±22,421				
Fall 1967	--	--	--	--	57	±20	515	±82	5,532	±1,247	207	±67		
Summer 1968	--	--	--	--	--	--	0	0	167	±192	132	±168		
Fall 1968	--	--	--	--	--	--	21	±8	990	±313	1,109	±548	869	±418

TABLE 4

Number of 1962, 1963, 1964, 1965, 1966, 1967, and 1968 Year Class Ocean Shrimp per Standard Trawl, March 1965–October 1968

3.1.3. October 2–October 21, 1965, Survey

The total catch of shrimp during the 1965 fall survey amounted to 5,303 pounds. The 224 samples analyzed contained 16,823 shrimp. Catch per haul values ranged from 1 to 1,831 pounds. The trawls averaged

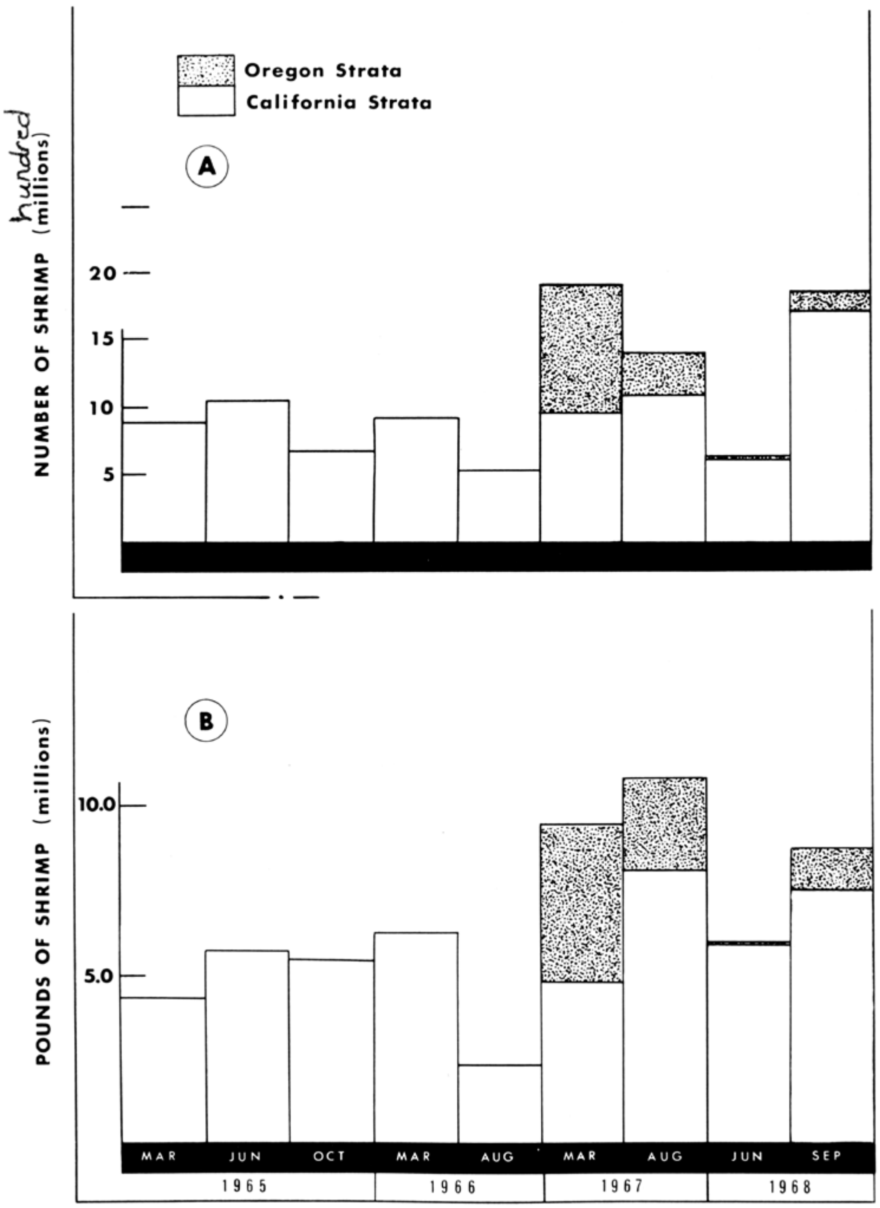

FIGURE 5 Estimated population of ocean shrimp in (A) numbers and (B) pounds off northern California and southern Oregon, 1965–1968.

FIGURE 5. Estimated population of ocean shrimp in (A) numbers and (B) pounds off northern California and southern Oregon, 1965–1968.

89 to 608 shrimp per pound. The catch per standard trawl for the combined strata was 5,291 shrimp and 18,849 g (41.5 pounds). Highest catches were recorded from Stratum 4; lowest from Stratum 8 (Table 3).

It is interesting to note that in October the two northernmost strata, 13 and 14, and the southernmost Stratum 11, had substantially more shrimp per standard trawl than we encountered on the March or June survey. By contrast, the southern Strata 1, 2, 3, and 4 showed decreases.

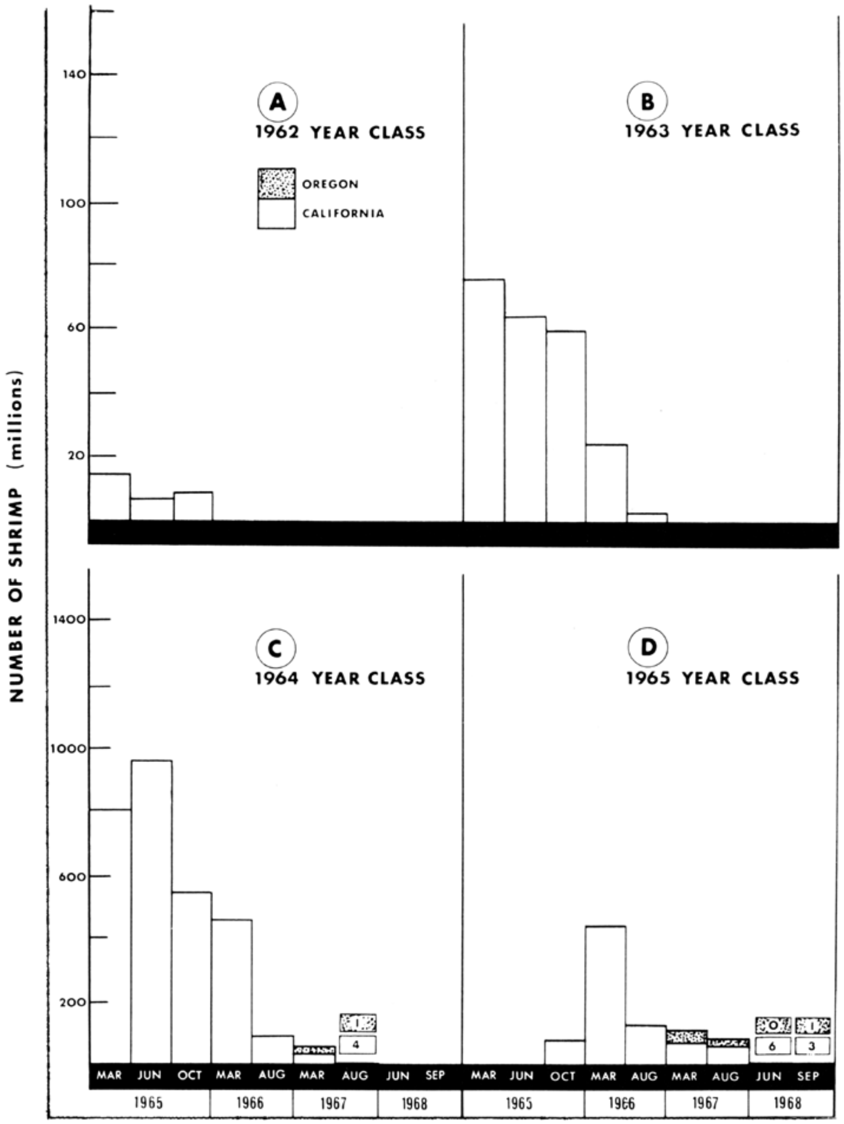

FIGURE 6 Estimated numbers of (A) 1962, (B) 1963, (C) 1964, and (D) 1965 year class ocean shrimp off northern California and southern Oregon.

FIGURE 6 Estimated numbers of (A) 1962, (B) 1963, (C) 1964, and (D) 1965 year class ocean shrimp off northern California and southern Oregon.

In Stratum 1, we recorded a slight increase over June but this still represented a significant decrease from our March figures. Possible reasons for these changes are reviewed in the discussion section.

The incoming 1965 year class appeared in these catches for the first time (Table 4). However, the 1964, 1963, and 1962 year classes made up the bulk of the catch (Table 4).

We calculated that the survey area contained 694 million shrimp weighing 5.4 million pounds (Figure 6).

3.1.4. March 24–April 25, 1966, Survey

The total catch during the 1966 spring survey, from 117 completed trawls, amounted to 5,559 pounds. One trawl yielded 1,066 pounds, the highest we had encountered since beginning the study.

We sexed and measured 14,818 shrimp from 182 samples. Catch per hour ranged from 0 to 3,549 pounds. These shrimp averaged from 70 to 299 per pound per trawl. The combined strata produced catch per trawl values of 6,990 shrimp and 21,506 g (47.4 pounds).

The highest catches (10,000–20,000 shrimp) were recorded from the Klamath River south (Figure 1 and Table 3), with Stratum 5 producing the most. Lowest catches were from Strata 7 and 8.

The 1964 year class, as 2-year-olds, continued to produce the highest numbers. The 1965 year class (1-year-olds) was a close second (Tables 4 and 6). The calculated total population was 917 million shrimp and 6.2 million pounds (Figure 5).

3.1.5. August 15–September 10, 1966, Survey

The total catch amounted to 2,843 pounds, the lowest for the entire study. We took 260 samples containing 35,440 shrimp for sex and length

TABLE 5

Sex Composition by Year Class of Ocean Shrimp
March 1965–September 1967

Period	Year class	Male	Transitional	Female	Total
Spring 1965	1963	5.4	37.8	56.8	100.0
	1964	80.3	16.7	3.0	100.0
Fall 1965	1963	0.0	T	100.0	100.0
	1964	38.3	0.2	61.5	100.0
Spring 1966	1964	6.8	38.2	55.0	100.0
	1965	98.4	1.5	0.1	100.0
Fall 1966	1964	0.0	6.9	93.1	100.0
	1965	62.0	29.2	8.8	100.0
Spring 1967	1965	0.8	65.6	33.6	100.0
	1966	81.8	16.3	1.8	99.9
Fall 1967	1965	0.0	1.4	98.6	100.0
	1966	27.9	12.5	59.6	100.0
Summer 1968	1966	0.8	21.8	77.4	100.0
	1967	81.4	16.8	1.8	100.0
Fall 1968	1966	0.7	3.1	96.2	100.0
	1967	47.9	44.5	7.6	100.0

TABLE 5
Sex Composition by Year Class of Ocean Shrimp March 1965–September 1967

determinations during the 1966 fall survey. Pounds per hour ranged from 0 to 1,496. Numbers of shrimp per pound ranged from 57 to 151. The numbers and weight per standard trawl, 4,077 shrimp and 7,652 g (16.8 pounds), were also the lowest recorded for California strata during the entire study period (Table 2).

The four strata (6, 7, 9, and 13) with the highest catches were encountered off the Klamath River and Crescent City (Table 3). Strata 10 and 12 yielded the lowest catches.

There was a considerable drop in the population weight between this and the spring survey. In spring we calculated 6.2 million pounds of shrimp in the survey area, but our fall survey revealed only 535 million shrimp weighing 2.2 million pounds (Figure 5). This drop in weight may be accounted for in part by the dominance of 1966 year class (light weight) shrimp in the population coupled with a corresponding reduction during the fall cruise in numbers of heavier shrimp in the 1965, 1964, and 1963 year classes during the fall cruise (Table 4). Over 50% of the population was composed of these 1966 year class shrimp, a calculated 336 million shrimp weighing approximately 450,000 pounds (Figure 7) . Males made up 62% of the 1-year-olds (1965 year class) caught (Table 5).

3.1.6. March 6–April 12, 1967, Survey

The 1967 spring survey was continually hampered by poor weather conditions, consisting of strong southerly winds. Our total catch amounted to 6,800 pounds and catch per hour ranged from 0 to 7,429 pounds, the largest individual catch recorded during the entire study. We processed 197 samples. These shrimp averaged from 37 to 500 per pound per trawl. Catch per trawl for the combined California strata was 7,485 shrimp and 16,802 g (37.0 pounds). The highest catches occurred from just south of the Klamath River, northward, with Strata 13 and 15 yielding the most; Strata 11 off California and 17 off Oregon produced the lowest catches (Figure 1, Table 3). The bulk of the population was recorded between Crescent City, California, and Brookings, Oregon.

The population off northern California and southern Oregon amounted to 1.96 billion shrimp weighing 9.5 million pounds (Figure 5).

Over 90% of the population was 1966 year class shrimp (Table 4). A few 1966 year class (1-year-olds) observed in the 197 samples processed were females, an unusual occurrence (Table 5).

3.1.7. August 22–September 10, 1967, Survey

A total catch amounted to 8,580 pounds of shrimp during the 1967 fall survey. A total of 252 samples were processed. Oregon strata yielded from 0 to 725 pounds per hour; California strata 0 to 3,170 pounds per hour.

Sampled shrimp averaged from 81 to 810 per pound per trawl, with an overall mean of 131. Numbers and weight per standard trawl amounted to 8,323 shrimp and 27,955 g (61.6 pounds) off California (Table 2).

There were two major areas of high density; between Patricks Point and the Klamath River in Strata 4, 5, 6, and 7; and from Point St. George to Cape Sebastian in Strata 14 and 16 (Figures 1 and 2, Table

3). I calculated 1.35 billion shrimp weighing 10.7 million pounds (Figure 5) resided off California and Oregon.

The 1966 year class dominated the catches. The number of incoming 1967 year class shrimp was substantially lower than the values determined for the prior two incoming year classes (Table 4). We determined this year class (1967) amounted to 69 million shrimp (Figure 7).

Over half (59.6%) of the 1966 year class shrimp were females (Table 5), atypically young for transition in this species.

3.1.8. June 18–June 20, 1968, Survey

This summer survey was conducted by 10 cooperating shrimp trawlers using standard commercial-size nets (57-foot head rope, 1.5-inch stretch mesh). We inserted 0.5-inch mesh liners in all of these nets to insure retention of 1-year-old shrimp. A total of 81 trawls was completed in 3 days. Trawling was not conducted in Strata 17 or 18 off Oregon. This cooperative survey was made immediately after the 1.5-million-pound shrimp quota had been reached and fishing operations terminated.

All catch values from this survey were adjusted by 0.719 to correct for differences in size between commercial and research trawls. Our total catch amounted to 4,722 pounds and from this catch we processed 53 samples. The catch per hour ran from 0 to 2,118 pounds; and the mean counts per pound per trawl ranged from 65 to 151.

The catch per standard trawl off California was 6,023 shrimp weighing 26,548 g (58.4 pounds). off Oregon (Strata 15 and 16) the catch per standard trawl was 298 shrimp weighing 1,241 g (2.7 pounds). The largest catches were obtained from Stratum 4 off Redding Rock, and Stratum 7 off the Klamath River (Table 3). Stratum 11 off California produced the low catches.

Analyses of these data indicated a population of 580 billion shrimp weighing 5.6 million pounds (Figure 5). Three year classes were observed in the samples with the 1966 year class dominating the catch, closely followed by the 1967 year class, and the 1965 year class contributing few shrimp (Table 4).

Most of the 1967 year class shrimp sampled were classified as males, only 1.8% were considered females (Table 5). This typical pattern was not followed by the incoming 1964 and 1966 year classes.

3.1.9. September 5–October 3, 1968, Survey

The 153 trawls during the 1968 fall survey produced a total catch of 7,240 pounds. We processed 12,542 shrimp from 286 samples for sex and age determination. Pounds per hour ranged from 0 to 3,942.

The average number of shrimp per pound per trawl was 226 with a range of 50 to 822.

The number (13,221 shrimp) taken per standard trawl in California was the highest recorded during this entire study (Table 2); however, the weight of 25,888 g (57.0 pounds) ranked only third. This seeming paradox (high number - low weight) was due to the very large number of incoming 1968 year class shrimp (Table 4).

The strata containing the highest concentrations of shrimp were 6, 4, 7, and 8 (Table 3). These strata are located between Redding

Rock and the mouth of the Klamath River. As in several previous surveys the lowest catches from off California came from Stratum 11. We calculated that the combined Oregon and California strata contained 1.88 billion shrimp weighing 8.7 million pounds (Figure 5).

The majority of the 1967 year class (1-year-olds) were classified as males (47.9%) but a very high percentage (44.5%) in comparison to other fall cruises were classified as transitionals (Table 5). If all of these transitionals functioned as females during the winter of 1968–69 this would follow the same pattern as observed for year-old shrimp during fall surveys in 1965 and 1967.

Confidence Limits

Our calculations indicate the 95% confidence half intervals (assuming a normal distribution) ranged from 18.0 to 49.2% of the number of shrimp per trawl, and from 18.7 to 50.9% of the weight of shrimp per trawl, for California. For Oregon these half interval ranges were 21.0 and 107.7% and 21.6 to 120.8% for numbers and weight of shrimp per trawl, respectively.

In summary, sea survey data disclosed:

(1) a trend towards an increase in both numbers and weights per trawl from 1965 through 1968;
(2) an unusual decrease in weight per trawl between the 1966 spring and fall survey;
(3) dominant year classes were produced in 1964, 1966, and 1968;
(4) an abnormally large percentage of 1-year-old females were found during the 1965 and 1967 fall surveys producing the dominant 1966 and 1968 year classes;
(5) an abnormal increase in shrimp per trawl during the June 1965 survey (when compared to the March survey), particularly in the values for the 1964 year class;
(6) a distinct northerly shift of population between the spring and fall surveys during 1965 and 1966;
(7) a shift concentrating the shrimp between the mouth of the Klamath River and Point St. George reef in 1967;
(8) a further southerly shift in shrimp concentrations in 1968.

3.2. Mortality Rates

Ocean shrimp hatch during the early spring, and after passing through several larval stages, metamorphose into small shrimp in early summer (Dahlstrom, 1970). Zero age (young of the year) shrimp first appear in catches during fall cruises and vary in size from 5 to 13mm carapace length. These shrimp enter the fishery as 1-year-olds the following summer and are available for the next two summers. A few survive their third summer, but none appear to survive long enough to enter the California fishery as 4-year-olds (Dahlstrom, 1970).

Based on this knowledge, I calculated mortality rates from shrimp per standard trawl data for the combined 14 California strata in 1965 and 1966. Beginning with the 1967 survey, I have used these data combined with the four Oregon strata. Some rates are higher while a few are lower than the preliminary calculations reported by Gotshall (1969) and Dahlstrom (1970).

The following equation (Ricker, 1958) and notation (Holt, 1960) were used:

$$Z(t - t_o) = (F + M)(t - t_o) = -ln(N_t/N_o)$$

where:

Z = annual instantaneous total mortality coefficient

$t - t_o$ = the fraction of the year between the estimate of N_o and N_t

F = annual instantaneous fishing mortality coefficient

M = annual instantaneous natural mortality coefficient

N_t = numbers per standard trawl of a given year class at time t

N_o = numbers per standard trawl of a given year class at some time previous to t

EQUATION

Fishing mortality rates were calculated between spring preseason surveys and fall postseason surveys from:

$$-ln(N_t/N_o) = q(F + M) + rM = (r + q)M + qF$$

Thus:

$$qF = -ln(N_t/N_o) - (r + q)M$$

where:

q = fraction of year when fishing occurred

r = fraction of year between spring survey and opening of fishing season and between close of fishing season and fall survey when only natural mortality was operating.

EQUATION

Overwinter instantaneous mortality rates (*Z*), calculated from the fall survey to the following spring survey, represent instantaneous natural mortality rates (*M*) since no fishing occurred during this period.

3.2.1. Natural Mortality

I was unable to calculate rates for the incoming 1965, 1966, and 1967 year classes during their first winter of life since these shrimp were not fully vulnerable to our net until the following spring.

Studies of Pacific hake stomachs indicate these fish feed extensively on ocean shrimp, and shrimp per stomach data may be used at times as an index of relative abundance (Gotshall, 1969). I have used first winter rates calculated from numbers of shrimp per Pacific hake stomach data for the 1964 and 1966 year classes (Table 6). The natural mortality rate (*M*) for the 1964 year class was 1.690 and the survival rate (*S*) was 0.18; while *M* for the 1966 year class equaled 0.997 and survival was 0.37. I was unable to calculate *M* for the first winter of the 1965 and 1967 year classes using this method. Mortality rates obtained from 1964 and 1965 year classes during their second winter of life were 0.384 and 0.604 respectively. The corresponding survival rates were 0.68 and 0.55 respectively.

The lowest survival rates were obtained for the 1963 and 1964 year classes during their third winter.

TABLE 6

Instantaneous Mortality Rates by Year Class of Northern California Ocean Shrimp March 1965–September 1967

Period	Year class	N_o	N_t	$t - t_o$	$M(t - t_o)$	Instantaneous natural mortality M	Instantaneous total mortality $q(F+M)+rM$	S $(t - t_o)$	Survival rate S
First winter	1964*	4.53	1.47	0.666	1.125	1.690	--	--	0.18
	1966*	2.39	1.23	0.666	0.664	0.997	--	--	0.37
Second winter	1964	4,162.02	3,458.78	0.479	0.184	0.384	--	--	0.68
	1965**	887.74	627.59	0.575	0.347	0.604	--	--	0.55
Third winter	1963	459.97	186.80	0.479	0.900	1.879	--	--	0.15
	1964**	610.18	282.05	0.438	0.772	1.343	--	--	0.26
First summer	1964†	6,068.29	4,162.02	0.532	--	--	0.377	0.68	--
	1964‡	7,327.44	4,162.02	0.320	--	--	0.566	0.56	--
	1965	3,344.01	887.74	0.397	--	--	1.325	0.27	--
	1966**	9,863.12	6,645.82	0.438	--	--	0.394	0.68	--
Second summer	1963†	578.50	459.97	0.532	--	--	0.229	0.79	--
	1964	3,458.78	610.18	0.397	--	--	1.736	0.18	--
	1965**	627.59	475.96	0.438	--	--	0.277	0.76	--
	1966**	3,140.59	1,687.43	0.252	--	--	0.623	0.54	--
Third summer	1962†	107.64	57.97	0.532	--	--	0.602	0.55	--
	1963	186.80	19.95	0.397	--	--	2.235	0.11	--
	1964**	282.05	36.47	0.438	--	--	2.045	0.13	--
	1965**	56.90	21.97	0.252	--	--	0.950	0.39	--

* Derived from number of shrimp per Pacific hake stomach (Gotshall, 1967).
** Includes Oregon strata after Spring 1967.
† Spring to Fall 1965.
‡ Summer to Fall 1965.

TABLE 6

Instantaneous Mortality Rates by Year Class of Northern California Ocean Shrimp March 1965–September 1967

TABLE 7

Fishing Mortality Rates of Northern California Ocean Shrimp, March 1965–September 1968

Year	Fraction of year between cruises $(r+q)$	Fraction of year when fishing occurred (q)	Fraction of year between cruises no fishing (r)	Year class	Instantaneous total mortality $(F+M)(r+q)$	Mean instantaneous natural mortality $M(r+q)$	Instantaneous fishing mortality qF	Instantaneous fishing mortality F	Mean instantaneous natural mortality $\bar{M}$*
1965**	0.532	0.252	0.279	1962*	0.602	0.857	--	--	1.611
				1963*	0.229	0.560	--	--	1.052
				1964**	0.377	0.489	--	--	0.919
1965†	0.320	0.041	0.279	1964	0.566	0.294	0.272	2.206	0.919
1965†	0.320	0.041	0.279	combined	0.517	0.226	0.291	2.360	0.707
1966	0.397	0.274	0.123	1963	2.235	0.242	1.993	7.274	1.611
				1964	1.736	0.418	1.318	4.811	1.052
				1965	1.325	0.364	0.961	3.506	0.919
				combined	1.322	0.281	1.041	3.800	0.707
1967	0.438	0.156	0.282	1964	2.045	0.706	1.339	8.575	1.611
				1965	0.277	0.461	--	--	1.052
				1966	0.394	0.402	--	--	0.919
				combined	0.408	0.310	0.098	0.628	0.707
1968	0.252	0.027	0.225	1965	0.950	0.406	0.544	19.584	1.611
				1966	0.623	0.265	0.358	12.888	1.052
				combined	0.318	0.178	0.140	5.040	0.707

* Mean calculated from all over winter mortality rates for each age (example, rates from Table 6 used for one-year-olds, 1.690, 0.997, 0.384, 0.604).
** April and October 1965 surveys.
† June and October 1965 surveys.

TABLE 7
Fishing Mortality Rates of Northern California Ocean Shrimp, March 1965–September 1968

TABLE 8

Instantaneous Mortality Rates by Combined Year Classes of Northern California Ocean Shrimp, March 1965–October 1968

Period	Year class	$t - t_o$	N_o	N_t	Instantaneous natural mortality M	Instantaneous total mortality $q(F + M) + rM$	$M(t - t_o)$	$S(t - t_o)$	Survival rate S
April 1, 1965 to October 11, 1965	1962–63–64	0.532	6,754.42	4,679.97	---	0.367	---	0.69	---
June 16, 1965 to October 11, 1965	1962–63–64	0.320	7,858.11	4,679.97	---	0.517	---	0.59	---
October 11, 1965 to April 14, 1966	1962–63–64	0.479	4,679.97	3,645.58	0.522	---	0.251	---	0.59
April 14, 1966 to August 27, 1966	1963–64–65	0.397	6,989.59	1,517.88	---	1.516	---	0.22	---
August 27, 1966 to March 25, 1967	1963–64–65	0.575	1,517.88	909.64	0.893	---	0.513	---	0.41
March 25, 1967 to September 1, 1967	1964–65–66	0.438	10,772.76	7,158.25	---	0.408	---	0.66	---
September 1, 1967 to June 19, 1968	1964–65–66	0.800	7,158.25	3,206.49	---	0.647	---	0.52	---
June 19, 1968 to September 19, 1968	1965–66–67	0.252	5,055.43	3,675.41	---	0.318	---	0.73	---

TABLE 8

Instantaneous Mortality Rates by Combined Year Classes of Northern California Ocean Shrimp, March 1965–October 1968

3.2.2. Fishing Mortality

Survival rates during their first summer for the 1964 and 1965 year classes were 0.56 and 0.27, respectively. These rates included both natural and fishing mortality. Instantaneous fishing mortality rates (F) were 2.206 for the 1964 year class and 3.506 for year class 1965 (Table 7). I used a mean instantaneous natural mortality value ([M]>) for each year shrimp were in the fishery to derive F. Mean mortality ([M]>) was calculated from all M values from the previous winter and upcoming winter. The 1964 year class F value was calculated using June to October data.

Survival rates during the second summer for the 1963, 1964, 1965, and 1966 year classes varied widely; the values were 0.79, 0.18, 0.76, and 0.54 respectively. These rates included effects of both fishing and natural mortality.

Instantaneous fishing mortality rates could not be calculated for the 1963 and 1965 year classes during their second summer in the fishery because the [M] value was larger than the $F + M$ value (Table 7). The rates for the 1964 and 1966 year classes were 4.811 and 12.888 respectively.

All survival rates during the third summer were quite similar except for the 1962 year class rate. Fishing mortality rates were derivable only for the 1963, 1964, and 1965 year classes (Table 7).

I also have derived survival, and natural and fishing mortality rates from the combined year classes (Tables 7 and 8). The M value for combined

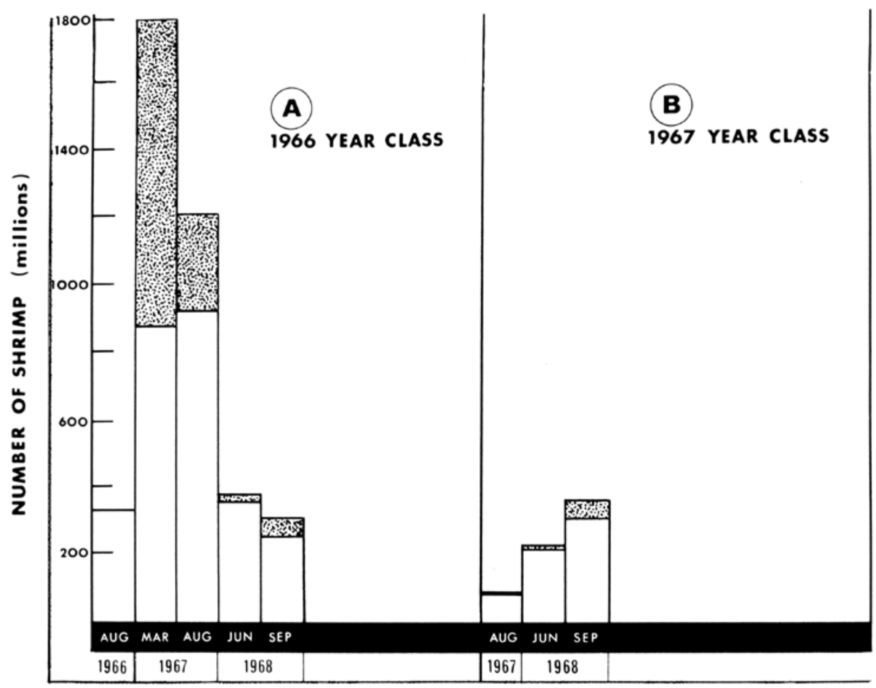

FIGURE 7 Estimated numbers or (A) 1966, and (B) 1967 year class ocean shrimp off northern California and southern Oregon, 1965–1968.

FIGURE 7 Estimated numbers or (A) 1966, and (B) 1967 year class ocean shrimp off northern California and southern Oregon, 1965–1968.

1962, 1963, and 1964 year classes from October 1965 to April 1966 was 0.522 and *S* was 0.59.

The mortality rate for the 1963, 1964, and 1965 year classes from August 1966 to March 1967 was 0.893 and the survival rate equaled 0.41.

Fishing mortality rates for combined year classes, using an [M] value of 0.707, were 2.360, 3.800, 0.628, and 5.040 for the 1965, 1966, 1967, and 1968 fishing seasons respectively.

Approximations of variances of instantaneous natural and fishing mortality rates (*M* and *F*) were obtained using the "delta" method (Kendall and Stuart, 1958). The equations were provided by Abramson (California Department of Fish and Game, pers. commun.). The estimated variances can only be applied when three successive surveys are used to calculate *M* and *F*. The variances of *M* were calculated for winter periods between the postfishing season fall survey and the prefishing season spring survey. Fishing mortality rate variances were derived from the periods between the spring and fall surveys.

The following equations were used:

$$V(M) = \left[\frac{1}{s^2}\,\frac{1}{N_1^2}\,V(N_1) + \frac{1}{N_2^2}\,V(N_2)\right]$$

$$V(F) = \left(\frac{r+q}{qsN_1}\right)^2 V(N_1) + \left(\frac{q+r+s}{qsN_2}\right)^2 V(N_2) + \left(\frac{1}{qN_3}\right)^2 V(N_3)$$

where:

s = fraction of year between a postseason survey (survey 1) and the following preseason survey (survey 2) when only M is operating.

$r + q$ = fraction of year between preseason survey (2) and postseason survey (3). Only M is in operation during r and $F + M$ is in operation during q (the open season).

N_1, N_2, N_3 = catch per standard trawl of a given year class on surveys 1, 2, 3.

$V(N_1), V(N_2), V(N_3)$ = variance of the catch per standard trawl of a given year class on surveys 1, 2, 3.

EQUATION

The fall 1965 and spring 1966 surveys were used to calculate variances of natural mortality *V* (*M*) and standard errors for the 1963 and 1964 year classes (Table 9). Variances and standard errors of fishing mortality for the 1963, 1964, and 1965 year classes were derived from 1966 spring and fall surveys. Estimates of variances of fishing mortality *V* (*F*) and standard errors also were calculated for the 1964 and 1965 year classes from fall 1966 to the 1967 spring survey; similarly, *V* (*F*) and the standard error were derived for the 1964 year class from the 1967 spring and fall surveys.

TABLE 9

Standard Errors of Instantaneous Natural and Fishing Mortality Rates for 1963, 1964, and 1965 Year Class Ocean Shrimp

Period	Year class	Instantaneous natural mortality (M)	Standard error	Instantaneous fishing mortality (F)	Standard error
Fall 1965 to spring 1966	1963	1.879	0.733	---	---
	1964	0.384	0.656	---	---
Spring 1966 to fall 1966	1963	---	---	7.274	2.443
	1964	---	---	4.811	1.999
	1965	---	---	3.390	1.613
Fall 1966 to spring 1967	1964	1.343	0.587	---	---
	1965	0.604	0.540	---	---
Spring 1967 to fall 1967	1964	---	---	8.575	2.279

TABLE 9

Standard Errors of Instantaneous Natural and Fishing Mortality Rates for 1963, 1964, and 1965 Year Class Ocean Shrimp

3.2.3. Mortality Rates as Determined from Catch Per Unit of Effort in the Commercial Fishery

The sea surveys were undertaken with the hope of determining a less expensive method of obtaining population estimates. One obvious method was to use the commercial fishery's catch per unit of effort to estimate instantaneous fishing (F) and natural (M) mortality. If these values were representative, preseason population estimates could be obtained. I obtained the weekly age composition of the catch and counts per pound from market sampling data. This information in turn was used to convert weekly average pounds per hour data into weekly average catch in numbers per year class, per hour. I used only the data for 1965, 1966, 1967, and 1968 (the years of our surveys). Least squares lines were calculated for each year class using the formula: $lnY = a + bx$ where: ln = natural log. Y = mean number of shrimp of a particular year class per hour. X = the week number for the particular fishing season.

All lines plotted for 1-year-old shrimp (1964, 1965, 1966, and 1967 year classes) yielded positive b values and could not be used. This indicates ocean shrimp probably do not become fully vulnerable to commercial nets until after their second birthday. The calculated b values for 2- and 3-year-olds were all negative [Figure 8] . Weekly mortality ($F + M$) for a given year class was derived using the b value (Table 10). I also attempted to derive values of M by subtracting the intercept (a) value from the previous years last weekly fitted lnY value, which would be comparable to estimated overwinter M values from our survey data. In the case of 1-year-old shrimp whose least square lines were positive, I used the last weekly observed ln of number of shrimp per hour (Y) from which to subtract the following seasons a value. With this method, M values for the second winter were derivable only for the 1964 year class.

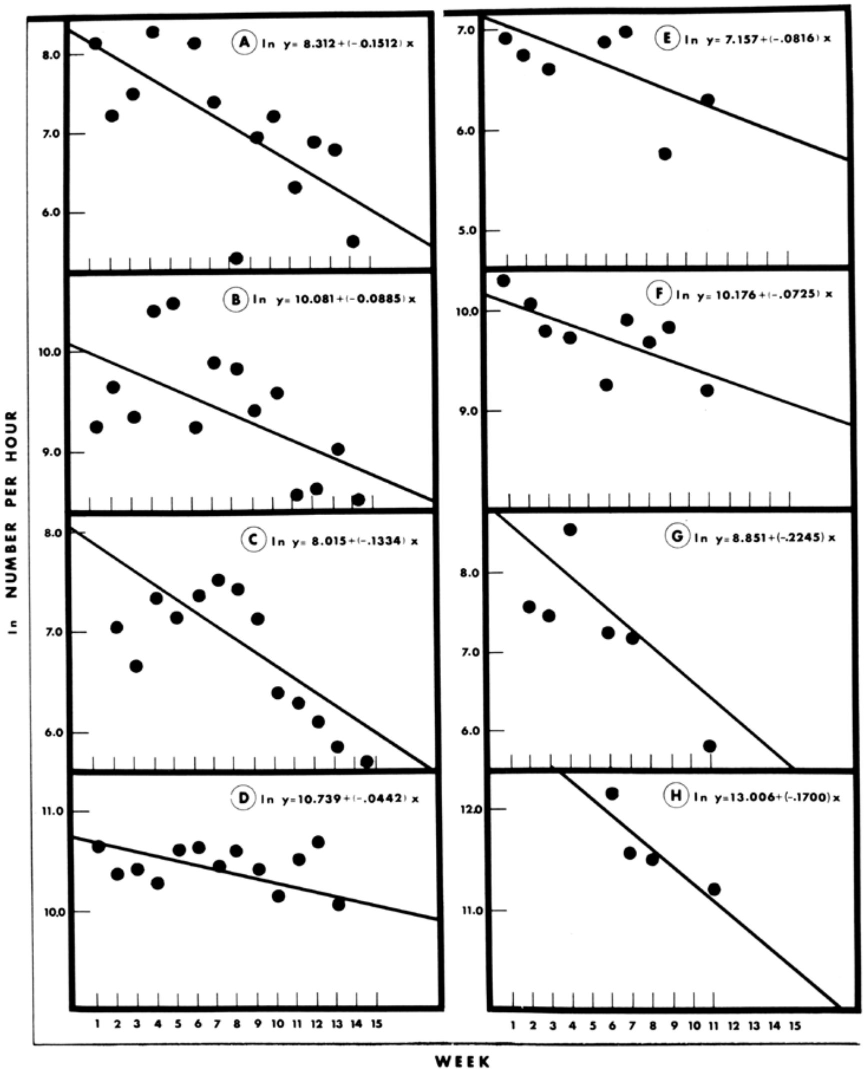

FIGURE 8 Least square lines of catch per hour of (A) 1962 and (B) 1963 year class ocean shrimp from northern California commercial fishery, 1965 season; (C) 1963 and (D) 1964 year class ocean shrimp from northern California commercial fishery, 1966 season; (E) 1964 and (F) 1965 year class ocean shrimp from northern California commercial fishery, 1967 season; and (G) 1965 and (H) 1966 year class ocean shrimp from northern California commercial fishery, 1968 season.

FIGURE 8 Least square lines of catch per hour of (A) 1962 and (B) 1963 year class ocean shrimp from northern California commercial fishery, 1965 season; (C) 1963 and (D) 1964 year class ocean shrimp from northern California commercial fishery, 1966 season; (E) 1964 and (F) 1965 year class ocean shrimp from northern California commercial fishery, 1967 season; and (G) 1965 and (H) 1966 year class ocean shrimp from northern California commercial fishery, 1968 season.

When *M* estimates are compared with those calculated from sea surveys, the 1964 year class second winter rates are surprisingly close; the estimated commercial fishery was 0.448 and that from the survey was 0.384 (Table 11). The corresponding survival percentages are 63.8 and 68.4 respectively.

TABLE 10

Ocean Shrimp Mortality Rates Calculated from Least Squares of Commercial Fishery Number of Shrimp per Hour, 1965–1968

Period	Year class	$\ln N_o$	$\ln N_t$	$t - t_o$	$M(t - t_o)$	Instantaneous natural mortality M	Instantaneous weekly total mortality $(F + M)$ (b)	Instantaneous annual† total mortality $F + M$	Mean instantaneous natural mortality $\bar{M}$*	Instantaneous fishing mortality F	Survival rate S
Second winter	1964	11.065	10.730	0.758	0.335	0.448	---	---	---	---	0.64
	1965	9.349	10.180	0.810	---	---	---	---	---	---	---
	1966	11.153	13.006	0.742	---	---	---	---	---	---	---
Third winter	1963	8.970	8.015	0.758	0.855	1.126	---	---	---	---	0.32
	1964	10.130	7.157	0.810	2.973	3.666	---	---	---	---	0.02
	1965	9.380	8.851	0.742	0.429	0.578	---	---	---	---	0.56
Second summer	1963	10.081	8.860	0.019	---	---	0.088	4.602	1.052	3.550	0.03
	1964	10.739	10.130	0.019	---	---	0.044	2.298	---	1.246	0.30
	1965	10.176	9.380	0.019	---	---	0.072	3.744	---	2.692	0.07
	1966	13.006	11.130	0.019	---	---	0.170	8.840	---	7.788	0.00
Third summer	1962	8.312	6.160	0.019	---	---	0.151	7.852	1.611	6.241	0.00
	1963	8.015	6.160	0.019	---	---	0.133	6.916	---	5.305	0.01
	1964	7.157	6.260	0.019	---	---	0.082	4.264	---	2.653	0.07
	1965	8.851	6.350	0.019	---	---	0.224	11.648	---	10.037	0.00

* From Table 7.
† Assuming year round fishery.

TABLE 10
Ocean Shrimp Mortality Rates Calculated from Least Squares of Commercial Fishery Number of Shrimp per Hour, 1965–1968

TABLE 11

Comparison of Ocean Shrimp Instantaneous Mortality (*M* and *F*) Estimates Calculated from Survey Catch per Trawl and Commercial Fishery Numbers per Hour Data, 1965–1968

Period	Year class	Survey estimates *M*	Survey estimates *F*	Commercial fishery estimates *M*	Commercial fishery estimates *F*
Winter 1965–1966	1963	1.879		1.126	
	1964	0.384		0.448	
Winter 1966–1967	1964	1.343		3.666	
Winter 1967–1968	1965	**		0.578	
Summer 1965	1962		*		6.241
	1963		*		3.550
Summer 1966	1963		7.274		5.305
	1964		4.811		1.246
Summer 1967	1964		8.575		2.653
	1965		*		2.692
Summer 1968	1965		19.584		10.037
	1966		12.888		7.788

* Value not derivable from data.
** Rate included both $F + M$.

TABLE 11

Comparison of Ocean Shrimp Instantaneous Mortality (M and F) Estimates Calculated from Survey Catch per Trawl and Commercial Fishery Numbers per Hour Data, 1965–1968

In looking at third winter mortality estimates only values for the 1963 year class are similar enough to be considered comparable. *M* calculated from the commercial fishery data equaled 1.126 as compared to 1.879 as calculated from the surveys. The survival rates from these *M* values are 0.15 from survey data and 0.32 from commercial fishery information.

Fishing mortalities calculated from survey data were generally higher than those estimated using commercial fishery information. The closest *F* values were for the 1963 year class during the 1966 fishing season.

The highest variability between plotted points and regression lines usually occurred during the first few weeks of the season; this was particularly true in 1965 (Figure 8). This variability may be caused by changes in availability due to vertical migrations of shrimp. If a method can be devised to decrease variability, mortality rate data would be more meaningful, assuming survey estimates are more representative. It is interesting to note that values for both the 1965 summer survey and commercial fishery were either not calculable or varied widely.

Judging from the literature, only a few studies have been made of shrimp mortality rates. At the United Nations Food and Agriculture Organization (FAO) Conference in Mexico City (June 1967) concerning the biology and cultivation of shrimp and prawns, mortality rates were mentioned in very few papers. However, rates have been estimated for some Gulf of Mexico peneids.

Costello and Allen (1968) derived mortality rates for pink shrimp, Penaeus duorarum, from the Sanibel and Tortugas grounds off Florida.

The rates were derived for fully exploitable shrimp during a 2-week period using mark recoveries (linear regression). The Sanibel grounds produced an M value of 0.1644 and the Tortugas grounds an M value of 0.2185. Mortality values included all causes of death other than fishing and included migration.

High estimates were reported by Kutkuhn (1966) for the Tortugas grounds pink shrimp; his M value was 0.55. These estimates were made from mark recoveries for a 1-week period.

Berry (1967) also estimated mortality rates for Tortugas pink shrimp. His M values of 0.024, 0.039, and 0.061 were considerably lower than earlier studies.

Since pink shrimp are short lived and only are exploitable during the last few months of their lives, it is useless to attempt any comparison with ocean shrimp rates. The important aspect of the three different rates reported for Tortugas is the fact that they varied quite widely; in most cases, the variation was greater than those calculated for ocean shrimp.

3.2.4. Relationship of Fishing Mortality to Total Fishing Effort

If catchability (c) is constant and our calculated fishing mortality (F) values are meaningful, there should be a linear relationship between total fishing effort and fishing mortality ($F = cf$, where c = catchability constant and f = total fishing effort).

I compared the annual total trawling hours expended by northern California shrimp fishermen within the survey area with fishing mortality rates, for the fraction of the year fishing took place (qF), derived from shrimp being fished for their second and third summer (Table 7). Ocean shrimp during their first summer in the fishery were not used because they are not fully vulnerable to the commercial nets.

Data suggest there is a relationship between fishing mortality and fishing effort. Higher qF values occurred when more effort was expended and low qF values were associated with seasons when the total effort hours were low (Table 12).

TABLE 12

Comparison of Ocean Shrimp Instantaneous Fishing Mortality Rates with Total Effort Hours During 1966, 1967, and 1968 Seasons

Fishing season	Year class	Total effort hours	Instantaneous fishing mortality qF
1966	1963	2,684	1.993
	1964	--	1.318
1967	1964	1,953	1.339
1968	1965	1,669	0.544
	1966	--	0.358

TABLE 12

Comparison of Ocean Shrimp Instantaneous Fishing Mortality Rates with Total Effort Hours During 1966, 1967, and 1968 Seasons

3.3. Spawner/Recruit Relationship

If a relationship exists between number of spawners and number of recruits and the fishery is supported by these spawners, then this relationship should be considered when formulating management recommendations. Unfortunately, at least 15 to 20 years of observations are needed to develop reliable data concerning spawner/recruit relationships (Ricker, 1958). I have used data from our sea survey study plus shrimp population estimates in the fall of 1963 and 1964 obtained from annual shrimp reports (Calif. Dept. Fish and Game, 1964). The estimated number of females in the population was used to represent spawners for the years of 1963, 1964, 1965, and 1966. One-year-old shrimp occurring in the spring 1½ years later were considered recruits to the fishery; these included year classes 1964, 1965, 1966, and 1967 (Table 13). I found the largest number of recruits, the 1966 year class, was the result of an estimated spawning population of 396 million females. The smallest recruitment, the 1967 year class, resulted from a spawning population of 152 million females. This definitely suggests a positive spawner/recruit relationship.

TABLE 13

Numbers of Female Ocean Shrimp (Spawners) and Resulting One Year Old Progeny (Recruits) 1964–1967

Spawning year	Number of females (millions)	Number of recruits (millions)
1963	75	961
1964	69	355
1965	396	1,797
1966	152	335

TABLE 13

Numbers of Female Ocean Shrimp (Spawners) and Resulting One Year Old Progeny (Recruits) 1964–1967

TABLE 14

Numbers of Adult Ocean Shrimp (Fall) and One Year Olds Surviving to Following Spring, 1964–1968

Year	Adult fall population (millions)	Resulting 1 year olds (spring survey) (millions)
1964	143	
1965		961
1965	602	
1966		355
1966	197	
1967		1,797
1967	1,304	
1968*		335

* June survey, after harvest of 1.5 million pounds.

TABLE 14

Numbers of Adult Ocean Shrimp (Fall) and One Year Olds Surviving to Following Spring, 1964–1968

I also compared number of recruits with total estimated population present during the fall previous to the recruit's first birthday to determine if abundance of 1-year-old shrimp was related to some density dependent function (Table 14). I found the largest recruitment occurred when the previous fall population estimate was 197 million shrimp (1966/67); conversely, the lowest recruitment occurred when there was an estimated fall population of 1.3 billion shrimp (1967/68). This strongly suggests an inverse relationship between recruitment and population density.

3.4. Growth

Age/length relationships have been presented for ocean shrimp by Butler (1964) and Dahlstrom (1970). Butler plotted mean carapace lengths and ranges for ocean shrimp from Vancouver Island by month from age 6 months to age 39 months. Dahlstrom compared Bodega Bay and Fort Bragg, California, ocean shrimp mean carapace lengths by month of age with Butler's Vancouver Island shrimp, but did not give size ranges associated with each mean.

To my knowledge the Von Bertalanffy growth equation has not been applied to ocean shrimp. A modified FORTRAN program, BGC II (Abramson 1971), was used to calculate the Von Bertalanffy growth curve and constants for 1964 and 1965 year class ocean shrimp. The following equation was used:

$$l_t = L\infty[1 - e^{-K(t - t_o)}]$$

where:

$L\infty$ = maximum expected carapace length
K = instantaneous rate of length increment decrease
t = actual age
t_o = hypothetical age at zero length

EQUATION

The calculated maximum expected carapace length ([L8]) was larger for the 1964 year class than that calculated for the 1965 year class (Table 15). However the hypothetical age at zero length (t_0) was less for the 1964 year class; —4.9304 as opposed to —1.0744 for the 1965 year class.

TABLE 15

Growth Parameters for the 1964 and 1965 Year Classes Calculated from Von Bertalanffy Growth Equation

Year class	$L\infty$	95 percent confidence interval	K	95 percent confidence interval	t_o	95 percent confidence interval
1964	26.94	2.450	0.042145	0.01089	−4.9304	1.9588
1965	25.67	1.000	0.058071	0.00657	−1.0744	0.62539

TABLE 15

Growth Parameters for the 1964 and 1965 Year Classes Calculated from Von Bertalanffy Growth Equation

I believe the hatching peak occurs in March, and have thus set March 1 as the birthdate for northern California ocean shrimp. The calculated carapace lengths (mm) at 6-month intervals for 1964 and 1965 year class shrimp generally were larger than those calculated for Vancouver Island shrimp (Figure 9 , Table 16), but were similar to means calculated for Fort Bragg and Bodega Bay shrimp.

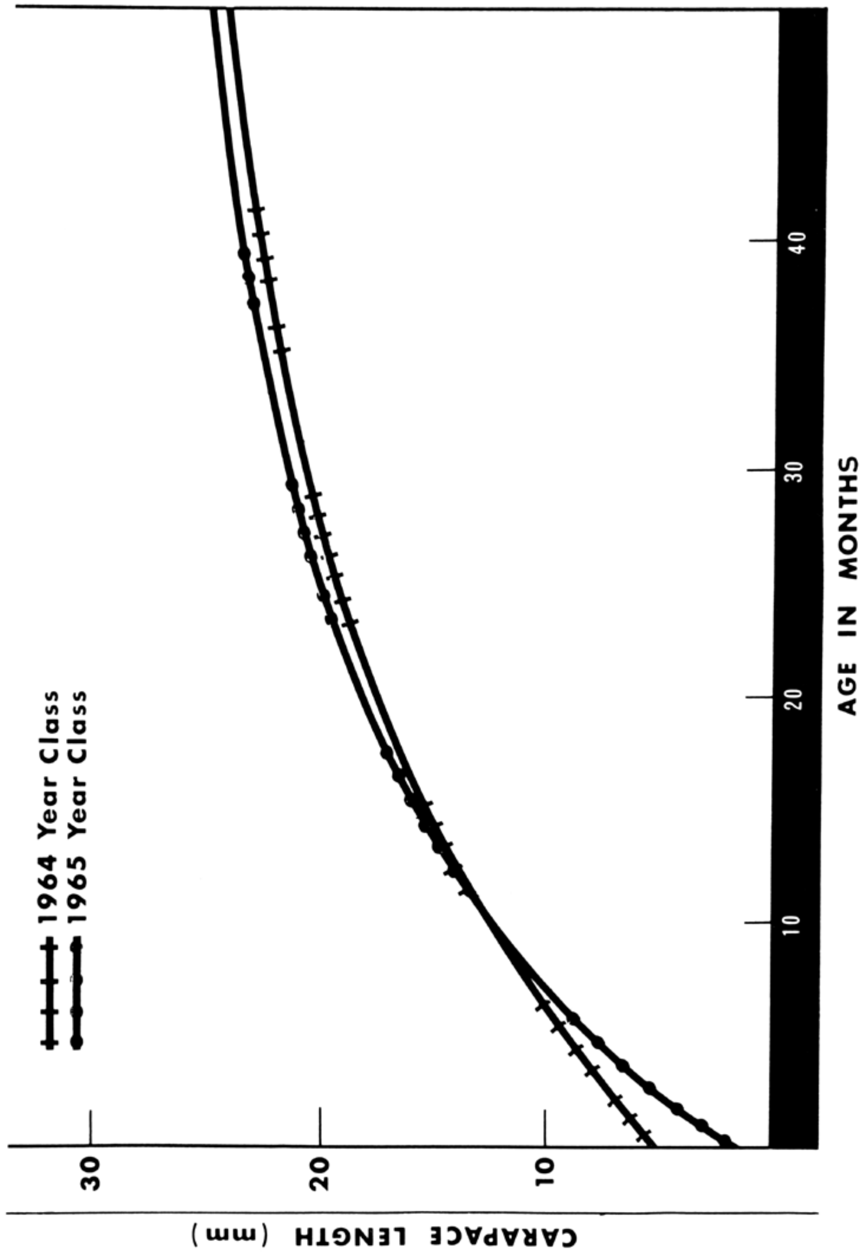

FIGURE 9 Growth rate of 1964 and 1965 year class ocean shrimp fitted by Von Bertalanffy growth equation.

FIGURE 9 Growth rate of 1964 and 1965 year class ocean shrimp fitted by Von Bertalanffy growth equation.

TABLE 16

Comparison of Northern California Ocean Shrimp Sizes at Six-Month Intervals with Vancouver Island, Fort Bragg, and Bodega Bay Shrimp

Age in months	Northern California		Vancouver Island	Fort Bragg	Bodega Bay
	1964 year class	1965 year class			
6	9.9	8.7	8.2[1]	*	*
12	13.7	13.7	13.1	*	*
18	16.7	17.1	16.9[1]	18.0	18.4
24	19.0	19.7	17.9	18.7	19.2
30	21.2	21.7	20.2[1]	*	*
36	22.1	22.6	20.9[1]	21.8	22.2

[1] Butler's mean lengths were for ages of 5, 17, 29, and 38 months.
* No data.

TABLE 16

Comparison of Northern California Ocean Shrimp Sizes at Six-Month Intervals with Vancouver Island, Fort Bragg, and Bodega Bay Shrimp

4. DISCUSSION

4.1. Validity of Estimates

Several assumptions were made in designing this study. Perhaps the most important and yet the least measurable, was that all shrimp in the area swept by the trawl were caught, and each trawl represented actual shrimp abundance in that particular area. Since this could not be checked accurately, I assumed that shrimp were at least equally available and vulnerable during the entire study period, and catch per standard trawl is an accurate measure of relative abundance. Availability, for this discussion, is defined as being directly in the path of the net and neither buried in the substrate nor swimming above the net. Vulnerability refers to the shrimp's ability to escape through the meshes once inside the net opening.

I further assumed the area surveyed contained an independent population, that the trawl was operating properly, and that little or no immigration or emigration occurred. Finally, I assumed length frequency data yielded reliable age composition of the samples.

As it turned out, the first two assumptions have been shown to be, partially, if not entirely, incorrect. A difference in vulnerability or availability was first indicated during the June 1965 survey. The catch per standard trawl values (numbers) were significantly higher than those obtained during the spring survey (Table 2), and the only values that decreased were the numbers of 1962 and 1963 year class shrimp per trawl (Table 4). The numbers per trawl of 1964 year class shrimp increased from 6,068 in March, to 7,327 in June. Even though there was an overlap of confidence half intervals, I feel the spring survey under-estimated the dominant 1964 year class. The 1964 year class was either more vulnerable or more available or both during the June survey. Catch per standard trawl values for the 1962 year class from the June survey were lower than the fall survey estimate; in addition, the June value for the 1963 year class seemed to be low when compared with the fall survey value. In fact, the value of the 1963 year class catch per standard trawl was too low to produce fishing mortality estimates (Table 7).

It became apparent that our estimates were not accurately reflecting relative abundance of shrimp during either the spring or summer 1965 surveys. There are several factors that could affect both availability and vulnerability of shrimp. First of all, it was possible that the 1-year-old 1964 year class shrimp were not large enough to be fully vulnerable to our net, even using the 0.5-inch-mesh liner. Secondly, there was a possibility that a movement of 1-year-old shrimp into the area occurred and there was a migration of 2- and 3-year-olds out of the survey area between the spring and summer surveys. Finally, there is growing evidence that ocean shrimp move off the bottom during hours of darkness (Milburn and Robinson, Oregon Fish Commission, Unpublished Manuscript; Pearcy, 1970; Barr, 1970).

Milburn and Robinson found a higher proportion of males (youngest shrimp) in midwater trawls and traps at night during November. Females were dominant from January to April. Pearcy (1970) captured ocean shrimp in midwater trawls off Oregon every month of the year except May and June, and stomachs of shrimp collected at night contained planktonic organisms. Barr (1970) reported similar migrations for pink shrimp, Pandalus borealis, and has evidence of their movement off the bottom during daytime. National Marine Fisheries Service (formerly the U.S. Bureau of Commercial Fisheries) shrimp trawl studies off Washington suggest a relationship between cloudy days and movement of shrimp off the bottom; on bright sunny days, shrimp tend to stay on or near the bottom (Jurkovich, 1969). Barr's studies indicate small shrimp move higher in the water column. In addition, National Marine Fisheries Service biologists using a 6-ft x 6-ft vertical distribution sampler, found ocean shrimp in all vertical compartments; however, upper compartments contained fewer shrimp than bottom compartments during daytime trials (Alan Beardsly, NMFS, pers. commun.). The catches seemed to be influenced by overcast days and murky water—more shrimp were found in upper compartments when trials were conducted under those conditions. More shrimp also were caught in upper compartments during early morning and late evening trials. Shrimp were distributed equally, but in small concentrations during nighttime trials. Beardsly suspects some sampling may occur as the net is being lowered or raised through the water column.

These vertical movements probably are feeding migrations and may extend into daytime during certain periods, particularly if there is a significant decrease in light penetration. This assumes ocean shrimp are negatively phototrophic and a decrease in light triggers the migration. I feel this latter possibility primarily was responsible for the poor estimates obtained during the spring 1965 survey, and may have had some effect on June estimates. These vertical migrations also could be a major factor in the wide variations of commercial catch per unit of effort during the first few weeks of the season. This in turn would affect mortality rate estimates derived from commercial catch per unit of effort data.

The spring 1965 survey was conducted during a period of strong north and northwesterly winds, which according to Sverdrup, Johnson, and Fleming (1942) give rise to upwelling along the California coast.

They also state that March is the usual beginning of the upwelling period. The heaviest plankton concentrations generally occur during and after periods of upwelling (Bolin and Abbott, 1963). Louis Barr (National Marine Fisheries Service, pers. commun.) found pink shrimp, collected at night, contained mostly planktonic organisms, while stomachs collected during daytime hours contained little or no food. Ocean shrimp collected at night off Oregon had been feeding on planktonic organisms (Pearcy, 1970). Since heavy plankton blooms decrease light penetration, it seems probable that ocean shrimp may remain off the bottom for longer periods during heavy plankton blooms, thereby decreasing their availability to bottom trawls. Northern California commercial shrimp fishermen report decreases in their catch per hour generally are associated with "dirty water," and I suggest these dirty water periods are actually heavy plankton blooms.

Fortunately, the spring 1966 and 1967 surveys were conducted before the advent of the northerly winds. In both cases, prevailing winds were from the south, and warmer surface waters were present during both surveys. These phenomena in turn are associated with winter oceanographic conditions near the coast (Sverdrup, Johnson, and Fleming, 1942). Midday surface temperatures during the spring 1965 survey ranged from 49.1 to 50.9°F (9.5–10.5°C), while the range during the spring 1966 survey was from 50.9 to 53.6°F (10.5–12.1°C), and 49.3 to 52.2°F (9.6–11.2°C) during the spring 1967 survey.

In summary, northern California ocean shrimp migrate off the bottom at night to feed. During periods of upwelling and resulting plankton blooms some of these shrimp may remain off the bottom during part or all of the day. This behavior greatly affects their availability to sampling and the commercial trawls.

Migration is considered responsible for the low population estimates obtained during our fall 1966 survey. The most significant decrease occurred with weight of catch; this value fell from 21,506 g (47.4 pounds) in the spring, to 7,652 g (16.8 pounds) in the fall (Table 2). During other surveys, the weight of shrimp per standard trawl remained about the same or increased in the fall as a result of shrimp growth. I believe the 1966 decrease was due to at least two factors. 1) A high survival of the incoming 1966 year class. These small shrimp formed 62.8% of the catches by numbers. 2) Unusually high mortality of the 1964 and 1965 year classes (large older shrimp). The total mortality rates for interval between the spring and fall cruises were 1.736 and 1.325 for the 1964 and 1965 year class, respectively (Table 6). These values are higher than total mortality rates computed for ocean shrimp during their second summer.

This high mortality rate may have been due to very high fishing mortality, increased natural mortality, or migration of these shrimp out of the survey area. Since both commercial landings and catch rates from this bed during 1966 were below the 6-year average (Table 17), I have ruled out fishing mortality as an explanation. I also have no reason to believe that any significant changes occurred in the area that might increase the natural mortality rate. I do have data that suggest a northerly movement of a segment of the population—out of the survey area.

TABLE 17

Pounds of Ocean Shrimp Landed in Northern California from Area A from 1963 * to 1968

Year	Pounds landed (thousands)	Mean pounds per hour	Effort hours
1963	1,862	488	3,813
1964	944	524	1,800
1965	1,168	431	2,706
1966	1,209	450	2,684
1967	1,403	718	1,953
1968	2,031	1,217	1,669
Means	1,436	589	2,438

* First year that otter trawls were legal shrimp gear in California.

TABLE 17

Pounds of Ocean Shrimp Landed in Northern California from Area A from 1963 to 1968

In the spring of 1966, Oregon Fish Commission biologists began a series of sea surveys (similar to ours) to determine distribution and abundance of ocean shrimp off the Oregon coast (Robinson, in press). One of their survey areas extended from the Oregon-California border north to off the mouth of the Rogue River. Their data indicate a significant increase in the relative abundance of shrimp between the spring and fall 1966 surveys, both in numbers and weight. This also was true for the spring of 1967. A major portion of the fall 1966 survey catch was composed of 1966 year class shrimp; however, there also was a substantial increase in the catch per standard trawl of 1965 and 1964 year class shrimp (57% and 43% respectively). Because of this apparent shift of the shrimp population, most of this area was subsequently added to our survey area beginning with the spring 1967 survey (Figure 1).

A comparison of our catches with the Oregon survey data revealed Oregon had greater numbers and weight per trawl of all shrimp combined than California catches in spring 1967; this also was true of catch values for 1966 and 1965 year class shrimp, but California catches of 1964 year class shrimp were higher than Oregon's (Tables 2, 4, 18, and 19). One word of caution, the standard errors and resulting variances were very large for both the Oregon and California data.

As another method of gaining insight into population density shifts, I examined numbers per standard trawl by stratum or groups of strata

TABLE 18

Catch per Standard Trawl of Ocean Shrimp by Numbers and Weight off Southern Oregon *

Survey dates	Number of trawls	Number of shrimp in standard trawl	95 percent confidence interval	Weight of shrimp in standard trawl (g)	95 percent confidence interval
March 3–March 23, 1966	16	1,352	±1,684	2,324	±2,350
October 1–October 4, 1966	11	24,874	±21,753	30,796	±21,984
April 3–April 4, 1967	10	29,889	±47,605	74,730	±119,013

* Calculated from data collected on Oregon Fish Commission surveys.

TABLE 18

Catch per Standard Trawl of Ocean Shrimp by Numbers and Weight off Southern Oregon

TABLE 19

Catch per Standard Trawl of 1963, 1964, 1965, and 1966 Year Class Ocean Shrimp off Southern Oregon *

Survey	1963 year class		1964 year class		1965 year class		1966 year class	
	Number per standard trawl	95 percent confidence interval	Number per standard trawl	95 percent confidence interval	Number per standard trawl	95 percent confidence interval	Number per standard trawl	95 percent confidence interval
Spring 1966	20	±30	669	±767	663	±892	--	--
Fall 1966	0	--	957	±883	1,044	±1,326	22,873	±21,550
Spring 1967	0	--	239	±459	2,623	±5,054	27,026	±42,276

* Calculated from data collected on Oregon Fish Commission surveys.

TABLE 19

Catch per Standard Trawl of 1963, 1964, 1965, and 1966 Year Class Ocean Shrimp off Southern Oregon

TABLE 20

Grouped Survey Strata and Corresponding Blocks

Stratum number	Block number
11	1
1, 2	2
3, 4, 5, 12	3
6, 7, 8	4
9, 10	5
13	6
14	7
15, 16	8
17, 18	9

TABLE 20

Grouped Survey Strata and Corresponding Blocks

so that northerly or southerly changes in relative abundance from spring to fall and from fall to spring could be detected. This required grouping of the strata into north-south blocks (Table 20).

The numbers of shrimp per standard trawl for each stratum were combined to conform to the respective blocks, and then the weighted (by area) number per standard trawl for each block was converted into the percentage of the total combined catch per standard trawl. Zero age shrimp were not included. The percentages were calculated with the following formula:

$$P_B = \frac{\sum_{i \epsilon K} W_i \frac{C_i}{St_i}}{\sum_{i=1}^{M} \frac{C_i}{St_i}}$$

EQUATION

where:

P_B = percentage of combined shrimp per standard trawl in any block of grouped strata.

W_i = relative area of stratum i.

i = ith stratum.

$\frac{C_i}{St_i}$ = catch in numbers of shrimp per standard trawl in ith stratum.

M = number of strata.

K = kth block.

ϵ = belong to.

EQUATION

In the spring of 1965 approximately 85% of the shrimp per standard trawl were in blocks 1, 2, 3, and 4; these blocks are located from off the Klamath River south to Trinidad Head (Figure 10) .

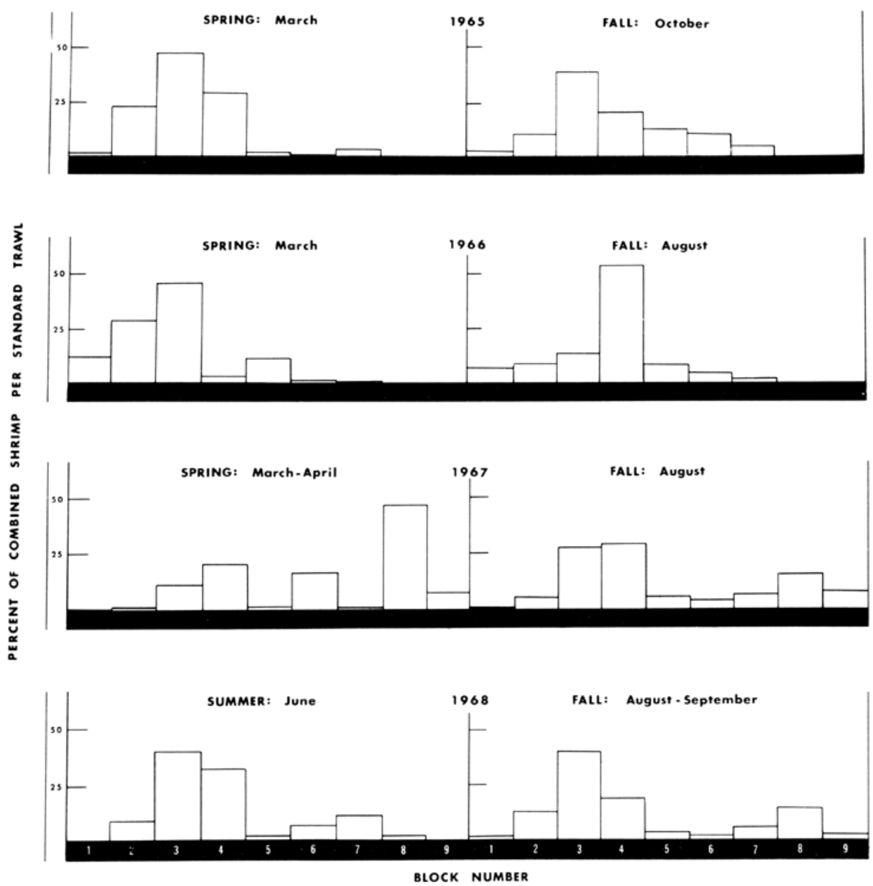

FIGURE 10 Relative abundance of ocean shrimp by north-south grouped strata, 1965–1968.

FIGURE 10 Relative abundance of ocean shrimp by north-south grouped strata, 1965–1968.

During the fall survey, we found that this percentage had decreased with a corresponding increase in blocks north of the Klamath River.

The spring 1966 survey again indicated a large percentage (about 85%) of the shrimp were located south of Klamath River. Block 3 had the highest relative abundance during these first three surveys. In the fall of 1966, the highest relative abundance shifted north to block 4. It was during this period that Oregon biologists noted the significant increase in catch per trawl off of Brookings, Oregon (Tables 18 and 19).

Our spring 1967 survey included the four strata off of southern Oregon (Figure 1), and we found the highest relative abundance in block 8 off of Brookings (Figure 10). Approximately 50% of the combined shrimp per standard trawl were encountered in this area. Contrary to previous spring surveys approximately 70% of the combined shrimp per standard trawl were located north of the Klamath River.

The shrimp population evidently shifted south during the summer of 1967 since large concentrations of shrimp were found off the Klamath River and Redding Rock during the fall survey. Block 8 off of Brookings still produced almost 15% of the combined shrimp per standard trawl.

Summer and fall 1968 surveys showed a distribution pattern similar to 1965 surveys. Block 3 produced the highest percentage of the combined shrimp per standard trawl. Blocks 7 and 8 were found to contain small shrimp concentrations during both 1968 surveys.

I consider ocean shrimp in northern California and southern Oregon as belonging to one intermingling population, and feel that all or part of this population is subject to north-south as well as inshore-offshore displacements. I suggest these movements are influenced by nearshore current patterns, upwelling, and plankton concentrations, and believe most displacement probably takes place during the animals' vertical migration phases. The work of Pearcy (1970) and Milburn and Robinson, Oregon Fish Commission, supports this hypothesis. Such movements may be influenced by the subsurface counter-current associated with the California Current as described by Pavlova (1966).

Because of the previously mentioned variations in availability during this study, I think the most representative population and mortality rate estimates were obtained during fall 1965 and spring 1966 surveys, and the spring and fall 1967 surveys.

5. RECOMMENDATIONS

Future ocean shrimp research should be directed at vertical and horizontal migration studies to determine the extent of these movements, and determining whether the various populations along the coast are separate or intermingling. We should find out what oceanographic conditions, if any, affect the movements of shrimp. Finally, further research is needed in the following areas: 1) factors controlling sex change; 2) relationship of secondary sexual characteristics and gonad development; 3) improvement of aging techniques; 4) determining spawner/recruit relationship; 5) finding out relationship between population density and incoming year class; and 6) developing methods to obtain mortality rates and population estimates from commercial catch per unit of effort data.

6. SUMMARY

1. A series of sea surveys of the northern California ocean shrimp population was initiated in the spring of 1965 to obtain estimates of population size, mortality rates, and growth rates. A stratified two-stage sampling plan was used on all surveys.

2. Nine surveys were conducted from March 1965 through September 1968 in a 270-square-mile area extending from off Mad River, California, north to Pelican Bay, California. Four surveys were conducted in a 105-square-mile area off southern Oregon during 1967 and 1968.

3. Estimates of the shrimp population off California ranged from 2.2 million in August 1966 to 8.1 million pounds in August 1967; off southern Oregon, the population ranged from 114 thousand pounds in June 1968 to 4.6 million pounds in March 1967.

4. There was a trend towards an increase in numbers as well as weight per standard trawl from 1965 through 1968.

5. The incoming year classes during 1966 and 1968 produced the highest numbers per standard trawl. The 1964 year class also was considered a dominant year class since these shrimp comprised the major share of catches through the spring 1966 survey. A large portion of these three year classes, as 1-year-olds, functioned as females. The usual pattern for 1-year-old ocean shrimp is to function as males. These 1-year-old females produced the dominant 1966 and 1968 year classes.

6. Ninety-five percent confidence half intervals ranged from 18.0 to 49.2% of the numbers per standard trawl and from 18.7 to 50.9% of the pounds per standard trawl for California strata. Confidence half intervals for the southern Oregon strata were 21.0 to 107.7% of the numbers, and 21.6 to 120.8% of the pounds per standard trawl.

7. Natural mortality rates (M) for ocean shrimp during their second winter of life for the 1964 and 1965 year classes were 0.384 and 0.604, respectively. Corresponding survival rates were 0.68 and 0.55. The 1963 and 1964 year classes experienced the highest mortality rates and lowest survival rates during their third winter of life. Natural mortality rates also were determined for combined year classes; from fall 1965 to spring 1966, natural mortality was equal to 0.522, and from fall 1966 to spring 1967, it equaled 0.893. Survival rates for these periods were 0.59 and 0.41, respectively.

8. Fishing mortality rates (F) varied considerably. The highest fishing mortality (F) was experienced by shrimp during their third summer in the fishery.

9. Variances were calculated for natural mortality (M) and fishing mortality (F).

10. Mortality rates also were calculated from least squares of weekly commercial catch per hour data. Second winter natural mortality rates for the 1964 year class were quite close to those estimated from the sea surveys. Fishing mortality rates (*F*) calculated from survey information generally were larger than those computed from commercial catch per hour data.

11. From limited data, it appears a relationship exists between fishing mortality rates calculated from survey data and total trawling hours expended by commercial shrimp trawlers.

12. A positive relationship exists between number of spawners and number of 1-year-old shrimp produced. An inverse relationship (density dependence) exists between population size and survival of the incoming year class.

13. The Von Bertalanffy growth equation was applied to mean carapace lengths and age in months of 1964 and 1965 year class shrimp. Values for the constants L8 and *K* were very close, the values of t_o varied considerably.

14. It is suggested that the spring 1965 survey produced underestimates of the population because of vertical migrations of the shrimp during daylight (sampling) hours.

15. The very low fall 1966 population estimates appear related to migration of part of the population northward into southern Oregon waters. Two factors support this conclusion: 1) distinct shifts in high and low relative abundance in a south to north direction between spring and fall surveys in the various strata; and 2) the Oregon Fish Commission surveys conducted off southern Oregon during 1966 and 1967 showed a significant increase in population density. Shifts in population may be the result of shrimp being translocated by currents vertical migration periods.

16. Because of apparent changes in availability during spring of 1965 and fall of 1966, I believe that the most representative population and mortality rate estimates were those obtained during the fall 1965 and spring 1966 surveys; and the spring and fall 1967 surveys.

17. Future ocean shrimp research should include oceanographic studies, evaluating possible affects of changes in oceanographic conditions on commercial catch per unit of effort, ascertaining extent of intermingling, and determining whether or not the various populations along the coast are separate. Additional research also is needed to assess factors controlling sex change, relationship of secondary sexual characteristics and gonad development, to improve aging techniques, to determine spawner-recruit relationship, to ascertain population density-recruit relationship, and to develop methods of estimating population and mortality rates from catch per unit of effort data obtained from the commercial fishery.

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