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The Life History of the Cabezon Scorpaenichthys marmoratus (Ayres)

By
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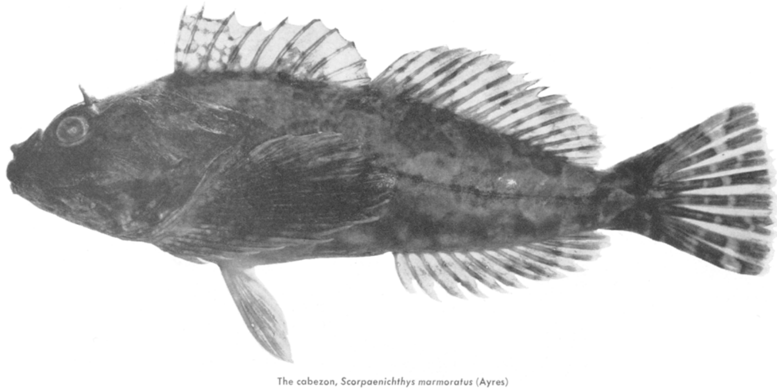

The cabezon, Scorpaenichthys marmoratus (Ayres)

TABLE OF CONTENTS

	Page
Foreword	7
Introduction	9
The Commercial and Sport Catches	9
Materials	23
Range and Habitat	24
Food and Feeding	25
Reproduction	
Introduction	34
Spawning Season	34
The Number of Eggs	41
Larval Development	44
The Length-weight Relationship	51
Age and Growth	
Growth During the First Year	56
Age Determination	58
Growth After the First Year	63
Color	70
Summary	74
References	75

FOREWORD

It is a pleasure to acknowledge here the advice and assistance rendered by a number of persons and organizations during the course of this work. I am especially indebted to Dr. Rolf L. Bolin of the Hopkins Marine Station for his guidance throughout this investigation and the writing of this paper. Mr. Julius B. Phillips of the Marine Fisheries Branch of the California Department of Fish and Game gave many suggestions and helped in locating sources of material. To my colleagues and the staff of the Hopkins Marine Station I wish to express my gratitude for their aid in collecting material and advice on various technical problems. Many thanks to Dr. T. W. Goodwin of The University, Liverpool, England, for his help and advice pertaining to the physiology of color.

I wish to extend my appreciation to the South Pacific Fishery Investigations of the U. S. Fish and Wildlife Service for supplying specimens, and to the Marine Fisheries Branch of the California Department of Fish and Game for purchasing specimens from the wholesale fish markets. The employees of the Liberty Fish Company and the General Fish Company of Monterey cooperated fully in the collection of specimens, and showed much patience with my persistent questions and intrusions.

This paper, in virtually its present form, was submitted in partial fulfillment of the requirements for the degree of Master of Arts at Stanford University in September, 1952.

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June, 1953

1. INTRODUCTION

During the past 15 years the cabezon, Scorpaenichthys marmoratus, the largest of the North American Cottidae and a species of minor economic importance, has gained considerable popularity in the California sport fishery. Its commercial status, however, has changed but little during this time. Jordan and Evermann (1898) remarked that the cabezon is used but not esteemed as a food fish, and, although the commercial landings have increased somewhat, this sentiment still prevails.

The enthusiasm of the sportsman and the apathy of the marketman are easily understood. To the former, the cabezon is a relatively large and quite edible prize. To the latter it is, although large enough, considered inferior in quality to most other market fishes. of course the attitude of the marketman is, in part, a reflection of customer preference, and unfortunately the customer may be repelled by nothing more than the allegedly unattractive appearance of this species.

Nevertheless, the cabezon, already a marketable fish, should be considered a potentially greater food resource. Although not markedly superior in quality, it is at least as palatable as many of the more popular market fishes. As Hubbs and Wick (1951) discovered, its only dietetic defect is the poisonous condition of the roe. Fillets of one and one-half pounds or more can be obtained from an average market specimen, but the species is usually sold in the round. Only one market in Monterey regularly fillets them in quantity for a local truck vendor. None are shipped to other markets from Monterey.

In view of the sixfold increase in sport landings of the cabezon since the end of the war, the drain on the population may conceivably reach proportions capable of diminishing the stock in the foreseeable future.

Should increasing demand for the cabezon eventually elevate it to a position of greater economic importance in the California catch, a knowledge of its biology would be desirable. To this end, the information here presented will facilitate further study of the species and ultimately contribute to its management.

2. THE COMMERCIAL AND SPORT CATCHES

There is no fishery operating exclusively for the cabezon. The bulk of the commercial landings are made by set-line boats directed primarily at certain species of rockfishes (Sebastodes). The commercial catch data compiled by the California Department of Fish and Game since 1916, although a record of the pounds landed, may not be a true indication of the number of cabezon actually caught. The species has little market value, so set-line fishermen sometimes dispose of them at sea to conserve time and space for more valuable fishes. A few fishermen always bring them back; a few others always throw them away; while yet others vary their procedure according to market demand and the availability of other species. Apparently the market situation fluctuates from day to day, as well as from market to market. In general, those boats working for the wholesale shipping companies set their lines beyond depths at which the cabezon normally occurs. The boats attached to wholesale companies that have retail markets on the premises fish in both deep and shallow water. When a large number of cabezon are brought in, the bulk is either sold to other retail markets at a low price, or disposed of slowly over a period of days. Interestingly enough, some of the market operators try to keep a few on display.

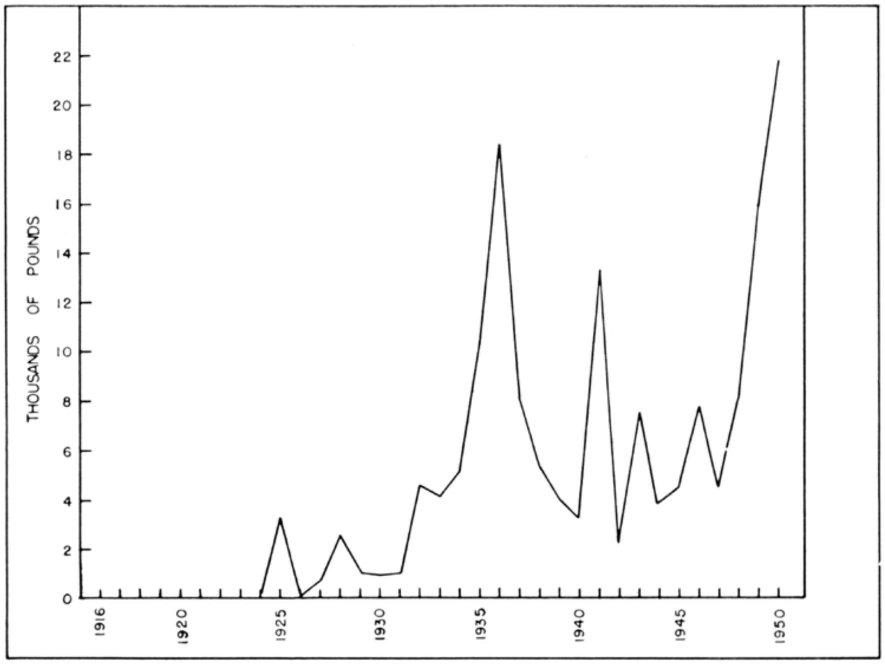

FIGURE 1. Commercial landings of cabezon in California

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The total commercial landings of cabezon in California varies considerably from year to year (Figure 1). The general trend, however, is upwards, and this is probably due more to an increase in the size of fishing fleets than to market demand. After fluctuating at a low level during the 1920's, the catch rose to an unprecedented figure in 1936. The regular decrease during the next four years is unexplainable, but the occurrence of another major peak in 1941 confirms the general trend. In 1942, the first full year of participation in World War II, the catch fell to its lowest point in 10 years, then fluctuated at a low level throughout the war and immediate postwar years, and ultimately rose over a period of three years to an all-time high in 1950. Where and at what time the catch will level off remains to be seen.

Because the commercial landings were available only in pounds and the sport landings only in numbers of fish, it was necessary, in order to compare the two, to estimate the sport catch in pounds. To this end, the lengths and weights of 156 cabezon landed at Monterey during all seasons were analyzed, and the mean weight calculated (Figures 2 and 3). Assuming this sample to be representative of the commercial catch at Monterey, it can readily be seen that the fishery is supported by individuals of moderate length and relatively low weight. Fish having a mean weight of 6.4 pounds, only one-third the weight of the heaviest specimen, are nevertheless worthy of commercial exploitation. Presumably, the sport catch is similar in composition, so the factor 6.4 was used to convert sport catch data to pounds.

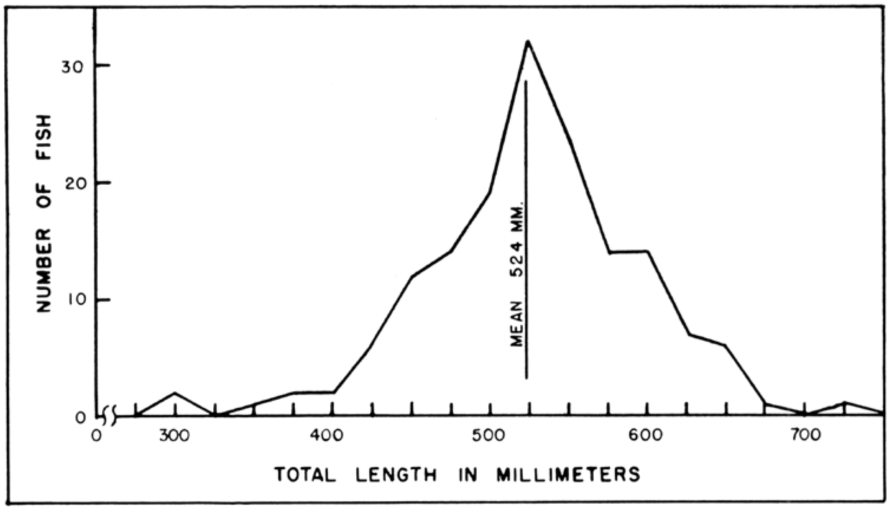

FIGURE 2. Length frequency distribution of cabezon landed at Monterey. Class intervals are 25 mm. and the data are plotted at the high limits.

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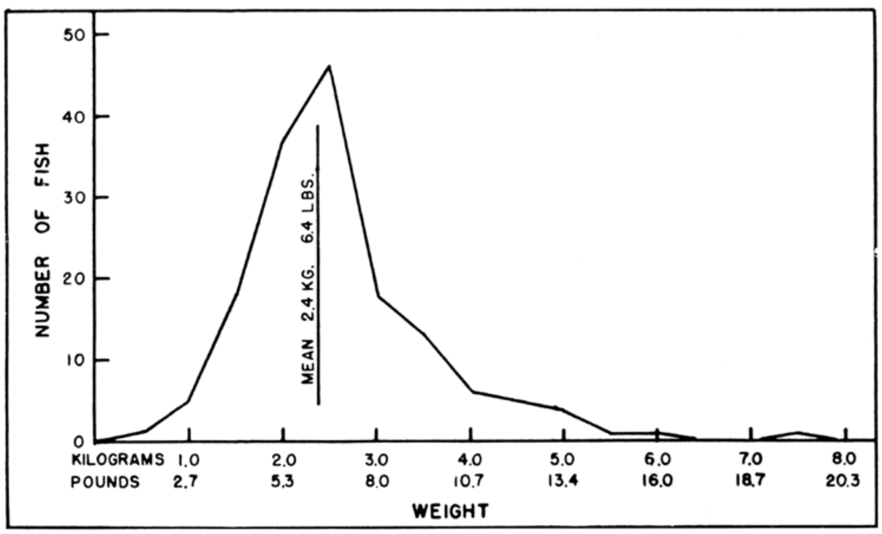

FIGURE 3. Weight frequency distribution of cabezon landed at Monterey. Class intervals of .5 Kg. plotted at the high limits.

FIGURE 3. Weight frequency distribution of cabezon landed at Monterey. Class intervals of .5 Kg. plotted at the high limits

In making various comparisons between the two catches, only the periods 1936–1940 and 1946–1950 are considered. Because of the war, there were no data for the intervening years. The basic data pertaining to the sport catch were compiled by the Department of Fish and Game and are presented in Tables 1 and 2. The numerical designations are

TABLE 1

Cabezon Sport Landings by Region and Year. "Cab" Is the Number of Cabezon; "Ang" Is the Number of Anglers. Data Collected From Mobile Fishing Boats Only.

Year	Region II Eureka		Region IV San Francisco		Region V Monterey		Region VI Santa Barbara		Region VII Los Angeles		Region VIII San Diego	
	cab	ang	cab	ang	cab	ang	cab	ang	cab	ang	cab	ang
1936				1,223	123	14,826	1,150	7,627	961	104,835	55	43,942
1937				1,305	1,200	18,760	731	9,516	492	141,458	102	45,937
1938			21	4,207	1,340	17,670	2,364	8,809	1,106	149,647	58	36,877
1939		263	73	5,614	964	17,412	775	10,982	517	170,830	66	36,548
1940		173	160	6,516	1,599	18,821	989	7,635	503	191,812	27	48,904
1946			8	1,979	2,264	14,306	–	606	535	175,551	17	16,601
1947		16	640	4,800	2,333	32,473	3,686	7,043	1,494	367,109	33	36,110
1948	17	122	845	14,495	3,565	31,892	8,742	21,392	1,888	403,566	107	59,995
1949		60	1,370	25,798	1,398	27,365	8,681	28,956	2,298	381,533	317	51,264
1950		604	2,443	57,486	2,318	24.073	9,895	37,274	1,976	423,890	341	56,237

TABLE 1

Cabezon Sport Landings by Region and Year. "Cab" Is the Number of Cabezon; "Ang" Is the Number of Anglers. Data Collected From Mobile Fishing Boats Only

TABLE 2

Cabezon Sport Landings by Region and Month for the Periods 1936-1940, 1946-1950. "Cab" Is the Number of Cabezon; "Ang" Is the Number of Anglers. Data Collected From Mobile Boats Only.

Month	Region II Eureka		Region IV San Francisco		Region V Monterey		Region VI Santa Barbara		Region VII Los Angeles		Region VIII San Diego	
	cab	ang	cab	ang	cab	ang	cab	ang	cab	ang	cab	ang
										*284		
January			133	133	188	643	1,086	925	52	11,483	17	2,190
February			219	1,087	316	1,688	1,618	2,699	122	16,867	24	3,420
March			130	6,247	852	6,449	1,654	3,381	814	56,733	34	8,694
April		9	333	12,153	1,265	13,682	3,367	6,593	2,083	168,399	163	42,361
May		85	448	10,510	2,410	22,225	3,465	12,315	1,997	336,117	257	72,594
June		286	473	15,145	2,855	30,463	5,152	21,663	1,492	449,285	177	76,374
July		569	1,093	23,424	3,300	52,925	7,994	34,439	1,380	566,161	176	92,199
August	17	289	1,094	23,593	3,364	51,305	6,345	31,077	1,394	502,680	113	85,607
September			839	23,157	1,753	28,029	3,279	17,397	1,024	244,429	82	38,859
October			450	6,477	362	7,925	1,221	6,034	879	97,071	21	6,919
November			310	1,156	252	1,654	1,195	2,442	374	41,956	27	3,067
December			38	341	187	610	637	875	159	18,766	32	3,131

* No month for trips given.

TABLE 2
Cabezon Sport Landings by Region and Month for the Periods 1936–1940, 1946–1950. "Cab" Is the Number of Cabezon; "Ang" Is the Number of Anglers. Data Collected From Mobile Boats Only

those assigned by the department to its statistical regions. These data apply to mobile boats only, and it is worth noting that Collyer (1949) estimates that at least 80 percent of the California sport catch is taken by such boats.

When the sport and commercial catches are compared for the two 5-year periods, some interesting differences become apparent (Figure 4). Before the war the sport catch fluctuated at a somewhat greater level than the commercial catch, but after the war the sport landings became increasingly greater than the commercial landings. Each has reached its greatest peak in 1950, with the sport catch more than five times greater than the commercial catch. The striking gain in sport landings became evident in 1947, while the commercial landings from 1948 through 1950, although showing an annual progressive increase over the low catch of 1947, reach a peak only slightly above that of 1936.

A comparison of the two catches by months (Figure 5) shows that the peak landings of each are made at different seasons of the year. The commercial catch has a broad but clear peak throughout the winter months. Summer landings are only about one-half, and fall landings are less than one-third of the winter landings. The sport catch, on the other hand, rises to an extremely strong peak in July, although it is somewhat lower than the commercial catch during the winter months.

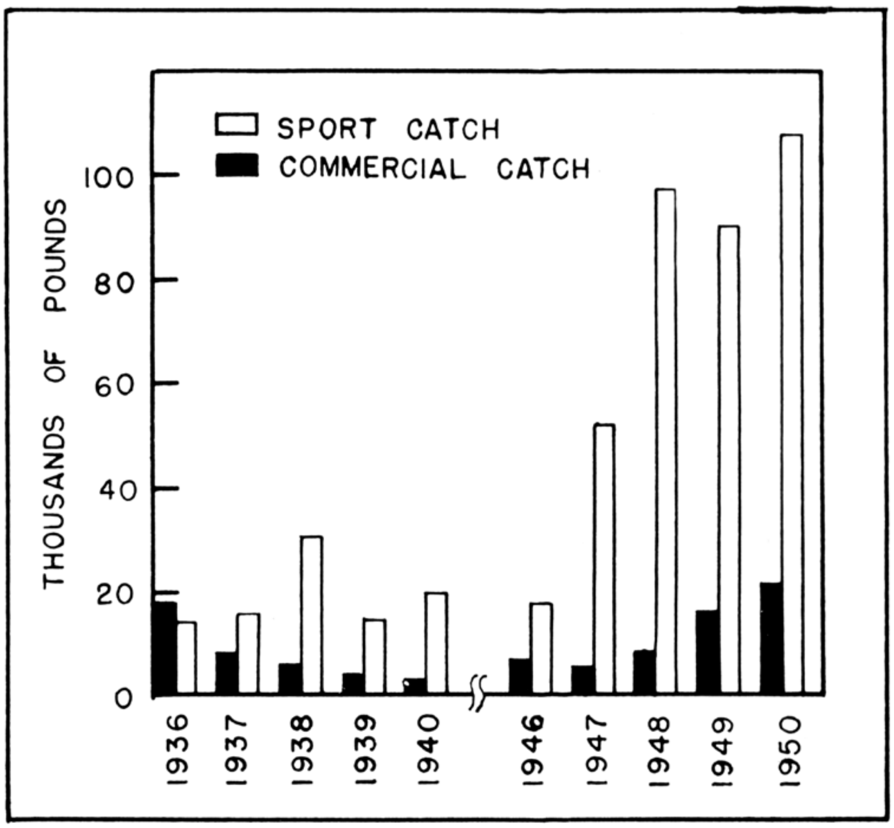

FIGURE 4. Comparison of commercial and sport catches by years

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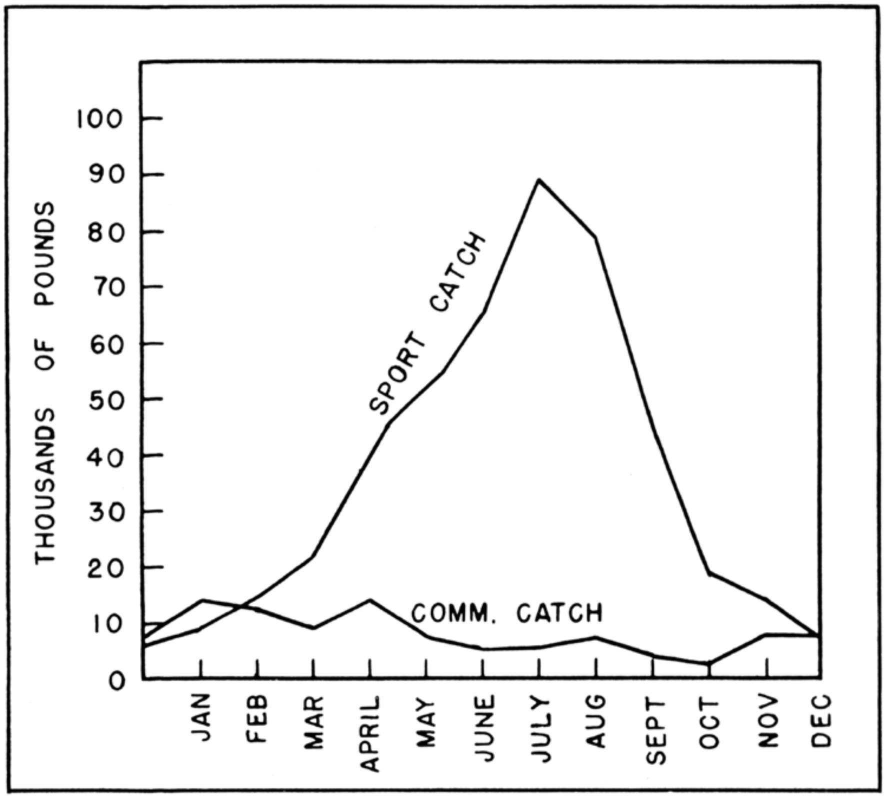

FIGURE 5. The commercial and sport catches compared by months. Catches have been summed for the periods 1936 to 1940 and 1946 to 1950.

FIGURE 5. The commercial and sport catches compared by months. Catches have been summed for the periods 1936 to 1940 and 1946 to 1950

The reasons for this seasonal difference are easily surmised. Undoubtedly the sport catch is greatest during the summer months because this is the season most conducive to angling, and because it is the season to which vacations are commonly relegated. Conversely, the low commercial catch in the summer and fall is probably due to the appearance of salmon and albacore in the coastal waters. Many of the small boats convert from set-lining to trolling in order to pursue these more valuable species. It is also possible that the increased commercial catch in winter reflects a somewhat increased demand for the cabezon at a time when housewives obtain relatively few through sport fishing.

It is noteworthy that the center of the sport fishery and the center of the commercial fishery for cabezon do not coincide geographically. Figure 6 shows the magnitude of the two catches for the periods 1936–40 and 1946–50 in six regions along the California coast. Both are negligible in Eureka, the northernmost region, but the sport catch increases progressively in San Francisco, Monterey and Santa Barbara, while the commercial catch rises at a lower rate through San Francisco and Monterey. Thus the greatest commercial landings are made in Monterey and the greatest sport landings in Santa Barbara. The disparity between the two catches is most marked in the three southern regions. The sport

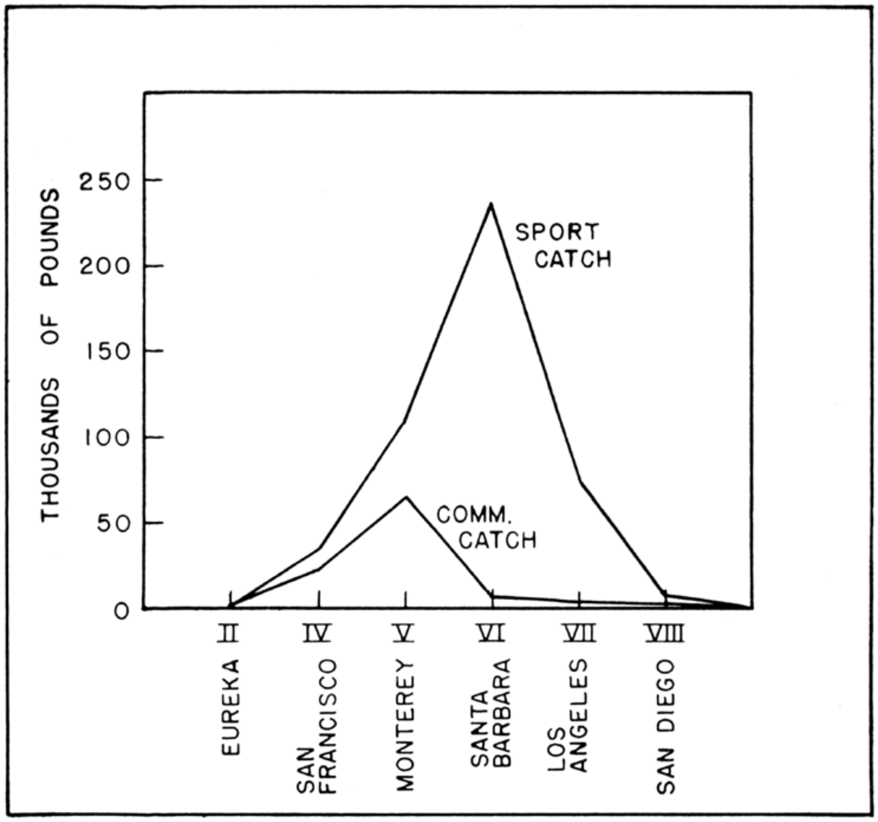

FIGURE 6. The commercial and sport catches compared by regions. Catches have been summed for the periods 1936 to 1940 and 1946 to 1950.

FIGURE 6. The commercial and sport catches compared by regions. Catches have been summed for the periods 1936 to 1940 and 1946 to 1950

catch declines from an extraordinary peak in Santa Barbara, to a moderate figure in Los Angeles and a very low figure in San Diego; whereas the commercial catch, already low in Santa Barbara, declines to negligible proportions in both the southernmost regions.

On the basis of the last three comparisons, it may be stated that the landings for the entire state have increased tremendously in recent years, and that the largest proportion of cabezon are caught by sport fishermen during the summer months at Santa Barbara. The increase in recent years can be attributed to an increase in ocean angling, which has risen from 172,000 man-days (a man-day represents one cruise by one individual) in 1936 to 599,000 man-days in 1950. The greater magnitude of the summer landings, as already explained, is probably due to increased angling during this part of the year. However, the variation in landings along the coast is not so simply accounted for. To understand this, it is necessary to consider the coastwise distribution of fishing effort. Once the relationship between effort and the numbers of fish landed has been ascertained, the influence of other factors, as they bear on this relationship, may be more clearly understood.

It is evident, from Figure 7, that there was much more sport fishing after the war than during the 1936–40 period. Los Angeles, obviously

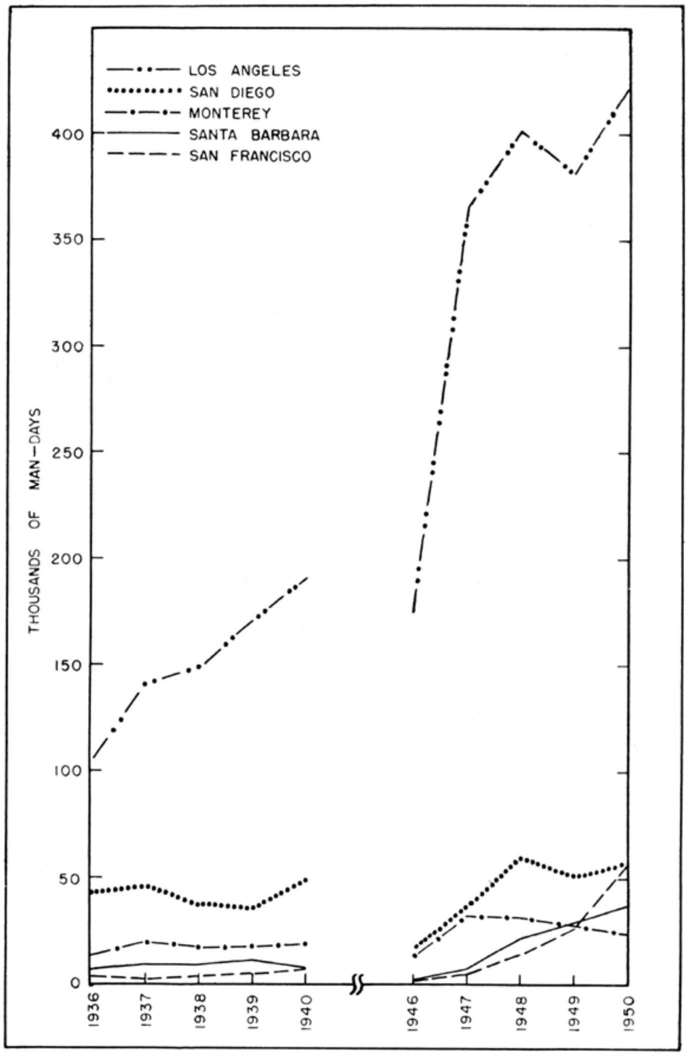

FIGURE 7. The sport-fishing effort in five regions along the California Coast

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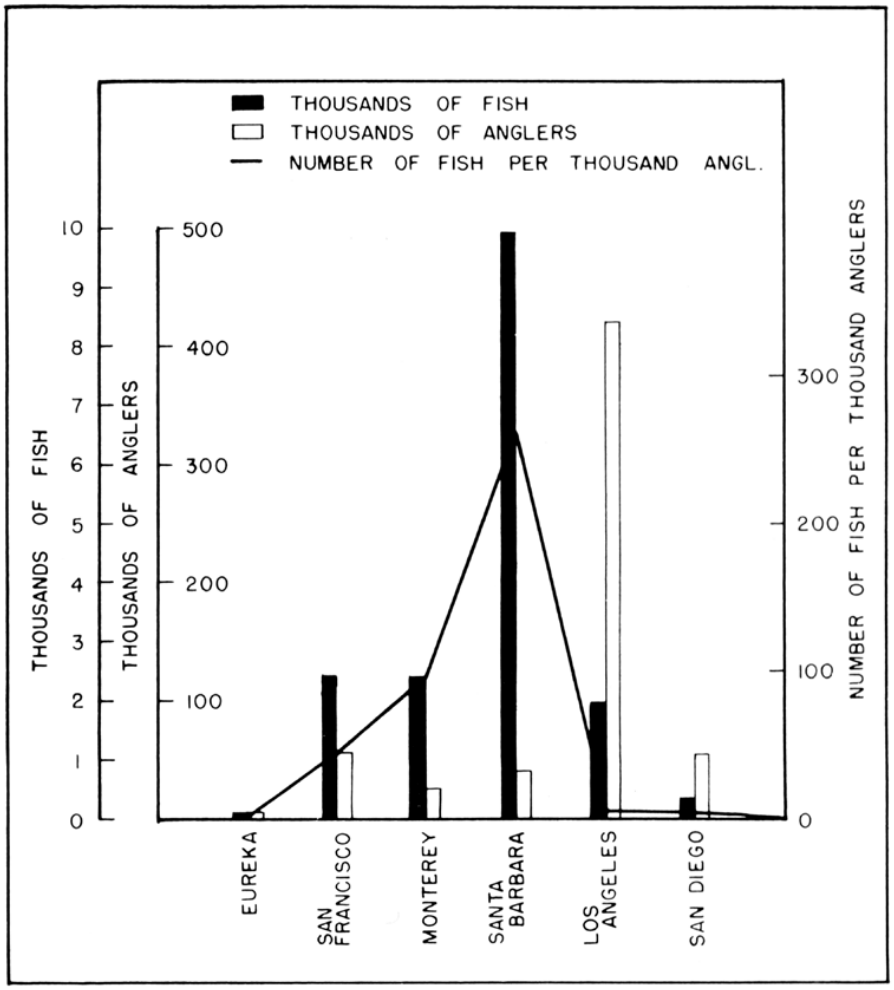

FIGURE 8. The sport catch of cabezon per unit effort for all regions in 1950

FIGURE 8. The sport catch of cabezon per unit effort for all regions in 1950

the center of sport-fishing activity, was the only region in which fishing effort was increasing at a rather high rate before the war. In all other regions it was relatively low and constant. Eureka is not shown on the graph because the fishing effort did not exceed 1,000 man-days in any year during the entire period.

Following the war, sport fishing increased in all regions. Los Angeles became even more outstanding as the center of activity, but the trends in the other four regions warrant more careful examination. Monterey and San Diego leveled off after 1948. San Francisco and Santa Barbara have continued to gain, and may very well continue to do so beyond 1950. San Francisco has shown the most phenomenal postwar change, having risen from 1,900 man-days in 1946 to 57,000 man-days in 1950. This puts it on a par with San Diego for the first time.

At Santa Barbara, where the greatest cabezon landings occur, the fishing effort is relatively low. In 1950 it exceeded only that of Monterey, although it had been increasing steadily since 1946. Throughout the earlier years, the fishing effort was less at Santa Barbara than at all other ports except San Francisco.

The meaning of this becomes clearer when the catch per unit effort, taken as the number of cabezon landed per thousand anglers (man-days), is superimposed on the total number of fish landed and the total number of anglers. This is shown in Figure 8 for all regions in 1950. The pattern, varying only in magnitude, is typical of all years. Here it can be seen that Los Angeles, the center of sport fishing, has many anglers catching

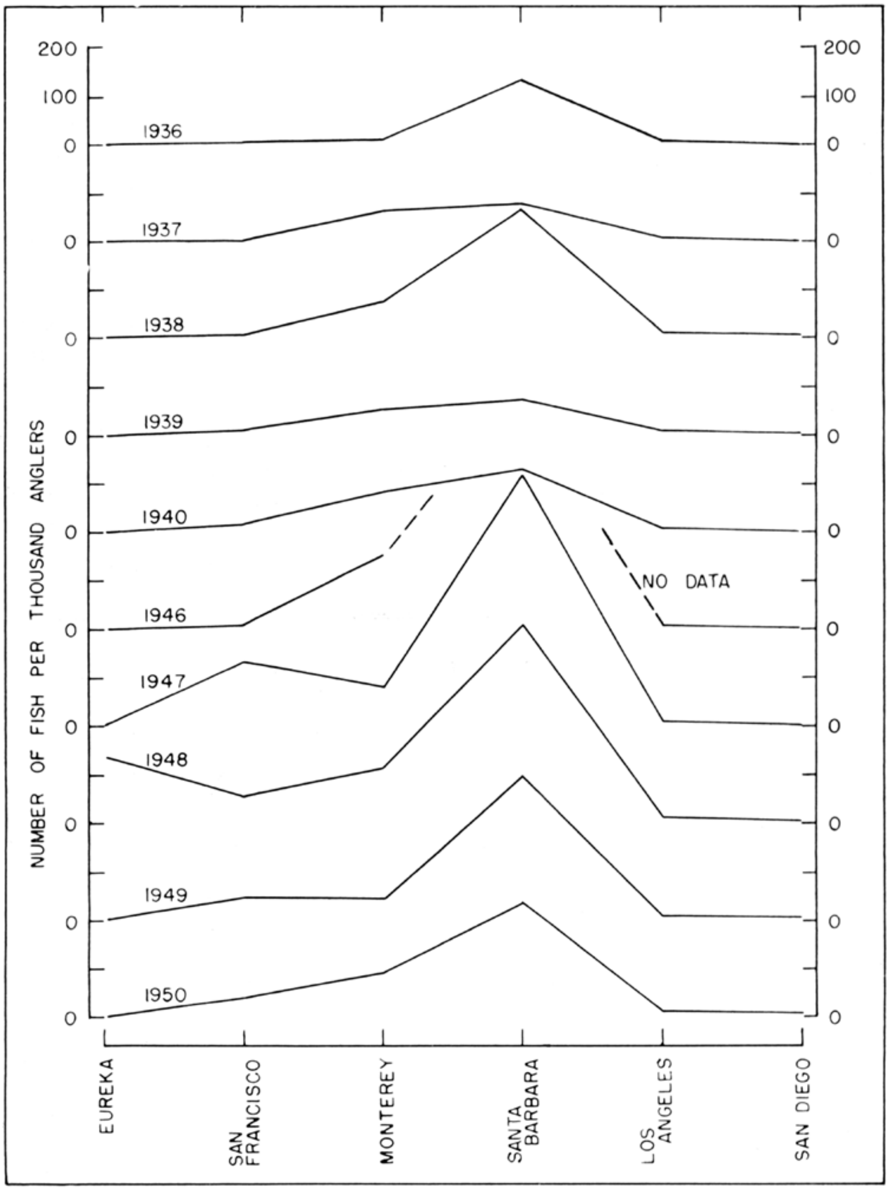

FIGURE 9. The sport catch of cabezon per unit effort by year and region

FIGURE 9. The sport catch of cabezon per unit effort by year and region

few cabezon, while Santa Barbara, the center of cabezon sport landings, has few anglers catching many cabezon. The catch per unit effort in San Diego is also very low, even though there is relatively little angling at this port. To the north of Santa Barbara, the catch per unit effort declines gradually with correspondingly low angling.

Similar plots made for each year (Figure 9) show very low and constant catches per unit effort for the two southern regions, as opposed to somewhat higher and more variable figures for Monterey and San Francisco. Santa Barbara is the only port at which there is a consistent change in the catch per unit effort. It fluctuated considerably before the war, when fishing effort was low, but immediately after the war it rose to a new high. There were 520 cabezon caught per thousand anglers in 1947, and only 130 per thousand caught in 1940. The difference cannot be explained by a change in the number of anglers, for it was almost the same in both years. The steady decline in catch per unit effort after 1947, however, is inversely related to the increase in angling. In 1950 the catch per unit effort had fallen to 238 per thousand, a figure exceeded in only one of the five pre-war years. When one realizes that in 1947 and the preceding years the numbers of anglers did not vary appreciably from 8,000 or 9,000, whereas in 1950 it was more than 37,000, the increased exploitation of the population cannot be doubted.

The inconsistency of the relationship between cabezon landings and fishing effort along the coast implies that there are other factors to be considered. All such factors can be classified as either (1) availability of the species, or (2) type of fishing.

Availability of this species is probably influenced more by the nature of the coastline than anything else. Cabezon occur on hard bottoms in shallow coastal waters, and it is well known that Point Conception marks a change from the rocky coastline of the north to the sandy beaches of

TABLE 3

Ports	Number of boats reporting (1947)	Species of fish most commonly taken	Types of fishing
Eureka	1	Salmon	Trolling for salmon
San Francisco, Bodega Bay, Princeton	52	Salmon, rockfish, lingcod, cabezon	Trolling for salmon, bottom fishing with cut bait
Monterey, Santa Cruz, Capitola	19	Rockfish, lingcod, cabezon, salmon	Bottom fishing with cut bait or with jigs
Morro Bay, San Simeon, Avila	13	Rockfish, lingcod, cabezon	Bottom fishing with cut bait or with jigs
Santa Monica Bay to San Clemente	174	Barracuda, kelp bass, California halibut, albacore, white sea bass, Pacific mackerel, yellowtail	Live bait used to take all species, some trolling for barracuda, albacore and marlin
San Diego	27	Same as above, except yellowtail most prized	Same types of fishing as in Los Angeles region

TABLE 3

the south. of course there are rocky areas south of Point Conception, and there is no doubt that populations are sparsely distributed along this part of the coast.

The type of fishing also differs north and south of Point Conception. A suggestion of this is contained in Table 3 (Collyer 1949), where number of boats, species most often taken, and type of fishing are enumerated for several areas. Unfortunately the Santa Barbara region is not included, but it can be seen that bottom fishing with cut bait is prevalent to the north, while there is more emphasis on trolling with live bait to the south. The reason for this difference is best summarized by Walford (1937): "Anglers can troll more or less successfully almost anywhere along the Pacific Coast of the Americas. From Point Conception (California) northward, however, the number of kinds of marine game fishes is rather limited and cannot be compared with the variety found to the south, where such fishes as marlin, swordfish, and tuna occur."

Thus it is quite probable that the cabezon catch in the southern part of the State remains low for two reasons: The population is sparse; and sportsmen prefer trolling to bottom fishing.

The fact that the catch per unit effort is greater at Santa Barbara than at other ports is probably due to the greater expanse of shallow water just south of Point Conception than elsewhere along the coast. The continental shelf broadens considerably in this region, and, with the coastlines of the channel islands added to that of the mainland, provides a wide habitat for Scorpaenichthys (Figure 26). It is also probable, because there is such an expanse of shallow water, that the sport fishing boats out of Santa Barbara spend relatively more time fishing in shallow water than do boats out of other ports along the coast.

The production potential of the population can be inferred from the relationship between yield and effort (sport fishing). In Figure 10 yield is plotted against effort at five ports for each of the 10 years being considered. The relationship is one of consistent increase in each port, indicating that the stock has responded to increases in sport fishing effort all along the coast. At Santa Barbara the catch per unit effort has decreased since 1947, but the yield has continued to increase. Since there is no way of knowing at what fishing intensity the yield will level off, I can only state that, in my opinion, the stock at Santa Barbara will support a further increase in fishing effort. If and when the yield does level off, there will be sufficient cause to investigate the possibility of depletion.

The variations apparent in the relationship of yield to effort are due in part to fluctuating year-class strength and availability, and in part to the kind of fishing. As already shown, the fishing differs in magnitude and kind between ports, making yields uncomparable along the coast. Furthermore, a good part of the variation at any one port may be due to variation in the kind of fishing in different years, a factor which cannot be evaluated from the available data.

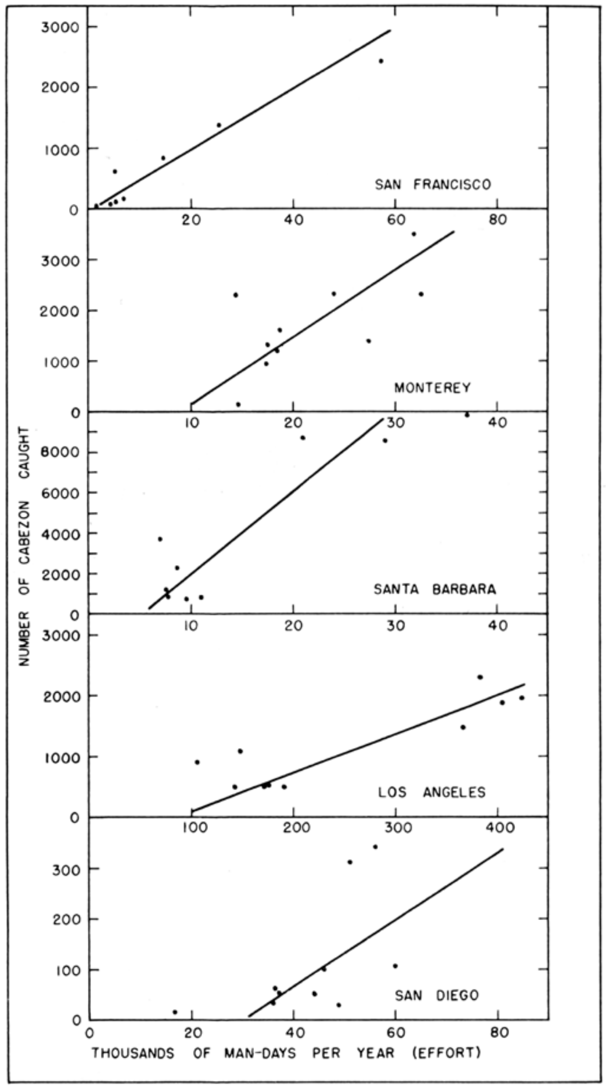

FIGURE 10. Yield of cabezon in the California sport fishery for the periods 1936 to 1940 and 1946 to 1950

FIGURE 10. Yield of cabezon in the California sport fishery for the periods 1936 to 1940 and 1946 to 1950

3. MATERIALS

Specimens used in this study were obtained from several different sources. By far the greatest number, ranging from 290 to 720 mm. in total length, were purchased by the California Department of Fish and Game from the Monterey fish markets. With the exception of September and October, 1950, specimens were obtained from this source during each month between July, 1950, and July, 1951. Since the catch at Monterey, incidental in the set-line fishery, was small and erratic, it was impossible to devise a valid random sampling technique. In an attempt to obtain material at regular intervals, I resorted to set-line fishing, but this was soon abandoned because too much time was consumed in catching relatively few cabezon. A very few specimens were purchased from a Santa Cruz market or obtained from sportsmen.

Eight dip-net collections from tide pools poisoned with rotenone accounted for most of the juveniles and some of the young adults ranging from 61 to 488 mm. in total length. These collections were not as successful as had been hoped, since Scorpaenichthys was usually present in very limited numbers and was entirely absent from two of the samples.

Additional material, numbering between 200 and 300 specimens, was examined and measured at the Stanford Natural History Museum and the California Academy of Sciences.

The pelagic larvae, between 4.44 and 9.69 mm. in length, were sorted out of the weekly plankton-net tows made by the Hopkins Marine Station research vessel TAGE, in and directly outside of Monterey Bay.

The absence of regular samples of juveniles and adults, and the time limitation of one year precluded a study of population composition and dynamics. The data necessary for such a study can only be compiled through an extended program of tagging and coastwise sampling. Without this knowledge, it is impossible to know whether specimens obtained from one area are representative of one or more static subpopulations, or whether they are representative of the species over its entire range. The information in this paper, therefore, must be accepted as applying only to the coastal area of Central California.

All length measurements are given as total length. In this species, which is characterized by heavy caudal rays embedded to their tips in a tough membrane, the total length can be measured much more easily and accurately than the standard length, particularly in the field, and the utilization of the latter measurement would have served no special purpose in this particular study. However, since other studies on this or related forms may use standard length, the relationship of the two values is presented in Figure 11, so that comparisons may more readily be made. Standard length is 82.5 percent of total length over the whole length range.

Ovaries, stomachs and otoliths were removed from each specimen over 60 mm. long, the first two preserved in 4 percent formalin and the last stored dry prior to examination. Color notes were also taken for each individual.

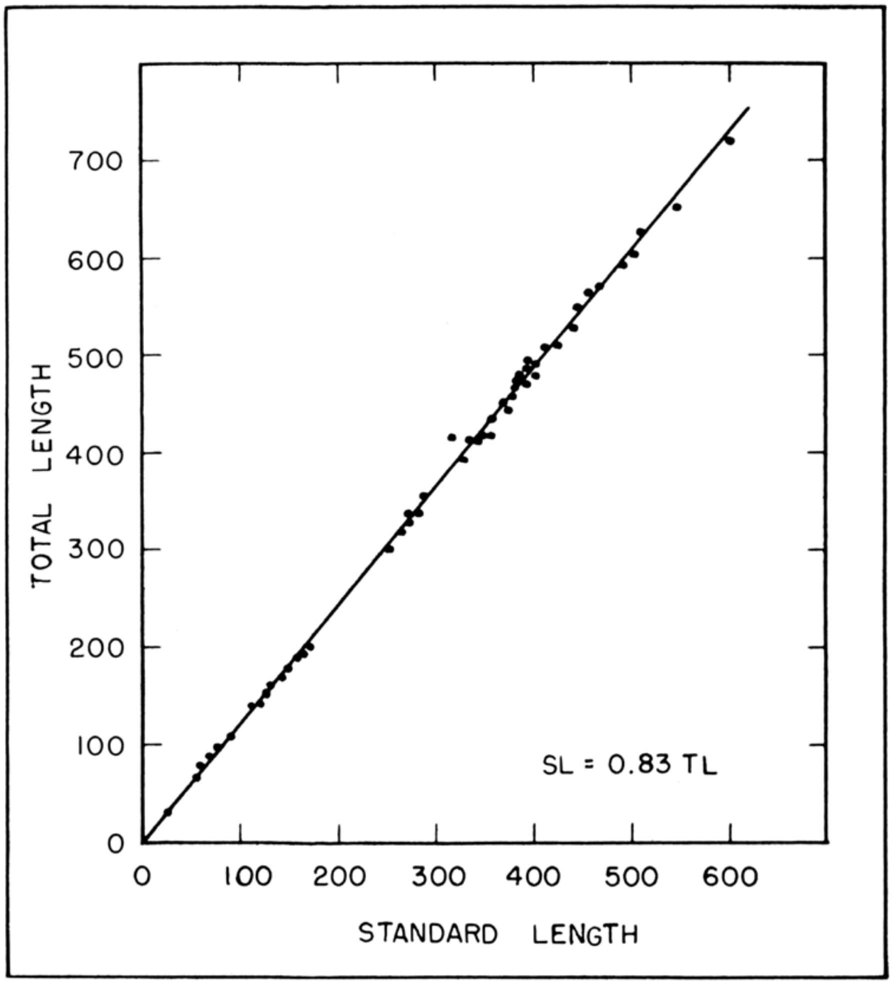

FIGURE 11. The relationship of total length to standard length for *Scorpaenichthys*

FIGURE 11. The relationship of total length to standard length for Scorpaenichthys

4. RANGE AND HABITAT

All members of the family Cottidae are demersal in habit, most occurring in coastal waters. Scorpaenichthys marmoratus has hitherto been reported along the west coast of North America from the Queen Charlotte Islands, British Columbia, to Central Baja California. The northern limit was reported by Clemens and Wilby (1949). Roedel (1953) gives the southern limit as Turtle Bay, Baja California. This record is based on a single small specimen, now in the collection of the University of California, Los Angeles, collected by John Fitch and Murray Newman, November 20, 1952.

Within the habitat, the niche occupied depends upon the stage of development. Newly hatched larvae are found in the plankton from November to March. They occupy the more superficial water layers and collections made by the research vessels of the Scripps Institution of

Oceanography show that, although they are most common in inshore waters, specimens may be found as far as 200 miles from the coast.

Upon reaching a length of approximately 40 mm., the young Scorpaenichthys take up a demersal mode of existence. Dr. Robert R. Harry, in his unpublished four-year survey of the Moss Beach reefs, found no individuals under 40 mm. in the tide pools. They first appeared in March. The smallest cabezon which I have taken in the tide pools was a 61 mm. specimen collected at Pacific Grove on May 22, 1951. Since collections were not made between early January and this time, the initial entry of the species into this niche was undoubtedly missed. In March, 1952, Mr. Robert W. Morris collected individuals between 40 and 50 mm. long under a light at the Municipal Wharf in Monterey. Whether these were demersal or pelagic is difficult to say; probably they were in transition. On June 10, 1949, one cabezon, 47 mm. in length, was pumped into the bait tanks of the California Department of Fish and Game research vessel N. B. SCOFIELD three miles off the coast at Eureka, California. This implies that there is some variation in the size at which the juveniles move into the tide pools—or more correctly, to the bottom. No doubt the primary urge is to reach the bottom in rather shallow water, the sudden infestation of the tide pools being but a secondary manifestation.

The largest individual in my tide pool collections was 488 mm. long. of 53 specimens obtained from tide pools, only 15 were more than 300 mm. in length. Sport fishermen casting from the coastal rocks, however, often catch larger cabezon. According to Harry, it appears that the adults move in to feed at high tide and move out again as the tide recedes. His extensive, methodical collecting also suggests that individuals prefer deeper water as they grow larger. Such a behavior pattern is common to many species and would be consistent with the occurrence of small and intermediate, but not large individuals in the tide pools.

The Monterey and Santa Cruz set-line fishermen say they do not catch the cabezon at depths beyond 30 or 40 fathoms. Since much of their fishing is done at greater depths, it may be surmised that the lower bathymetric limit lies within the 50-fathom curve, and that the species occupies a narrow strip of coastal water. Furthermore, it is a matter of common knowledge that the species is found only in association with hard bottoms. Sport and commercial fishermen do not catch them where there is sand or mud. This, of course, suggests that the distribution may be somewhat restricted within the coastal range; expanses of sand or mud may be effective in isolating subpopulations from each other.

5. FOOD AND FEEDING

For analytical purposes in the study of feeding habits, the cabezon were separated into four length groups. They are (1) the pelagic larvae between 10 and 40 mm. in length, (2) juveniles between 41 and 200 mm. in length, (3) preadults between 201 and 400 mm. in length, and (4) adults 401 to 720 mm. in length. Except for the pelagic larvae, divisions are quite arbitrary, although they approximate the stages of development by which they have been named.

The stomach contents of the pelagic larvae were difficult to identify. All available specimens had been in formalin for months and the

TABLE 4

The Weight-percentage Distribution of Major Groups of Food Organisms by Season for Three Size Groups of Scorpaenichthys. All Figures in the Table Proper Are Percentages Calculated Separately for Each Horizontal Array.

Group	Crustacea	Mollusca	Fish	Annelida	Eggs	Debris	Av. Stom. Wt. / Av. Fish Wt.	No. of Spec.	
Juveniles	40.0	----	60.0	----	----	----	5.3	1	Fall*
Preadults	----	----	----	----	----	----	------		
Adults	86.2	4.2	----	----	----	9.4	3.4	3	
Juveniles	41.9	----	59.1	----	----	----	3.3	14	Winter
Preadults	98.0	----	----	----	----	2.0	2.1	2	
Adults	40.8	12.0	41.3	1.0	3.5	1.6	3.3	36	
Juveniles	70.0	----	30.0	----	----	----	3.0	19	Spring
Preadults	81.1	11.7	----	----	----	7.2	2.6	6	
Adults	43.8	30.2	25.8	----	----	1.0	3.6	18	
Juveniles	----	----	----	----	----	----	------	1	Summer
Preadults	100.0	----	----	----	----	----	2.5	3	
Adults	78.3	9.8	1.5	----	8.2	2.1	2.8	35	
Juveniles	46.4	----	53.6	----	----	----	3.3	35	Total
Preadults	91.6	5.1	----	----	----	3.3	2.5	11	
Adults	51.8	16.7	26.2	1.0	3.4	1.5	3.2	92	

* **Fall** (September-November); **Winter** (December-February); **Spring** (March-May); **Summer** (June-August).

TABLE 4
The Weight-percentage Distribution of Major Groups of Food Organisms by Season for Three Size Groups of Scorpaenichthys. All Figures in the Table Proper Are Percentages Calculated Separately for Each Horizontal Array

stomachs, when opened, each contained a hard amorphous ball of matter. In a number of these stomachs, however, copepods could be identified; thus crustaceans are an important food item from a very early age.

The data presented for the other three groups were obtained from stomach contents removed from 138 specimens and preserved in 4 percent formalin. The contents of each stomach were separated to species or the lowest systematic category possible, after which the weight and the number of specimens in each group were recorded. These data were augmented by occasional notations concerning size and condition of organisms in the stomachs.

The composition of the diet can be most conveniently discussed in terms of weight percentage and frequency of occurrence of particular organisms or groups of organisms. For this purpose the total weight of each class of food is given as a percentage of the total weight of food taken from all stomachs. This was calculated for each of the three size groups of Scorpaenichthys during each quarter of the year (Table 4). It is only in the adults, which are represented by the largest samples, that there is any clear indication of a seasonal change in diet. In this group, the percentage of Crustacea is somewhat higher in the summer and fall than in the winter and spring. Conversely, the percentage of molluscs and fishes are higher in winter and spring than in summer and fall. Because of the comparatively small size of the samples, these may be largely chance differences, so it seemed best to sum the data over the entire year for further analysis. To facilitate interpretation, weight percentages given at the bottom of the table for the year are presented graphically in Figure 12.

To the right of Table 4, the average weight of food is given as a percentage of the average weight of the fish in each category. The resulting figures merely indicate that food accounts for approximately 3 percent of the total weight throughout the year, and throughout the life of the fish.

While the weight percentages indicate the relative importance of the major categories of food organisms in the diet of Scorpaenichthys, the frequency distributions given in Table 5 are better indicators of the availability of the various groups. The frequencies were obtained by counting the number of stomachs in which each of the major groups of organisms occurred.

TABLE 5

The Number of Stomachs in Which Various Classes of Food Organisms Were Represented. Percentages Are Included for Each Column to Facilitate Comparisons

No. of Specimens	Juveniles 35		Preadults 11		Adults 92	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Crustacea	30	75.0	8	72.7	70	59.8
Mollusca	----	----	2	18.2	32	27.4
Fish	10	25.0	1	9.1	10	8.5
Annelida	----	----	----	----	1	0.9
Egg Mass	----	----	----	----	4	3.4

TABLE 5

The Number of Stomachs in Which Various Classes of Food Organisms Were Represented. Percentages Are Included for Each Column to Facilitate Comparisons

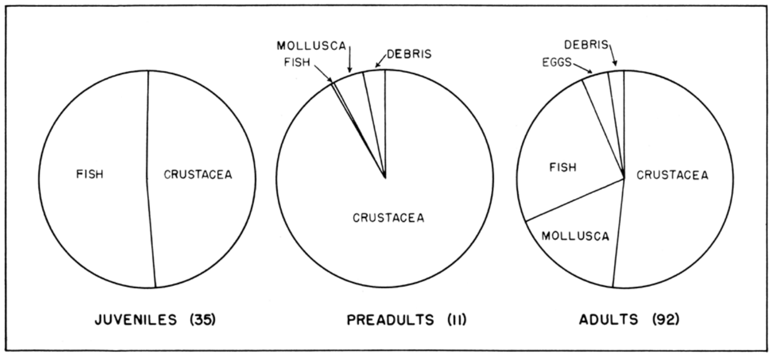

FIGURE 12. The weight-percentage distribution of major groups of food organisms for three size groups of *Scorpaenichthys*

FIGURE 12. The weight-percentage distribution of major groups of food organisms for three size groups of Scorpaenichthys

As soon as the young cabezon assumes a demersal existence, the Crustacea become the major item of its diet. Amphipods were predominant in the stomachs of two 40 to 50 mm. individuals examined, but occurred in only one of the 60 to 90 mm. specimens, where the dominant organisms were small shrimps (Spirontocaris and related forms). Each of the 19 juveniles within this size range had one to three shrimps in its stomach, and in only three of them were other organisms found. At about 140 mm. Scorpaenichthys begins to eat crabs, which become the most conspicuous crustacean item in the diet from this time on. In the juveniles most of the crabs were species of the genus Cancer measuring between one and four centimeters across the carapace. The succession of food types—copepods, amphipods, shrimps, crabs—signifies the ability of Scorpaenichthys to attack larger and more heavily armed organisms as it grows older, and also shows increasing predation on demersal forms.

Fish first appear in the stomachs of 150 to 200 mm. juveniles. All are common tide-pool forms one to three inches in length. Although they occur in fewer stomachs than Crustacea, the fishes constitute about one-half of the diet by weight (Figure 12).

Molluscs, quite important in the adult diet, were not found in the stomachs of juveniles. There can be little doubt that the younger fish have not yet attained the strength necessary to dislodge even the smallest of the tenacious gastropods.

Little can be determined from the inadequate preadult sample. It contained only 11 individuals, and these, furthermore, were all over 290 mm. in length. The appearance of molluscs, one small limpet and one small abalone, however, is indicative of the fact that the cabezon must reach a length of approximately 300 mm. before it possesses the strength necessary to remove these gastropods from the rocks.

The high weight percentage of Crustacea in the preadult stomachs is probably a chance deviation in this small sample. The distortion is due to the lack of fish, which, it might be added, cannot be taken as indicative of avoidance. Sparse skeletel remains of a fish were found in one stomach, and this has been indicated in Figure 12, although no weight was taken.

Both weight percentage and frequency of occurrence are probably quite representative for the adult sample, which contained 92 specimens. Here the Crustacea are somewhat more prominent by weight percentage (Figure 12) than in the juvenile sample. Assuming that the preadult sample is distorted, it may be reasonably stated that Crustacea constitute about one-half of the diet of Scorpaenichthys throughout its demersal existence.

Fishes have become less prominent in the adult diet, being only 26 percent as compared to 53 percent in the juvenile diet. The difference in frequency of occurrence is even more marked, as Table 5 shows. The decreased importance of fish probably reflects a shift to deeper foraging grounds where small demersal fishes are less available.

Molluscs partly replace fish in the adult stomachs. They represent 17 percent of the weight, whereas they were entirely absent from juveniles and contributed only 5 percent to the preadult diet. Although they occupy a smaller part of the diet by weight, they are more heavily preyed

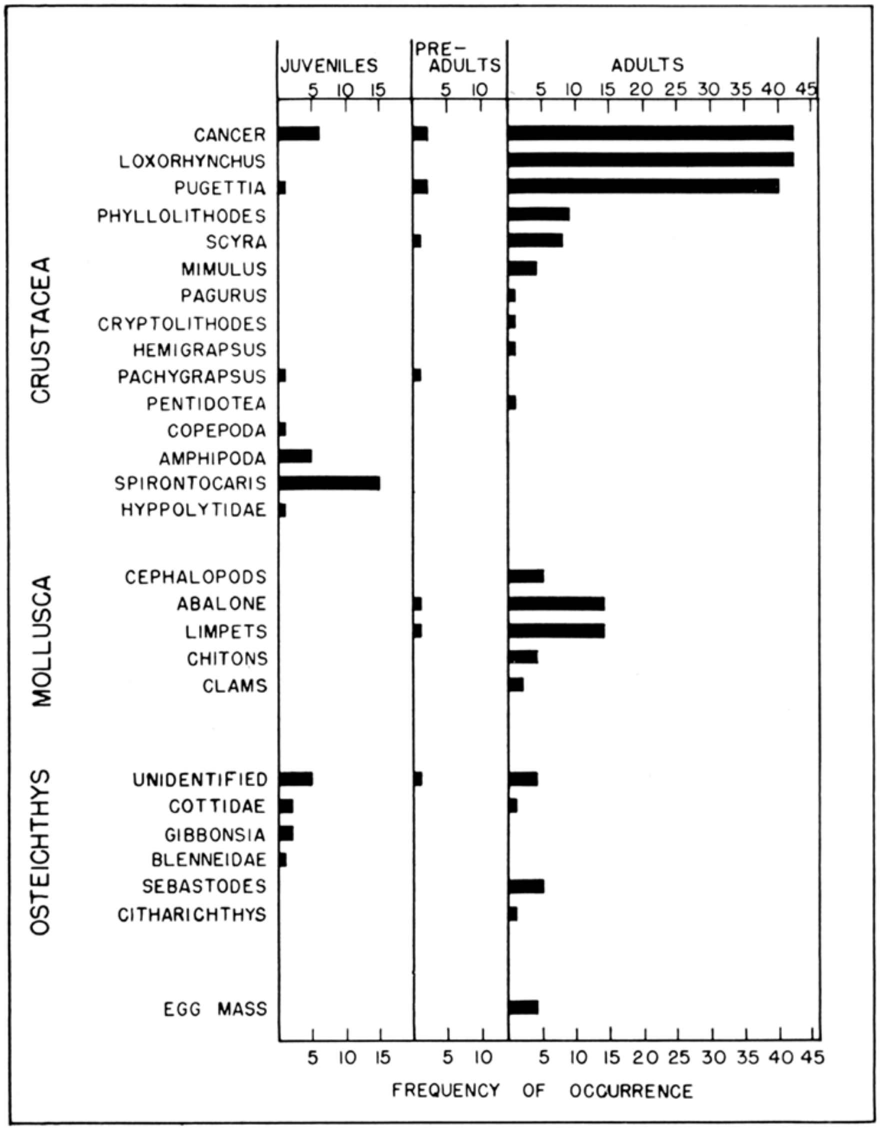

FIGURE 13. The frequencies of occurrence of various genera and other groups in the stomachs of *Scorpaenichthys*. The bars indicate the number of stomachs in which the groups were represented.

FIGURE 13. The frequencies of occurrence of various genera and other groups in the stomachs of Scorpaenichthys. The bars indicate the number of stomachs in which the groups were represented

upon than the fishes, as shown by the greater number of stomachs in which they occurred (Table 5). Whereas Crustacea remain a constant proportion and fishes decrease in importance, it is apparent that molluscs become a more important food item as Scorpaenichthys grows older.

Thus far, the description of food and feeding habits has been general, sufficing to establish the composition of the diet and the manner in which it changes with age. A more complete account of the feeding habits can be obtained by considering the relative importance of certain individual food items. Frequencies of occurrence of various genera and other pertinent groups are shown in Figure 13. The Crustacea are the most prominent and also the most diversified of the three major groups, and will therefore be considered first.

Crabs are the most important item in the diet. Walking on the bottom, they are certainly more available than the tenacious limpets and abalones, or the faster-moving, more elusive fishes. They are, furthermore, probably desirable for their considerable bulk. Certain of the crab genera are preyed upon more heavily than others, and again this is largely a matter of availability.

The genus Cancer becomes prominent earlier than any of the others and remains outstanding throughout the life of Scorpaenichthys. Young cabezon, of course, are restricted to the smaller Cancer specimens, but adults, although they customarily attack crabs four to seven inches wide, also devour the young specimens. Apparently they are as satisfied to eat a quantity of small individuals as one or two large ones. Four adults were found with stomachs containing between 20 and 30 crabs one inch or less in width.

In the entire sample, only one specimen was identified as C. magister, the commercially important member of the genus. This is not surprising, since this species is known to live on sand while others of the genus live on rocky bottoms.

Loxorhynchus, Pugettia and Phyllolithodes are the next three most important genera. All are common inhabitants of the subtidal region, but only Pugettia is common in the tide pools, where specimens are easily collected by man. This is reflected by the occurrence of Pugettia in the stomachs of juveniles and preadults as well as adults.

Pagurus, Cryptolithodes and the grapsoids occur infrequently. The hermit crabs (Pagurus), although common enough, are probably not desirable because of the small proportion of their bodies relative to the heavy, indigestible shells most of them inhabit. Cryptolithodes, on the other hand, is rare around Pacific Grove and not known south of that point. It is also characterized by a heavy, expanded carapace which would probably render it undesirable. The grapsoids, of course, inhabit the higher tide levels, and must be rather inaccessible to Scorpaenichthys. this is particularly true of Pachygrapsus crassipes, the common shore crab, which occurred in one juvenile and one preadult stomach; another indication that the younger fish forage in shallower waters.

It is difficult to understand how the cabezon can successfully attack such well armed animals as the crabs, particularly the Cancers with their large, powerful chelae. In some way the predator must quickly immobilize the crabs, yet there is no evidence of dismemberment. Almost all were taken from the stomachs with all appendages neatly folded against their bodies.

of equal interest is the fact that the crab is entirely sheathed in a hard, chitinous exoskeleton, which apparently retards the digestion of the organism in the stomach. Almost all crabs taken from stomachs were in one piece, but the exoskeletons of many were so delicate that they could easily be punctured with the finger. Appendages would usually fall off at the lightest touch. In a few stomachs, however, the remains of decapods were so well digested that it was difficult to recognize them as such. The inference is that the exoskeleton must be destroyed rather slowly, after which the organism falls apart to be digested rapidly.

Molluscan food consisted almost entirely of abalone, limpets and chitons. Occasional small, spiralled gastropods were found, but were probably taken incidentally. In general, the cabezon seems to select large forms with a lot of meat in relation to the shell. How these notoriously strong holders are removed from the rocks is puzzling. If they are knocked off, the element of surprise must be important; it is difficult to imagine that they can be pried loose with deliberation.

of the abalones, Haliotis corrugata and H. wallalensis were the only two species found in 15 stomachs (Figure 13). The absence of H. rufescens and H. cracherodi seemed curious, since these are the two most common species of abalone in the Monterey region. The black abalone (H. cracherodi) does live somewhat higher in the intertidal zone than the others, and is often found in crevices (Rickets and Calvin 1939; Bonnot 1948). Although these two factors would tend to protect the species from the adult cabezon, it is difficult to imagine that they would render it entirely inaccessible. The literature contains nothing that might explain the absence of the red abalone, but whatever the reason, Scorpaenichthys does not seem to prey upon this one commercially important species of the region.

The occurrence of two pelecypods is again indicative of the opportunistic feeding habits of Scorpaenichthys. For the most part they are found on sandy bottoms, and therefore imply occasional deviation from the usual foraging on rocky bottoms. One of the two specimens mentioned above was small and intact, but the other displayed two interesting features. It weighed 166 grams, almost five times the weight of any other mollusc found, and, although the animal appeared to be in good condition, neither of its valves was present in the stomach. The only alternatives are that the fish was fortunate enough to find this morsel already shucked, or, less likely, was somehow able to remove the valves before swallowing it.

With the utilization of these large molluscs there arises the question of how hard parts taken into the stomach are disposed of. It must be accomplished either by digestion or regurgitation. Figure 14 is a photograph of the shells from all the abalone collected. The smaller shells are somewhat fragmented, while the larger ones are all intact. In two cases, isolated shell fragments were recovered, but in all others the bodies were housed in the shells. The two fragments and apparent thinning of the smaller shells are indicative of digestion, but the paucity of fragments or empty shells strongly suggests regurgitation, as it is not likely that the shells could be digested as rapidly as the exposed body tissues. Unfortunately regurgitation could not be demonstrated.

Shell-less molluscs were found in five stomachs. The two octopods were taken at different times of the year, but squid occurred in stomachs of three fish from the same boat catch in February. Fields (1950) states that spawning of Loligo opalescens has been observed during every month of the year, although maximum spawning occurs from April through July. McGinitie and McGinitie (1949) observed that L. opalescens congregates in groups of 6 to 8 during mating, and that egg masses are attached to the bottom following this. Obviously such behavior would

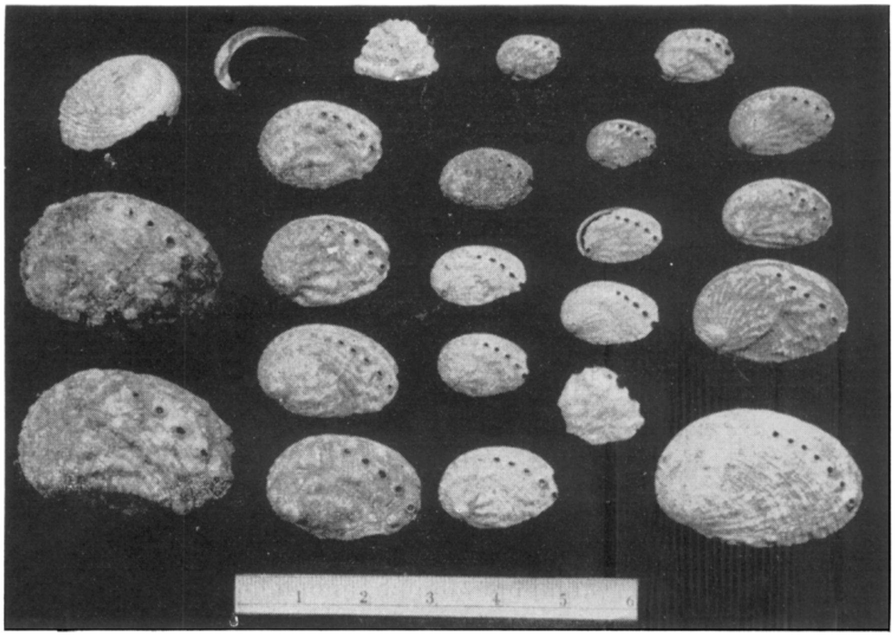

FIGURE 14. The shells of abalones removed from cabezon stomachs

FIGURE 14. The shells of abalones removed from cabezon stomachs

render them more vulnerable to attack by Scorpaenichthys, but for this very reason it is difficult to understand why none were found among the stomach contents of fish taken during the spring and summer. Temporary lack of other food organisms cannot be postulated in these three cases, since each of the fish also had gastropods and crabs in its stomach.

While the importance of small tide-pool fishes in the diet of juveniles has already been discussed, little has been said of the fish eaten by adults. They too occasionally eat the smaller forms, which are represented by the four unidentified cases and the one cottid in Figure 13. But far more important were the five rockfishes (Sebastodes) recovered. These were up to nine inches in length and far outweighed anything else found in the stomachs, ranging from 121 to 570 grams. Consequently they are an important constituent of the diet even though they are captured infrequently. Since the members of this genus, although not demersal in habit, do forage along rocky bottoms in coastal waters, it is not difficult to understand why they sometimes fall prey to the bottom-dwelling cabezon.

The occurrence of the sanddab, Citharichthys sordidus, in one stomach again shows that Scorpaenichthys is not averse to an occasional excursion on the sand. The presence of the sea mouse, Aphrodite, indicates that muddy bottoms may sometimes be invaded too.

In summary, it is clear that the cabezon is a voracious and powerful predator. Being an inhabitant of the rocky intertidal and subtidal zones, the species preys primarily on crabs, abundantly available in the same niche. Although molluscs are also abundant here, their procurement is more difficult. Demersal fish, readily devoured, are obviously better able to avoid capture than the decapods and molluscs. Fishes not strictly demersal in habit are probably readily devoured when they venture close to the bottom. Oddities of the diet, such as the sanddab and sea mouse, infer that Scorpaenichthys is not strictly limited to rocky bottoms. Egg masses, squid and clams are probably indicative of an essentially opportunistic feeding behavior.

6. REPRODUCTION

6.1. INTRODUCTION

Spawning behavior varies considerably among the Cottidae, and many of the differences are reflected in the diverse anatomy of the external sex organs. For example, genital papillae may remain undeveloped, or large penes may be formed from them. Consequently, there is both internal and external fertilization.

Considerable variation in selection of spawning sites and care of the eggs has also been reported. Some species, judging from the locations of egg clusters in tide pools, extrude them into small crannies such as are found in kelp holdfasts or in empty barnacle shells; some fasten them to the bottoms of rocks, while others apparently do not attempt to seclude them at all.

Little is known of the spawning behavior of Scorpaenichthys. The absence of a penis is strong evidence of external fertilization. The scarcity of egg clusters in the tide pools is indicative of subtidal spawning. No egg clusters were found in the tide pools during the winter of 1950–51, although two people searched for them at several different times. During the preceding winter one cluster was found, from which the larvae were later identified as Scorpaenichthys. The number of eggs was roughly estimated to be 40 or 50 thousand. The apparent paucity of spawning adults in the tide pools further supports the suggestion of subtidal spawning. Harry, in his study of the tide pools at Moss Beach, found no cabezon with maturing gonads in his collections. The tide-pool collections made during this investigation, however, did contain a few individuals with maturing gonads. of four young adults, ranging from 343 to 479 mm., taken between November 4 and January 5, one male and one female had maturing gonads, while the other two, both females, were immature.

6.2. SPAWNING SEASON

The period of spawning can be most precisely defined by the presence of larvae in the plankton. In 1950 the first larva appeared in the November 13 sample, and in 1951 the first two larvae appeared in the November 14 sample. The incubation period is about two or three weeks; thus it appears that spawning commences in late October or early November.

In the same manner, it can be shown that spawning ends in the latter part of March. Eight recently hatched larvae were found on April 4, 1951, and only one, the last of the year, on April 11, 1951. This establishes a winter spawning period of about five months duration.

When the number of larvae in the plankton collections are plotted against time (Figure 15), January is indicated as the month of peak spawning. The net tows upon which these data are based were taken

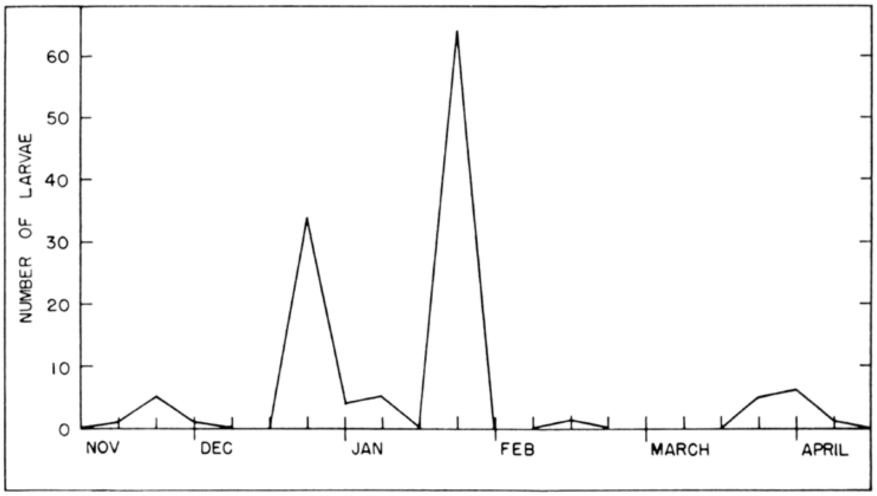

FIGURE 15. The number of *Scorpaenichthys* larvae in weekly plankton-net tows at Pacific Grove, California. All specimens were between 4.1 and 6.8 mm. in length.

FIGURE 15. The number of Scorpaenichthys larvae in weekly plankton-net tows at Pacific Grove, California. All specimens were between 4.1 and 6.8 mm. in length

once a week in the same manner. The net was towed a few feet below the surface for five minutes. The resultant collections, however, were too small and variable to be used for any quantitative estimate. Without knowing to what extent variation in the numbers of larvae is due to the collecting technique and the spottiness of distribution, the upward trend during the first half of the season to a maximuim in January is considered a valid indication that recently hatched larvae (arbitrarily taken to be all of those less than 6.8 mm. long) were most numerous during that month.

The length of the spawning season and the occurrence of a spawning peak in January can also be shown by a study of the ovaries. No attempt was made to study gonadal development in the males except to note that they exhibited the mature condition throughout the spawning season.

The ovaries of Scorpaenichthys are blunt anteriorly, round in cross-section, and broadly joined posteriorly, with the stroma occupying all available space when the eggs are maturing. The united ovaries open directly through the genital pore without the intervention of any tubular oviduct. Because of the broad connection, both ovaries were removed and preserved together. They were not separated for any part of this study, since, because of the connection, differences between left and right would have been difficult to measure, and probably inconsequential within the scope of this investigation.

A satisfactory classification of ovarian stages was established by visual inspection and these are described below.

Resting. During the resting stage the ovaries are small and firm with smooth walls characterized by an opaque grayish-white color. No distinction was made between those individuals which had spawned in previous years and those which had never spawned. All ovaries were in the resting condition throughout the late spring and summer.

Maturing. During this stage the ovaries are enlarging. The distension emphasizes the transparency of the ovarian wall. The characteristic color, grayish-pink, is imparted by the growing ova, which are all uniform in color and opacity. The ovaries begin to enlarge in the fall.

Mature. In the mature ovary the ventral lumen is filled with clear, amber-colored eggs. The germinal tissue, composed of lamellae aligned antero-posteriorly and suspended from the dorsal wall of the ovary, recedes dorsally as the mature eggs are released from their follicles. The margin of the stroma thus becomes visible as a roughly horizontal line around the ovary, separating it into differently colored parts, orange above and red below. Only three females exemplifying this condition were taken. One of them was fully mature with all of the clear eggs in the ventral lumen. The other two were partially mature, one with free ova in only the posterior one quarter, the other with free ova in all but the anterior one-third of the lumen. These observations suggest that expulsion of the eggs from the follicles is initiated posteriorly and progresses anteriorly. Such mature ovaries apparently occur only during the winter.

Spawned. Spawned ovaries are still enlarged but somewhat flaccid. Although their color is grayish-pink, they are easily identified by the few amber-colored mature eggs scattered through the stroma. This condition was noted during the latter half of the spawning season.

Spent. Spent ovaries are those in which all yolked eggs are undergoing resorption. They vary considerably in size and color according to the stage of resorption. All are flaccid and rather heavily vascularized. Spent ovaries occurred throughout the second half of the spawning season.

In order to describe the course of ovarian development and the fecundity of the species, the eggs in small samples from 20 ovaries were counted and measured. Each pair of ovaries was weighed to the nearest gram, after which the small sample was removed and weighed to the nearest thousandth of a gram. Weights of these samples varied from approximately one hundredth to seven-tenths of a gram, most being close to three-tenths of a gram. Prior to weighing, the excess fluid was drained from each ovary and each sample on absorbent paper.

Following the method described by Clark (1925), the eggs from each sample were spread on a slide marked with vertical parallel lines and measured with an ocular micrometer aligned horizontally across the microscope field. The lines on the slide prevented repeat measurements, while the constant alignment of the micrometer eliminated bias due to selection of longer or shorter axes of the eggs. Frequency polygons, upon which much of the following discussion is based, were constructed from these data. Preliminary examinations indicated that measurements to the nearest tenth of a millimeter would produce adequate frequency polygons. Therefore measurements exceeding any particular tenth graduation were recorded under the next highest tenth. Samples taken from different parts of a few pairs of ovaries showed only slight differences. The maturing mode tended to be almost a tenth of a millimeter greater in posterior than in anterior samples, but growing eggs of all sizes were randomly distributed throughout the stroma.

A stratification was effected by the spacial separation of maturing and mature ova, when the latter occurred. To avoid bias, all samples were taken from the anterior portion of the ovaries, which matured last. Only one fully mature ovary was used in this study and it is, admittedly, slightly biased. The entire weight of this ovary is imputed to its mature eggs, but the effect of this is negligible, for the stroma occupied little of the total volume, and, of course, the estimates based on these data are no more than gross approximations.

Several facts may be determined from an analysis of the size of the eggs. Figure 16 and Table 6 present the pertinent data and were arrived at in the following way. Diameter-frequency polygons representative of the same stages of ovarian development were grouped together, and from each group a typical example was selected. These were arranged at the left of the figure in the sequence affording the most logical modal progression. The stages, arbitrarily numbered 1 to 7, are characterized as follows:

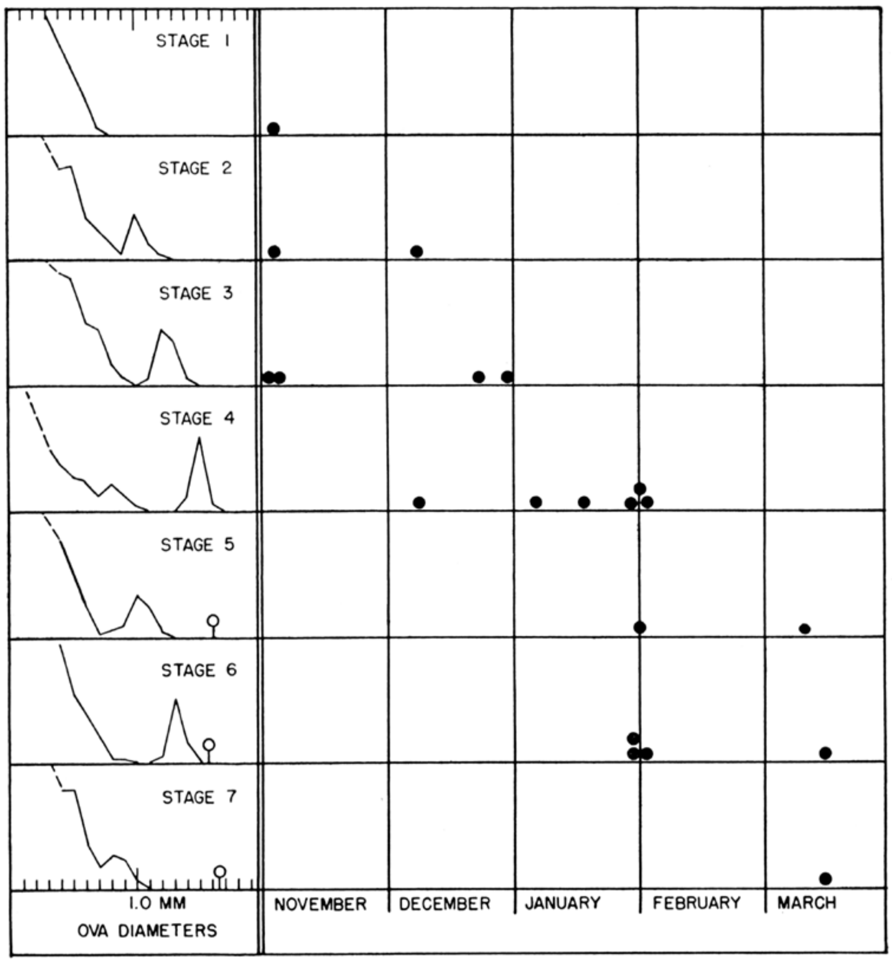

FIGURE 16. Frequency polygons constructed from ova-diameter measurements, and the distribution of different stages in time

FIGURE 16. Frequency polygons constructed from ova-diameter measurements, and the distribution of different stages in time

TABLE 6

Descriptive Features of the 20 Ovaries Represented in Figure 16

Stage	Date	Ovary weight (grams)	Modal diameter	Average ovary weight	Average modal diameter
1	11–3	52	none	52	------
2	11–3	182	1.0	130	.92
	12–7	79	.85		
3	11–1	134	1.4		
	11–3	265	1.4	180	1.30
	12–21	115	1.2		
	12–29	206	1.2		
4	12–7	359	1.6		
	1–5	142	1.4		
	1–17	154	1.4	251	1.50
	1–30	305	1.5		
	2–1	183	1.5		
	2–1	365	1.6		
5	2–1	139	1.0	111	1.00
	3–9	83	1.0		
6	1–30	107	1.2		
	1–30	200	1.3	185	1.25
	2–1	170	1.2		
	3–14	262	1.3		
7	3–14	99	.8	99	.80

TABLE 6

Descriptive Features of the 20 Ovaries Represented in Figure 16

1. Ova are maturing, but none are larger than 0.7 mm. There is no distinct mode present.

2. Ova are further developed. One distinct mode is present at an average diameter of 0.92 mm.

3. Ovaries are still maturing, with one distinct mode present at an average diameter of 1.30 mm.

4. Some ovaries are maturing and some are mature. There is a prominent mode at an average diameter of 1.50 mm. and an incipient mode at 0.7 or 0.8 mm.

5. Scattered mature eggs 1.5 and 1.6 mm. in diameter are present, indicating a previous spawning. There is a distinct mode at an average diameter of 1.00 mm.

6. Scattered mature eggs are present, and there is a distinct mode at an average diameter of 1.25 mm.

7. Scattered mature eggs are present, and there is an incipient mode at 0.8 mm. All yolked eggs are being resorbed.

7a. Resorption has advanced to the point where measurements are impractical. The nine ovaries in this category are not represented in Figure 16.

In this arrangement of the polygons, the progression of a maturing group of eggs can be traced from stage 2 through stage 4, and from stage 5 through stage 7 there remains a residue of scattered mature eggs, evidently destined for degeneration. By stage 4, a second class of eggs becomes evident, which in stages 5 and 6 undergoes a history similar to that of the previous group. In the single specimen depicting stage 7, all yolked eggs, including an incipient developing class, are being resorbed, and in stage 7a resorption is further advanced.

That the arrangement of the polygons is not simply arbitrary, but reflects the actual sequence of events taking place in the ovary is clearly indicated in the timetable adjacent to the polygons in Figure 16. Each point here represents a fish captured on a particular date, as shown on the horizontal axis, and in a particular stage of development as indicated by its position relative to the polygon on the left. Ovarian development advances from stages 1, 2 and 3 in November to stages 5, 6 and 7 in March. The spread of the same stage through two or three months, and also the occurrence of three stages in any one month are evidences of individual variation in the time ovarian growth starts and the time maturity is reached. Had more specimens been used, the spread undoubtedly would have been greater along both axes, but it is improbable that the clear progression of stages would have been obscured.

The relationship between ovary condition and time is most readily interpreted in the following way. As time progresses in the earlier part of the season, the average condition of the population shifts from maturing to mature. During January the mature condition is predominant, and after January a large portion of the females are developing a subsequent class of eggs. Resorption also becomes evident at the end of January, and by the end of April the entire population is in this condition.

Table 6 contains the date of capture for each specimen plotted in the timetable, together with the ovary weight and the modal diameter of the most prominent group of maturing eggs. The average ovary weight and average modal diameter increase through stage 4, at which time a batch of eggs is extruded. Weight and diameter immediately fall, but increase as the next group of eggs approaches maturity.

The growth in weight of the ovaries, and the subsequent transition to the condition of resorption can be more precisely described by plotting ovary weight/total weight of the fish against time (Figure 17). To facilitate the use of mean and range values, the data were grouped in 20-day intervals and plotted at the first date of each interval. Separate means were plotted for maturing, spawned and spent ovaries. The means of each type conform to reasonably smooth lines, and, of more concern here, adjacent range boundaries are distinctly separated from each other. The considerable difference between the maturing and spawned groups is to be expected, since it represents the sudden loss of weight upon extrusion of a mature generation of eggs. The fact that the range of the spawned group is so narrow, and that the means do not approach those of the maturing group is probably a matter of chance, since there were only six specimens in this category. The broad range of the spent ovaries, and the proximity of the maximum line of this group to the minimum line of the spawned group indicates that the onset of resorption is independent of the degree to which a subsequent class of ova is developed. The maximum point at March 1st represents the ovary of Stage 7 in which there was a developing class of ova undergoing degeneration. It was apparent from the condition of the eggs that degeneration had started quite recently.

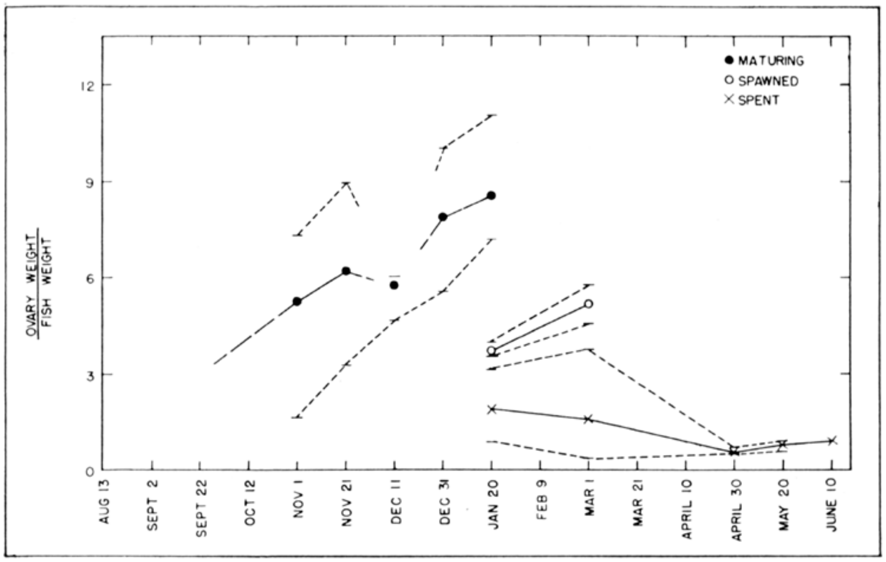

FIGURE 17. Ovary weight as percentage of total weight plotted against time. The solid lines connect means and the dashed lines connect minimum and maximum points for each of the three conditions represented. Time intervals are 20 days and points are plotted at the first date of each interval.

FIGURE 17. Ovary weight as percentage of total weight plotted against time. The solid lines connect means and the dashed lines connect minimum and maximum points for each of the three conditions represented. Time intervals are 20 days and points are plotted at the first date of each interval

The position of the spawned ovaries in this figure does not permit any conclusion as to whether or not there is more than one spawning per female. It may represent a transition between first spawning and the onset of resorption as well as the growth of a subsequent generation of eggs to maturity. Fulton (1898) associates the presence of an intermediate group of ova with a prolonged spawning season. He states that this condition was to be found in fishes which deposit few eggs at one time, and which shed their eggs in more than one batch during the season. As Clark (1925) points out, even though the number of generations of ova during the spawning season varies in different species, Fulton's interpretation of the presence of an intermediate group probably has general application. In Scorpaenichthys an intermediate group is clearly developing in Stages 4, 5, and 6. Although this is not conclusive, it can be surmised, on the basis of Fulton's observations, that individuals of this species spawn more than once during the season; and when the knowledge of a subsequently maturing mode during January, February and March is coupled with the occurrence of recently hatched larvae in the plankton during March and April, it can hardly be doubted that at least some part of the population spawns more than once.

The minimum line of the spent group in Figure 17 represents ovaries which have almost reverted to the resting condition, even in the January 20th period. There can be no doubt that degeneration started in these ovaries at least one period earlier, meaning that it first occurred in the latter part of December or the early part of January. The individual variation in the time that resorption starts logically follows the variation in the time that development starts and the time maturity is reached. It is not possible to determine from these data, however, whether those showing early degeneration had also matured early and spawned more than once, or whether they matured with the bulk of the population and spawned only once.

6.3. THE NUMBER OF EGGS

The problem of fecundity here resolves itself into two questions: How many eggs are spawned at one time, and how many does each female spawn during the season? The second problem was discussed above and it was shown that, in general, individual females shed more than one batch of eggs during a season.

To estimate the number of eggs per spawning, all ova larger than 0.3 mm. were counted in the ovarian samples, but estimates are based only on the number of eggs in the peak destined for maturity. Estimates

TABLE 7

Regressions of Egg Production on Weight

Unspawned		Spawned	
Hundreds of grams	Thousands of eggs	Hundreds of grams	Thousands of eggs
14	61	18	53
17	37	27	56
24	65	38	99
25	69	45	82
27	54	46	81
33	93	56	77
34	87		
37	89		
40	100		
41	90		
42	97		

TABLE 7
Regressions of Egg Production on Weight

were derived from the proportion, weight of sample: weight of ovary:: number of maturing ova in sample: number of maturing ova in ovary.

The regression of eggs (in thousands) on the total weight (in hundreds of grams) of 16 specimens is expressed by the equation Y = 27.3 + 1.53X. The calculations are set forth in Table 7 and graphed in Figure 18. The relationship is assumed to be linear between 1.4 and 4.6 Kg. The point 5.6 Kg, 77,000 eggs, was excluded from the calculation because the number of eggs appeared to be low for a specimen of such great weight. Such an isolated point, though it may be within the limit of expected deviation, would have influenced the regression disproportionately.

In an attempt to find some explanation for the deviation of this latter point, ovaries known to have been spawned at least once were separated from those presumably not yet spawned. The criterion was the presence or absence of scattered mature eggs. The 5.6 Kg female, which had already spawned, was included in the spawned group. The regressions for these two sets of data (Table 7 and Figure 19) were not significantly different, although that for spawned ovaries has a lesser slope than that for unspawned ovaries.

On the basis of the first regression, Y = 27.3 + 1.53X, females weighing 1.4 Kg (average length of 433 mm.) spawn an average of 48,700 eggs in one batch. This increases by 1,500 for each 100 grams of total weight to an average of 97,600 at 4.6 Kg. For the specimens measured, there is no significant difference between the number of eggs in the first batch and the number of eggs in subsequent batches, as shown above.

The assumption of more than one spawning per female credits this species with much greater fecundity than has been recorded for other

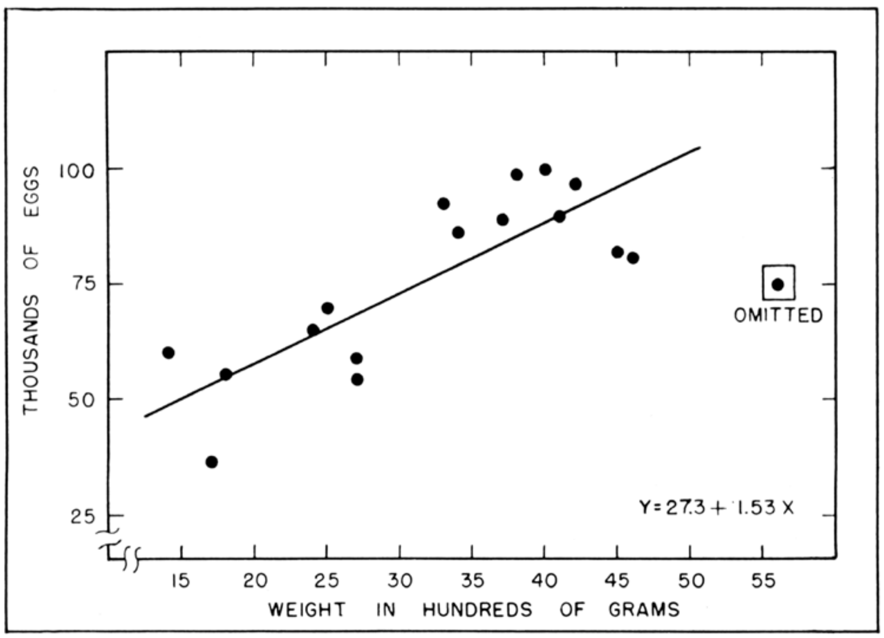

FIGURE 18. Regression of thousands of maturing ova on total weight of fish. The isolated point at 5.6 Kg was omitted from the calculation.

FIGURE 18. Regression of thousands of maturing ova on total weight of fish. The isolated point at 5.6 Kg was omitted from the calculation

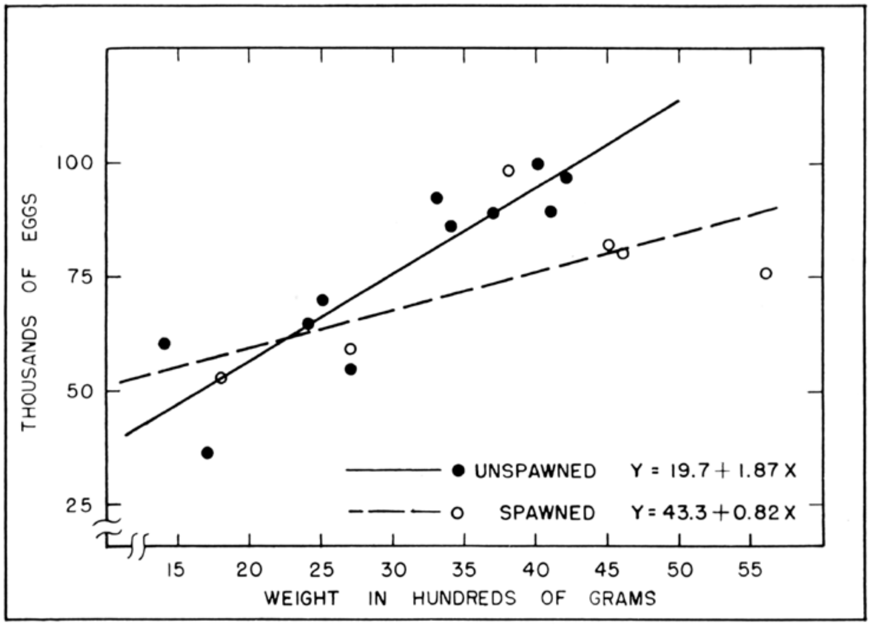

FIGURE 19. Regressions of number of maturing ova in unspawned females and number of maturing ova in spawned females. The slopes of these lines are not significantly different.

FIGURE 19. Regressions of number of maturing ova in unspawned females and number of maturing ova in spawned females. The slopes of these lines are not significantly different

members of the family. Even a single spawning of 37,000 to 100,000 eggs per female far surpasses that of other cottids as revealed in the literature. of course most of the cottids are much smaller than Scorpaenichthys and as Fulton (1898) points out, there is a broad correlation between size and the number of eggs produced. For the longhorn sculpin, Myoxocephalus octodecimspinosus Mitchell, a species considerably smaller than Scorpaenichthys, Morrow (1951) estimates, by volumetric measurement, that the average female produces about 8,000 eggs each year. Warfel and Merriman (1944) state that Hemitripterus americanus, another species somewhat smaller than Scorpaenichthys, normally produces 15,000 eggs, and that one aberrant individual contained almost 45,000. The authors also state that more than one spawning per year is highly improbable for this species.

It is evident from Fulton's work that the devices commonly resorted to for safe propagation of the species are the production of large numbers of eggs, or the protection of a small number of eggs. Some smaller species produce several batches of ova during a season to fulfill the requirement of large numbers, while some larger species are capable of producing a sufficiently large number at one time. The species which rely upon the protection of a small number of eggs accomplish this by either hiding or guarding them. The fact that Scorpaenchthys produces more eggs than either Myoxocephalus or Hemitripterus at a single spawning, that it spawns more than once in a season, and that it is not known to seclude its eggs in sponge cavities or similar hiding places, suggests that it depends largely on numbers of eggs to insure the survival of the species.

7. LARVAL DEVELOPMENT

Unfortunately the opportunity to follow development in the laboratory occurred only once. Females with ovaries at full maturity were obtained twice during the spawning season. One was rendered useless by the unavailability of mature males, but the other was stripped and fertilization was effected with milt from a male of the same boat catch. Both specimens had been on ice aboard the fishing vessel for more than 36 hours prior to stripping. The resulting low viability, therefore, was not surprising. After the cluster had hardened sufficiently, it was anchored to the bottom of a one-gallon jar by means of a small stone, and incubated in running sea water. A blastodisc formed in all eggs, but cleavage failed to follow in almost all of them and consequently was not observed. At 24 hours the blastodisc started to disintegrate, and by 33 hours it was a nondescript ball of white matter imbedded in the yolk. The yolk, although retaining its color, shriveled considerably during the next few weeks. In retrospect it is evident that the bulk of the eggs were not fertilized, but an unknown stimulus, perhaps the presence of the milt, caused the formation of the blastodisc.

Seventeen days after fertilization, one "eyed-egg" was detected in the cluster. Partition of the cluster disclosed 34 developing ova, three of which hatched the same day. Only one larva, however, was vigorous and healthy. The description and drawing of the newly-hatched larva are based upon this specimen. Other growth stages were described from preserved specimens of different sizes, for which date and place of capture but not age are known.

7.1. THE UNFERTILIZED EGG

Mature unfertilized eggs from several females, spawned and unspawned, exhibited a range of 1.4 to 1.7 mm. in diameter. The eggs from a single female, however, had a somewhat narrower range. The shells were about 0.045 mm. thick. At a magnification of 440 diameters the egg surface had a fine granular texture, although it appeared smooth and transparent to the naked eye. The yolk, which entirely filled the capsule, was clear and amber in color. No color variation was apparent in the mature eggs from several ovaries. A large oil globule, about 0.27 mm. in diameter, was present, and one to four small ones were usually found adjacent to it.

Before preservation the eggs were sticky and adhered to each other on contact. Eggs from the stripped female, after being kept in salt water for a few hours, had formed a hard, compact mass. Shells were mutually flattened or depressed at their points of junction.

7.2. THE NEWLY-HATCHED LARVA

The length of the newly-hatched larva (Figure 20) was 5.85 mm. Almost all larvae taken in the plankton collections were between 5 and 6.8 mm. in length. Two consecutive samples in January, however, contained larvae that ranged between 4.4 and 5.6 mm. This at first seemed strange and it was thought that two different species might be involved. However, body proportions and pigmentation were the same as in the 5.0 to 6.5 mm. specimens. In no way did they appear to be malformed or distorted. Since Warfel and Merriman (1944) recorded a range of

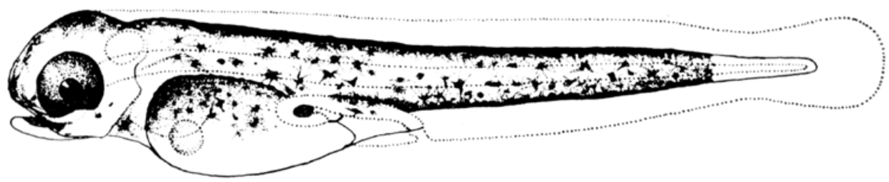

FIGURE 20. Newly hatched larva, 5.85 mm. in length

FIGURE 20. Newly hatched larva, 5.85 mm. in length

9.9 to 14.1 mm. for newly-hatched Myoxocephalus larvae, a range of from 4.4 mm. (the smallest plankton specimen) to 5.85 mm. (the laboratory-hatched specimen) appears reasonable for the newly hatched larvae of Scorpaenichthys.

The head is smooth and dome-shaped with a slight depression at the tip of the snout. Otic capsules are large and well defined. The choroid fissure is still apparent on the ventral margin of the heavily pigmented eye, which measures 0.47 mm. along its horizontal diameter. Although well formed, the lower jaw is subterminal. Definite movements of the jaw were observed in the living specimen, but the mouth remained open most of the time. The opercular flap is well developed, its posterior margin ascending obliquely to a point level with the pupil of the eye. Above this point it recurves and merges with the body behind the otic capsule.

From a depression across the nape, the dorsal margin of the body tapers with a barely noticeable concavity to the end of the pigmented region, and from there to the posterior tip of the body in a straight line. The ventral margin extends in a straight line from the anus to the posterior tip. The median finfold originates at the nape and is continuous around the tail, extending forward along the ventral margin of the body to the posterior end of the yolk sac. It is interrupted by the anus a short distance behind this point. The pectoral fins are present, but so transparent that they are difficult to see.

The yolk sac, containing one oil globule, is somewhat elongate. Its greatest depth goes 2.1 times in its length. The anterior margin is slightly behind the point of the opercular flap. One loop of the gut is imbedded in the yolk. Most of the viscera are hidden by the yolk, and the heart is concealed by a large melanophore. The notochord, although masked by heavy pigmentation, was traced from the posterior margin of the eye to the posterior end of the body. Because of the heavy pigmentation, somites were not readily visible.

The larva, heavily covered with melanophores, is tinted orange-yellow by splotches of diffuse xanthin. The melanin is confined to dendritic melanophores which have solid centers. Approximately 20 of these form a circular patch on the crown of the head. From the patch, 6 to 10 attenuated melanophores extend down the snout in two vague lines. The upper lip itself is covered by several elongate melanophores. The cheeks, except for a few tiny melanin spots, are devoid of pigment. The numerous lateral melanophores are irregularly spaced, except at the margins of the body, where they form a double row on each side of the finfolds, more definite in arrangement dorsally than ventrally. The posterior end of the body is entirely unpigmented. When the larva is viewed laterally with the naked eye, these two lines, as well as the sharp demarkation between the pigmented and unpigmented portions of the body, are its outstanding characteristic.

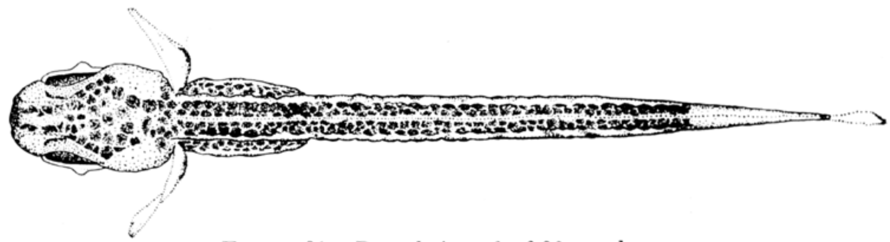

FIGURE 21. Dorsal view of a 6.26 mm. larva

FIGURE 21. Dorsal view of a 6.26 mm. larva

The melanophores of the dorsal wall of the yolk sac are also dense enough to form a solid line in lateral aspect. They are overlaid by dermal melanophores which extend about halfway down over the yolk sac. The largest pair of melanophores on the body are located on each side of the isthmus between the opercular flap and the yolk sac. Although it varied considerably, this pair was prominent in most of the 5 to 6 mm. specimens examined. There is no pigment on the median finfolds or the pectoral fins.

Figure 21 was drawn from a 6.26 mm. larva collected on January 29, 1951, and preserved in 4 percent formalin. Probably it is not more than a few days older than the newly-hatched larva. The patch on the head has begun to approximate a diamond-shaped pattern, the lines on the snout are better defined, and the anterior depression (not visible) has deepened. In general, the head has become more definitely shaped. The number of melanophores has also increased, particularly on the sides. They are, consequently, closer together and more regularly spaced. The melanophores on all the preserved specimens were more dense and rounded than those on the larva in Figure 20. Whether this is their natural state or the result of preservation was not discovered. The dorsal view better illustrates the arrangement of melanophores along the base of the dorsal finfold.

The larva of Scorpaenichthys differs considerably from the types described for other cottid species from California (Budd 1940, Bolin 1941, Morris 1951). Most obvious is the much heavier and more general pigmentation of Scorpaenichthys at the time of hatching. Others have relatively few melanophores arranged in rather definite, specific patterns. Most unique is the small pre-anal finfold of Scorpaenichthys, which has no counterpart in the species described by the above authors. of course it is a common larval feature in a number of other groups, i.e., Anguillidae, Heterosomata, Gobioidea, Blennioidea. The yolk sac also differs in being more elongate.

Among the Cottidae, Hemitripterus americanus is the only other species for which similar characters were found in the literature. The newly hatched larva is described by Warfel and Merriman (1944) as having "Chromatophores . . . most abundant along the dorsal side of the larval body, especially along the base of the dorsal fin." Their drawing shows that melanophores cover most of the body except for the last 25 percent. They further state that "The median fin was continuous and ended very slightly in advance of the anus." Otherwise the two larval types differ in that H. americanus is much more fully developed and approximately twice the length of S. marmoratus upon hatching.

In view of the above, it is interesting to note the supposed phylogenetic positions of these two species. Jordan and Evermann (1898) believed Hemitripterus to be one of the most specialized of the American cottoid genera. Bolin (1947) places Scorpaenichthys among the most primitive of the California Cottidae. Since larval characteristics may well provide important evidence of relationships, it is entirely possible that the conclusions expressed in one or the other of these works will eventually be revised. More larval types will have to be described within the family in order to appraise their value as indicators of phylogenetic relationship.

7.3. TEN MILLIMETER POST-LARVA

At 10 millimeters Scorpaenichthys has changed considerably (Figure 22). Except for the distended body cavity, it is well compressed. The yolk, of course, has disappeared. Body depth goes into total length four times. The head goes into total length 3.8 times. The general appearance is that of a very sturdy little fish with a well formed, prominent head.

The head, in dorsal view, is broad and subrectangular. A median ridge, which extends down the snout, divides at the tip of the snout to form a pair of low ridges which descend the remaining short distance to the premaxillary, enclosing the depression noted earlier. Above each eye there is a flat ridge which broadens as it descends along the anterior margin of the eye to the premaxillary. It is the lateral expanse of these ridges on either side of the snout that gives the head its box-like appearance in the dorsal aspect. Three prominent preopercular spines project latero-posteriorly from the preopercular flap. The branchiostegals are well formed, and the maxillary is clearly discernible.

Dorsal, ventral and caudal rays are forming, but the spines of the first dorsal have not yet appeared. The caudal rays are developed further than the others. The anterior and posterior halves of the dorsal finfold have grown differentially, so that the former is much narrower than the latter. The terminal portion of the notochord has turned up, swinging the hypural plate into a posterior position. There is a noticeable wrinkle in the ventral finfold just posterior to the anus. Since this was present in several specimens, it probably denotes the anterior margin of the prospective anal fin. The short length of finfold anterior to the anus is still present, but it has not broadened; nor is there any indication of fin-ray development. The pelvic fins, well formed but small, lie flat against the body, not easily seen from the lateral aspect.

The body is now tawny and silvery rather than black. The melanophores, scattered uniformly over most of the body, are inconspicuous because of their increased numbers and the greater size of the larva.

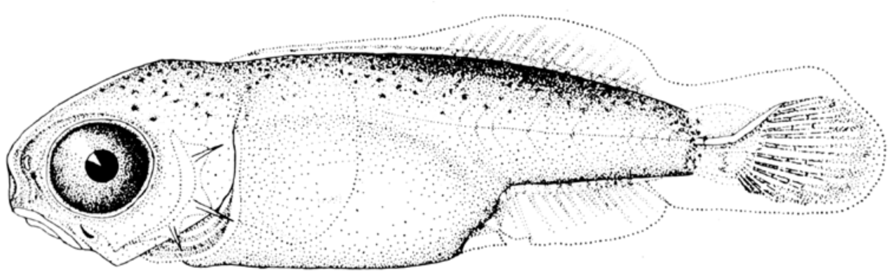

FIGURE 22. Post-larva 10 mm. in length

FIGURE 22. Post-larva 10 mm. in length

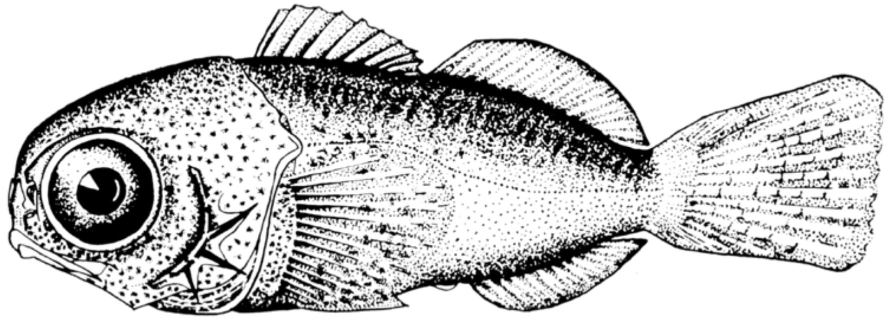

FIGURE 23. Post-larva 17 mm. in length

FIGURE 23. Post-larva 17 mm. in length

7.4. SEVENTEEN MILLIMETER POST-LARVA

Only the broad band of larger melanophores on the dorsal part of the body has been represented in Figure 22.

The most obvious changes at 17 mm. (Figure 23) are those of body proportions and fin development. Head length now goes approximately 3.1 in total length, and body length (first dorsal spine to pelvic base) approximately 3.3 in total length. The orbit, perfectly circular, goes 2.1 in the head. In general the fish has a more compressed and deep-bodied appearance.

The most striking change on the head is the differentiation of the nasal spines. The two short, broad spines project dorsally from the flat nasal plates. The apical plate, a slightly depressed and unpigmented area between the premaxillary and the base of the nasal spines, is continuous with the skull above it across a broad median (ethmoid) ridge between the spines. Both pairs of nostrils are visible, each of the upper ones being situated more than a nostril diameter laterad of the nasal spines. Lateral-line pores are present on the head, but as yet no cirri have appeared. Both the premaxillary and maxillary are well formed. The preopercular margin, bearing three spines, is now prominent. All the fins are well formed with a complete complement of rays (D. X, 16; A. 12; P. 15; V. I,5; C. 9). The membranes of the dorsal fin are slightly incised back to the fifth spine, the notch preceding the latter spine being the deepest. The pre-anal finfold, still present, is little more than a papilla. The caudal fin is truncated with the ventral margin shorter than the dorsal. The hypural plates, not yet covered by pigmentation, are plainly visible. The pectoral fins extend to the vertical of the anus. Although well formed, the pelvic fins are still carried rather close to the body.

The over-all color of the fish is still tan, but the black pigmentation has been somewhat altered. The melanophores on the body are inconspicuous and evenly distributed. The broad black band just below the dorsal margin is composed of melanophores deeply imbedded in the dermis. They are distinct when viewed from the inner but indistinct when viewed from the outer surface of the integument. Just behind the base of each dorsal ray there is a small spot of melanin. Similar spots occur behind some of the spines of the first dorsal. All of the other fins are still without pigment. The melanophores on the head, though numerous, are quite distinct. They stand out in contrast to the light membrane bones of the skull developing beneath them. Except on the lips and nasal spines, the melanophores are quite evenly distributed, giving the head a speckled appearance. The melanophores on the lower half of the cheek, on the base of the pectoral fin, and especially on the lateroventral region of the abdomen, are characteristically larger and more widely spaced than any others on the fish. Red pigment is also less prevalent in these areas.

7.5. THIRTY MILLIMETER POST-LARVA

At 30 mm. Scorpaenichthys seems a little less robust, although the proportional measurements of the head and the body depth have not changed.

Figure 24 is a facial view showing the relative positions of the nasal spines and nostrils. The nasal spines have increased in length and breadth, their lateral borders now lying just over the inner margins of the upper nostrils. The basal portions of the spines are more definitely shaped and are covered by a few small spots of melanin. The ethmoid ridge is relatively narrowed and the median nasal cirrus is present as a low flap between the bases of the spines. The apical depression has disappeared, its position now being occupied by the median nasal cirrus.

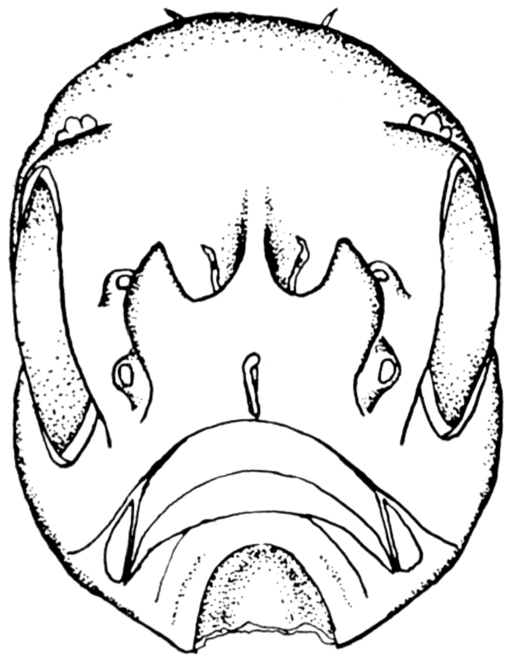

FIGURE 24. Facial view of a 30 mm. post-larva

There are three pairs of cirri on the head. Above each orbit there is a short three-lobed bud. At the posterior margin of the skull there is a pair of simple cirri which, although inconspicuous, can be found in the adults. Just mesad and slightly posterior to each nasal spine there is a simple cirrus containing two small melanin spots. As yet, neither the cirri at the ends of the maxillary, nor those on the mesial edge of the nasal spines have appeared.

The fins show no change except for a slight increase in the length of the pelvics and a further reduction of the preanal finfold. The latter has become a short, rather broad median ridge immediately preceding the anus. The second dorsal spine is longer than the first, and the third, fourth and fifth are subequal; the sixth spine is the longest one of the fin. In outline the fin is slightly bilobed.

The most important change in pigmentation is the advance of melanin on the dorsal fins. Associated with this is the appearance of a relatively unpigmented zone between the longitudinal dorsal band of melanin and the base of the fins. This zone is crossed by four vague, vertical black bars, and melanophores have migrated onto the dorsal fins above each of these bars, but have not yet extended quite half the distance between the base and the upper edge of the fins. There are two patches on each dorsal fin, which extend from the second to the fourth, and from the seventh to the ninth spine; and from the third to the seventh and the 12th to the 16th ray. The dorsal borders of these patches parallel the edge of the fin above them. All other fins are still unpigmented.

The only other noticeable changes in pigmentation have occurred on the head. Here the small melanophores have become more numerous on the lower portions of the cheek. Some have appeared on the preopercular spines, over which the skin has thickened. At this stage only the melanophores across the ventral surface of the abdomen appear relatively large and well spaced. Although the basic red color still predominates, the proliferation of melanophores has given the fish a darker appearance than in the last stage described.

7.6. FORTY-EIGHT MILLIMETER POST-LARVA

Body measurements indicate some slight change in growth proportions at this stage. Head length goes in total length 3.4 times and depth into total length 4.0 times. Obviously the fish is "stretching out." The snout looks less square in both lateral and dorsal view, and the preopercular spines are stouter. The orbits are relatively smaller and more dorsally placed.

No pigmentation has yet appeared on any but the two dorsal fins. The four bars previously mentioned have begun to ramify, although they still do not quite extend to the fin margin. Each of the two hypural plates is covered by a small patch of melanin.

The coloration now consists of five irregular dark brown vertical bars on a silvery background. The fifth bar has no counterpart on the dorsal fins. It occurs across the caudal peduncle. In Figure 25, a photographed specimen, this barred pattern is quite apparent.

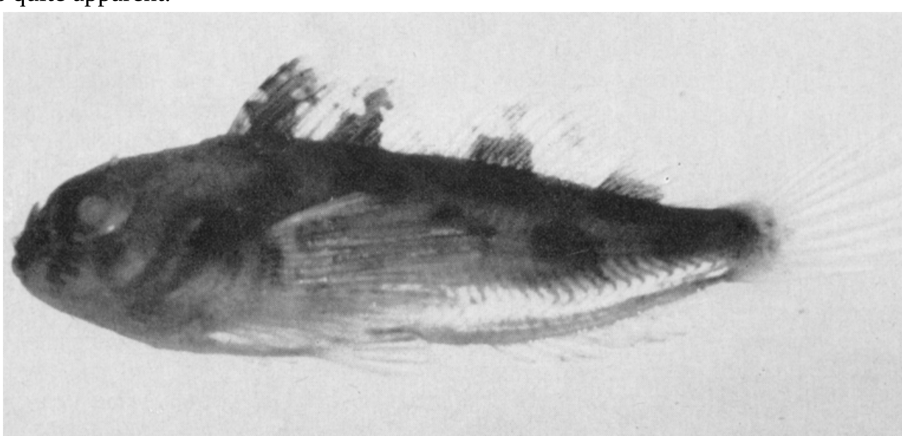

FIGURE 25. Post-larva 48 mm. in length

FIGURE 25. Post-larva 48 mm. in length

At 60 mm. Scorpaenichthys has acquired all of its outstanding characters. Cirri are well developed. Body and fins are heavily pigmented, often splotched or barred. It remains only for body proportions to alter more towards the somewhat depressed adult form.

It may not be out of place to append to the above discussion of early development a few remarks on the distribution of larvae and postlarvae, and the possible effects of larval drift on the population as a whole. Dispersion of the pelagic young by ocean currents could not be ascertained from the plankton collections of the TAGE, but dipnet collections made by research vessels of the Scripps Institution of Oceanography during 1949 and 1950 illustrate that it is extensive. This series is composed of individuals ranging from 7.4 to 29.0 mm. in length, and the greatest offshore distance at which specimens were found was 200 miles. The stations at which these larvae were taken are plotted in Figure 26 The correlation between length and the vertical distance from the coastline is low, but one feels, intuitively, that a relationship, at least between time and distance, does exist, obscured, perhaps, by the variation in individual growth rates and the deflection of the currents. Since the adults occupy and spawn in shallow waters, some of these larvae must have been carried long distances by the prevailing currents, for several were captured well beyond the edge of the continental shelf. Oceanographic charts of the surface waters along the coast show clearly that organisms at the mercy of the currents would drift away from the coast on a slightly angular (southward) rather than a perpendicular course. The perpendicular distance from shore would not, therefore, be a valid index of the drift distance.

Two interesting questions are posed by this dispersion. To what extent does it shuffle the gene flow over the entire range, and do those larvae carried far offshore succeed in returning to the shallower coastal waters? The answer to the first question would be a corollary to the second, were it known. In all probability, the young carried offshore perish, unable to attain the bottom at the proper time. Assuming this to be true, extensive coastwise mixing would not occur.

It is also interesting to speculate as to the possible effects of shifts in ocean currents on year-class strength. Walford (1938) found the current and actual site of spawning on Georges Bank to be the critical determinants of year-class strength for the haddock (Melanogrammus aeglefinus); but where demersal eggs are spawned in the coastal eddies, the resulting larvae are not likely to be carried to sea en masse. Those remaining should be more than adequate to sustain local populations.

8. THE LENGTH-WEIGHT RELATIONSHIP

One important aspect of growth is the relationship between length and weight. For many species it has been found that weight increases as the cube of length, but for others it has been shown that weight accrues at a greater or lesser rate than the cube. Since length is only one of many possible linear measurements, and since growth is generally allometric, the fact that the relationship between length and weight remains close to the cube among fishes implies that changes in form with

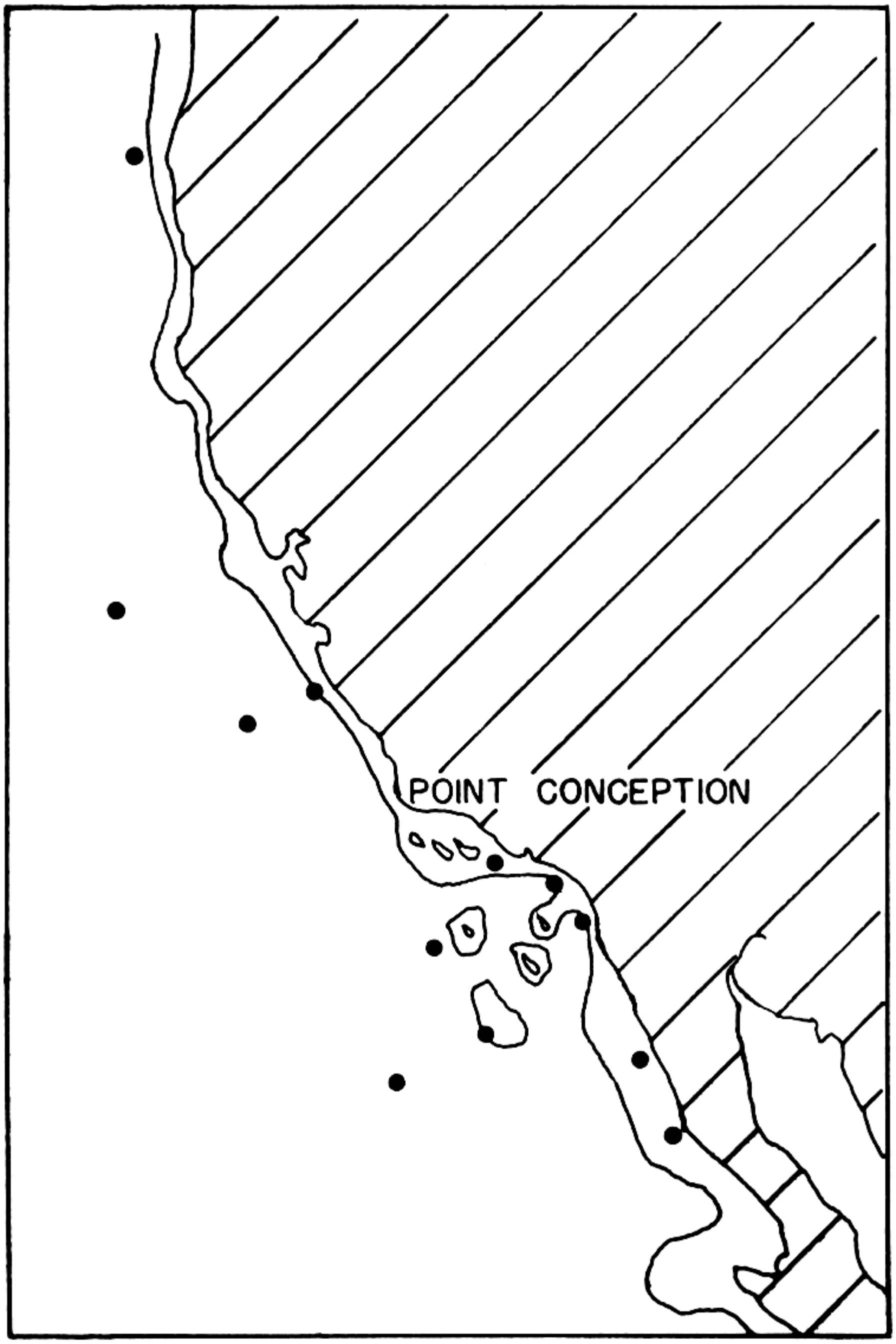

FIGURE 26. A map of the West Coast of North America, showing the stations at which Scorpaenichthys larvae and juveniles have been collected. The 100 fathom curve is indicated

age are relatively conservative. Although form does change with growth, there are very few fishes that show marked deviations from the simple, quasi-fusiform shape. This is in contrast with the diversification of form common among the higher vertebrates.

The relationship was calculated for Scorpaenichthys from the lengths and weights of 210 specimens. Total length was measured to the nearest millimeter, and total weight was measured to two significant digits. Thus the smallest individual weighed 4.5 grams and the largest 7.1 kilograms, or 7,100 grams. The scales used did not permit more accurate measurement of the larger fish, but since the length-weight relationship is exponential, measurements to the nearest 100 grams in the fourth order of magnitude introduce no more error than measurements to the nearest tenth of a gram do in the first order of magnitude.

By converting the natural numbers to logarithms, the exponential relationship can be conveniently expressed as the linear equation, $\log W = k + n \log L$, where W is the weight, k is a constant, n is the relative growth constant, and L is the length. The regression of log weight on log length was calculated by the method of least squares. Because the number of individuals was small, the data were not grouped, and each individual constituted a separate entry.

Sexes were pooled when it was found that the relative growth constants calculated separately for males and females were not significantly different. For males the equation of the fitted line was $\log W = \bar{4}.7817 + 3.0045 \log L$, and for females it was $\log W = \bar{=};4.6980 + 2.9700 \log L$.

The fitted line for the pooled data, shown in Figure 27, is $\log W = \bar{=};4.7323 + 2.9836 \log L$. Since the relative growth constant (n) does not differ significantly from three, it is concluded that weight increases as the cube of length for lengths between 60 and 700 mm.

The curve presented in Figure 28 is derived from the antilog equation $W = .00054\, L^{2.9836}$, and denotes a constant percentage relationship between length and weight, or, stated differently, it expresses a constant relationship between the multiplication of weight and the addition of length. It may be noted that the largest females lie on the left side of the curve, suggesting that beyond lengths of about 600 mm. the relative growth constant is less than three. This can only be confirmed, of course, by measuring a greater number of large specimens.

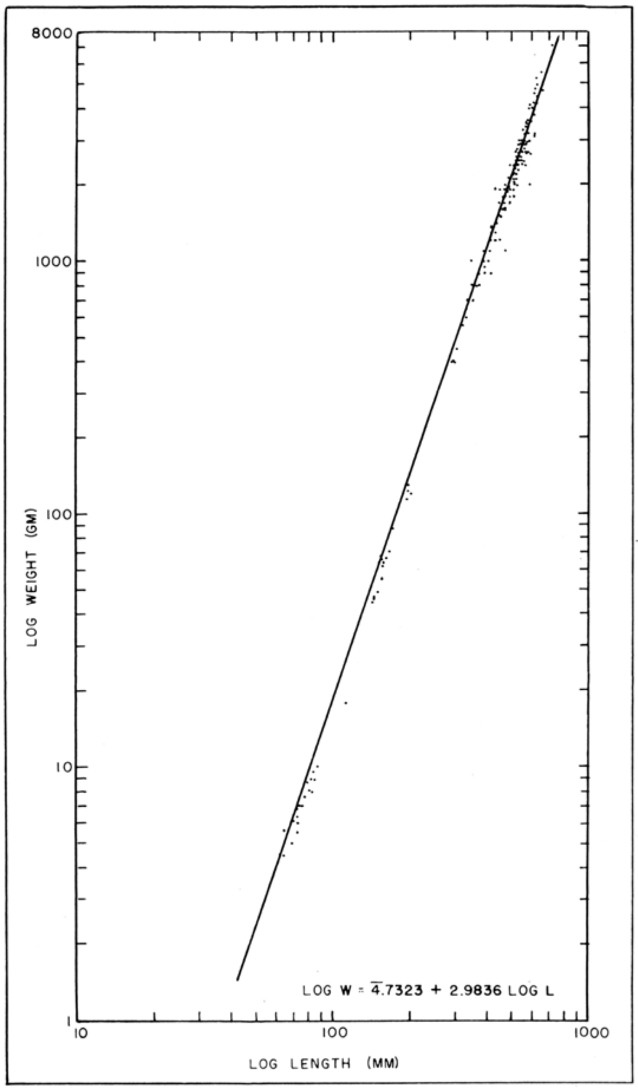

FIGURE 27. The regression of weight on length, sexes combined

FIGURE 27. The regression of weight on length, sexes combined

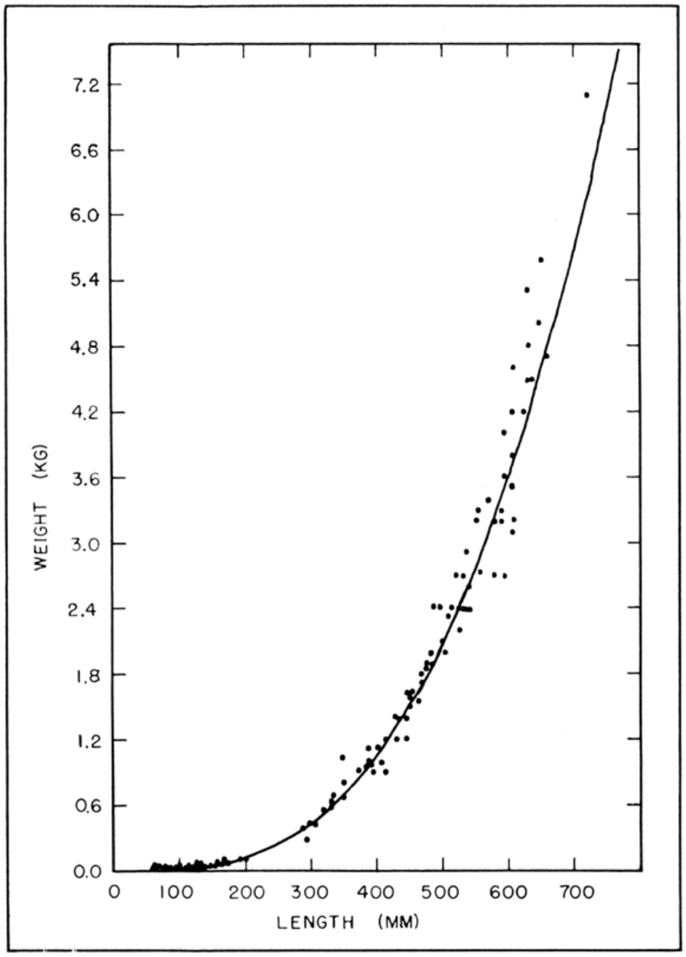

FIGURE 28. The length-weight relationship of *Scorpaenichthys*

FIGURE 28. The length-weight relationship of Scorpaenichthys

9. AGE AND GROWTH

9.1. GROWTH DURING THE FIRST YEAR

Growth during the first year of life is best illustrated by plotting the lengths of all specimens up to 300 mm. at their respective dates of capture (Figure 29). Collections from Southern California and Baja California are included with those from Central California, since no differences in growth were manifest.

The five-month period during which larvae occurred in the plankton of Monterey Bay is indicated along the bottom of the graph. Above this, the smallest specimens collected in tide pools virtually form a line at 40 mm., which extends from early February through late August.

The growth rate of the youngest age group can readily be followed for a period of about one year. A line extended from the end of the spawning season through the last 40 mm. specimen taken during the year (August 24th) defines the lower size limit of the year class, while a line drawn from the beginning of the season through the largest undoubted member of the year class (88 mm. in April) similarly defines the upper size limit. The divergence of these lines is logical, for the lower one represents the smallest, therefore the slowest growing fish from the end of the spawning season onward, while the upper one represents the fastest growing fish hatched at the beginning of the season. This difference in rates is also reflected in the fact that the first fish appear in the tide pools about three months after the first appearance of larvae in the plankton, whereas the last entry into the tide pools follows the disappearance of pelagic larvae by four months; this indicates that individuals become demersal in habit between the ages of three and four months.

The two lines are no more than gross approximations and therefore probably do not portray the real nature of growth, which may occur in more than one stanza. As many as five stanzas, each with a different rate of growth, have been demonstrated for some species. Such a change might occur in the growth of Scorpaenichthys, for example, upon entry into the tide pools (40–50 mm). Nevertheless, a perusal of the graph will show that these lines enclose all the specimens that obviously belong to the incoming year class, and may therefore be considered valid for the purpose of showing the broad trend of growth during the first year.

The gap between the incoming year class and the one-year-old group is distinct until June or July, but beyond that point the upper size limit of the former overlaps the lower size limit of the latter. In July individuals 8 months old may be the same length as individuals 15 months old. Using January as the month to represent one year of growth, it is possible to say that the mean length is about 160 or 170 mm., and that the range falls within 80 and 210 mm. It must be remembered, however, that this range represents individuals between 9 and 14 months old.

In Figure 30 all individuals between 40 and 200 mm. collected at Pacific Grove are plotted. The means form a straight line, passing through 172 mm. at January. This mean is compatible with the foregoing interpretation.

The length range of earlier year classes cannot be similarly determined due to the insufficiency of specimens larger than 200 mm.

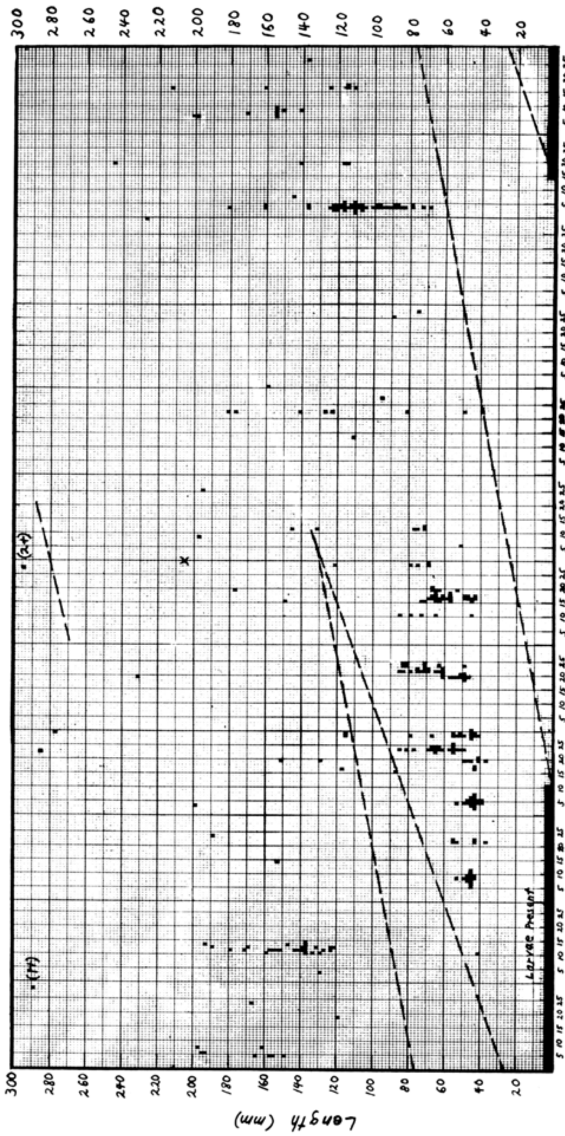

FIGURE 29. The length-time distribution of larvae and juveniles taken along the California coast. The × represents the mean at 1+.

FIGURE 29. The length-time distribution of larvae and juveniles taken along the California coast. The X represents the mean at 1 +

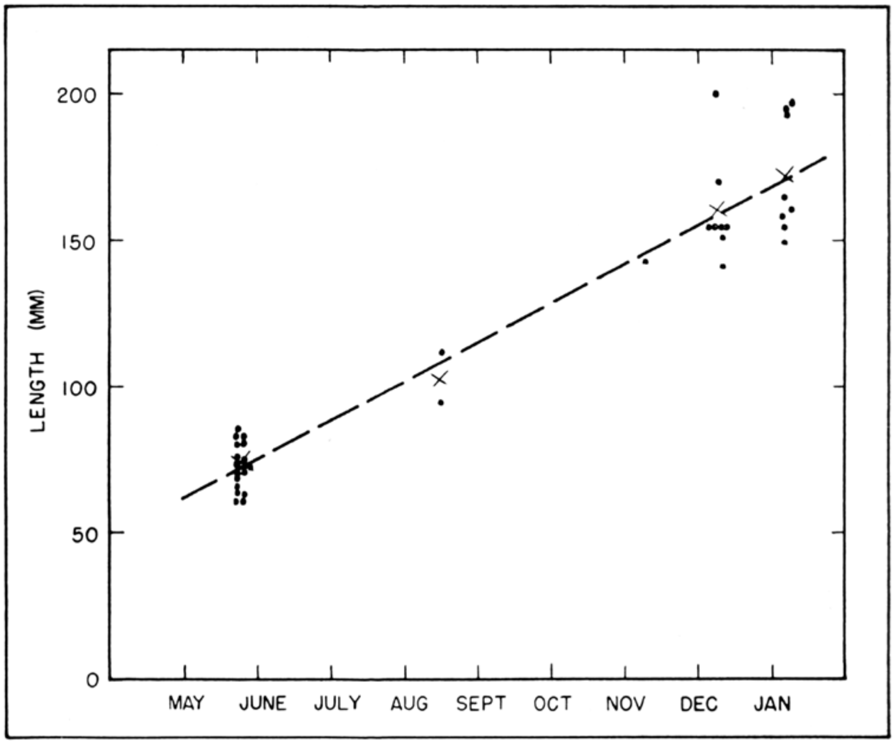

FIGURE 30. The length-time distribution of juveniles taken in tide pools at Pacific Grove in 1950-51. The ×'s are monthly means.

FIGURE 30. The length-time distribution of juveniles taken in tide pools at Pacific Grove in 1950–51. The X's are monthly means

9.2. AGE DETERMINATION

The study of growth beyond the first year is based on the ages of 105 specimens, as determined from their otoliths. Fin spines, vertebrae and opercular bones were also examined, but evidence of incremental growth was vague or complicated. The species is scaleless except for deeply imbedded lateral-line scales, which showed no growth increments.

The sagitta, largest of the three otoliths, is, in Scorpaenichthys, elliptical in shape, bluntly rounded at the posterior end, and well-pointed at the anterior end. The lateral face is concave, and the medial face, traversed by a deep sulcus, is convex. The anterior point is an attenuation of the zone below the sulcus, and tends to be short in very young fish and long in the older specimens. Variation in the shape of otoliths was best reflected by the variability of this point. The otoliths of older specimens often showed excrescenses on the dorsal margin of this tip.

When age is to be determined from a structure, it is desirable to establish the growth of that structure relative to the over-all growth of the fish. Since variation in shape of the otoliths precluded the use of their linear measurements, the relationship between otolith weight and the total length of the fish was ascertained. Each pair of otoliths was weighed to the nearest thousandth of a gram on a chainomatic balance. The difference between otoliths of the same pair was negligible, being less than 2 percent of the total weight of the pair in five cases. It is apparent in Figure 31 that the dispersion around the fitted line is considerable, but the curvilinear relationship is quite evident. The equation of the fitted line, $W_o = .354\ L_f^{1.47}$ where W_o = weight of otolith and L_f = length of fish, indicates that the otolith grows at a constant but lower rate than the fish as a whole. Weight accrues to the fish as the cube of length, and to the otolith as the 1.47 power of length (of fish).

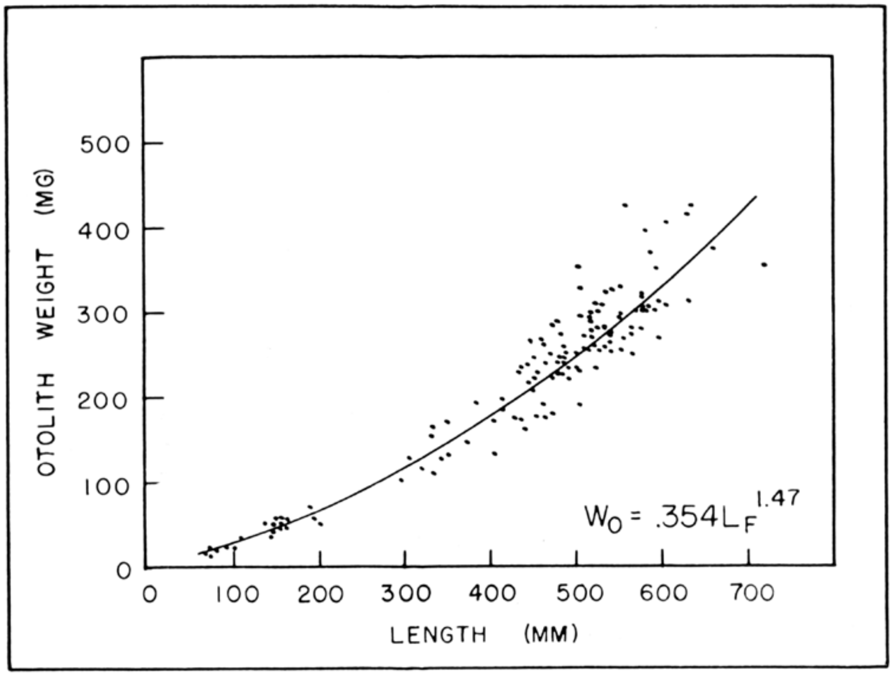

FIGURE 31. The relationship between otolith weight and fish length. Both sexes are included.

FIGURE 31. The relationship between otolith weight and fish length. Both sexes are included

Readings were made with a compound microscope at various magnifications. The most critical factor was illumination. Transmitted light was not used because it obliterated the peripheral circuli. In reflected light the periphery retained its differential opacity, while the central region, though more opaque than in transmitted light, could still be interpreted. Varying the illumination frequently improved the readability, but, in general, the best resolution was achieved by placing the source of light at an angle of 40 or 50 degrees above the otolith.

Grinding, or sectioning, polishing and staining were tried, but did not improve the readability of the otoliths. Various liquid media were also tried, but none were found to be better than water.

Criteria were established after making a subjective study of 20 otoliths. Rings which could be traced completely around the otolith were considered valid. All rings were broad and reasonably distinct on the anterior tip, but narrow and crowded on other parts of the otolith. With the expanded tip as a starting point, it was possible to trace these rings, or at least count the same number at three or four different places on the otolith. In general, the more rings present, the more difficult they were to count.

Only the completed translucent rings were counted, so that the margin was eliminated. Accordingly, all groups were designated as n+ in age, indicating that some growth beyond the most recent ring had occurred.

Ages were determined from three complete series of readings. To eliminate bias, otoliths were examined unidentified and in random order. The 38 fish of the year were disregarded after the second reading. Their otoliths were opaque except for vaguely translucent margins. The remaining 126 otoliths were read a third time to resolve the differences between the first two readings. Twenty-one of these were considered unreadable, either because no reading could be obtained, or because readings differed by more than one ring. In 44 cases all three readings agreed, while in 61 cases a difference of one occurred, with two out of the three readings in agreement. In all cases where two or three readings agreed, appropriate ages were assigned. Table 8 contains the lengths of specimens in each age group.

TABLE 8

The lengths of Individuals (mm.) Assigned to Each Age Group. The Means Are Tabulated for Each Sex.

Females

1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+	13+
290	296	394	445	479	471	515	558	605	630	659		720
	320	417	481	503	508	540	578	624	632			
	338	417	485	506	510	540	581	630				
	388	428	500	508	531	584	598					
		432	523	515	533	585	608					
		450	595	518	538	590						
		456		520	556	594						
		459		522	558	606						
		464		526	568							
		479		528	570							
		503		537	577							
				539	580							
				552	589							
				580	608							
---	336	445	504	524	550	569	585	---	---	---	---	---

Males

1+	2+	3+	4+	5+	6+	7+	8+	9+
	302	404	435	445	460	484	543	502
	331	407	437	450	462	515		559
	334	444	465	470	504	540		
	343	453	474	481	558	540		
	350		475	486				
	350			493				
	365			494				
				543				
---	339	427	457	484	496	520	---	---

TABLE 8
The lengths of Individuals (mm.) Assigned to Each Age Group. The Means Are Tabulated for Each Sex

Only one individual, 290 mm. in length, was aged at 1+. The 2+ to 8+ groups were reasonably well represented, with the greatest numbers of individuals in the 5+ and 6+ groups (females). Only seven females had nine or more rings, and the oldest of these, by far the largest specimen captured (720 mm.), was tentatively aged at 13+. Figures 32, 33 and 34 are photographs of otoliths having one, eight and thirteen rings, respectively. It was not possible to reproduce photographically the central as well as the peripheral rings in the latter two, although they could be detected visually. Consequently the first two rings on the 8+ specimen, and the first four rings on the 13+ specimen cannot be seen in the photographs. All were photographed at the lowest possible magnification on the Leitz Ultropak, an instrument with a vertical light source. The larger otoliths could only be photographed in part, but better contrast was obtained with this instrument than with other compound microscopes.

Although the dark rings are definitely an index of age, it was not possible to establish their annual character by direct means. Usually this is accomplished by determining the time of year that the annulus is formed on the margin, but the margins of all otoliths used in the present study appeared to be opaque. If the degree of opacity varied, it was not

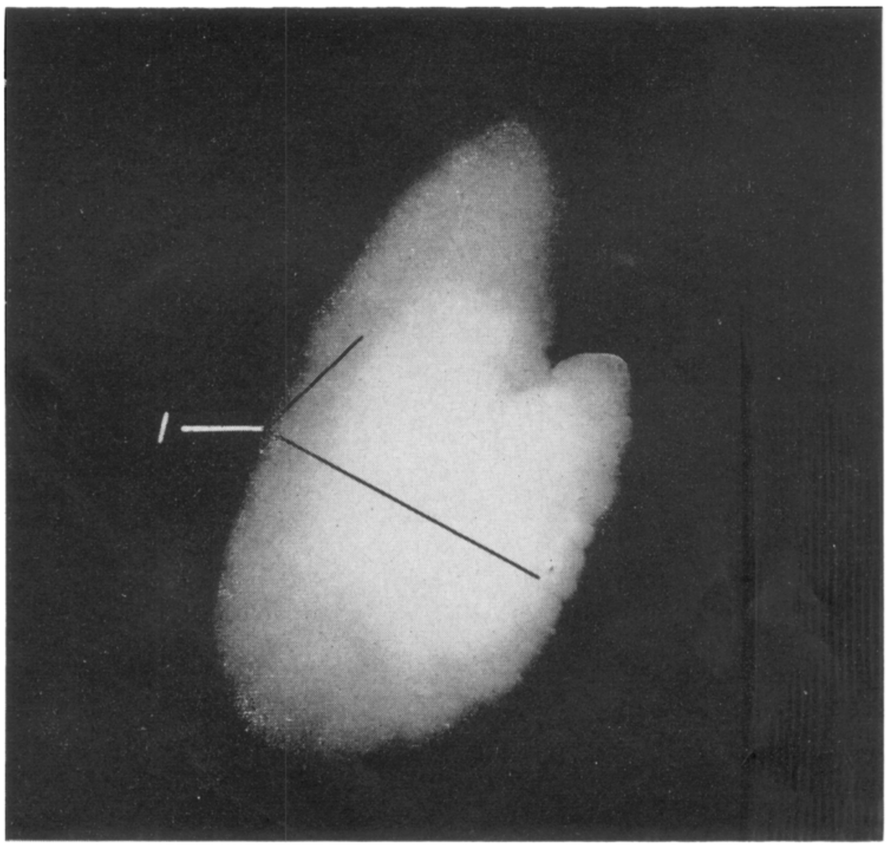

FIGURE 32. Female of 290 mm. aged at 1+. Taken at the end of January. The second winter ring is forming on the margin.

FIGURE 32. Female of 290 mm. aged at 1+. Taken at the end of January. The second winter ring is forming on the margin

evident. The only alternative is to justify the assumption of the annual character of these growth zones by indirect means.

All larvae hatch during the winter and fall, and, as already shown, are between 9 and 14 months old the following January. A number of such specimens, ranging from 150 to 200 mm. in length, did not exhibit circumscribed winter (translucent) rings, but the 290 mm. specimen captured in January showed a broad translucent zone bordered by an opaque zone (Figure 32). It is apparent from the distribution of lengths in Figure 29 that the former specimens are just completing their first year of life, while the latter individual must be about two years old (1+). The second winter ring is in fact being formed, as the photograph shows. Morrow (1951) remarks that most sculpins form the same type of zone at the same time of year. It is probable, therefore, that in the otolith of Scorpaenichthys, the dark or translucent zone is formed in the winter, while the light or opaque zone is formed in the summer.

To facilitate the study of growth that follows, a length of 205 mm. was chosen to represent the 1+ age group. It is the midpoint of the tentative length range (Figure 29) at the beginning of July, by which time the first winter ring should be completely circumscribed on individuals between 14 and 19 months old.

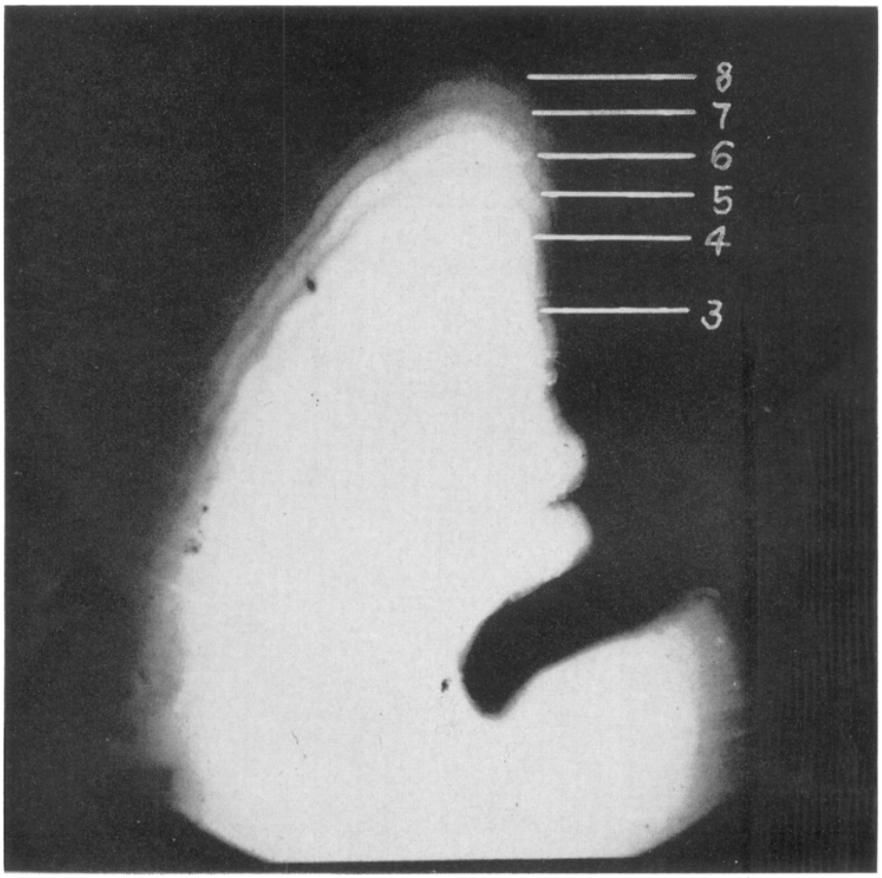

FIGURE 33. Female of 558 mm. aged at 8+. The first two annuli are not visible in the photograph.

FIGURE 33. Female of 558 mm. aged at 8+. The first two annuli are not visible in the photograph

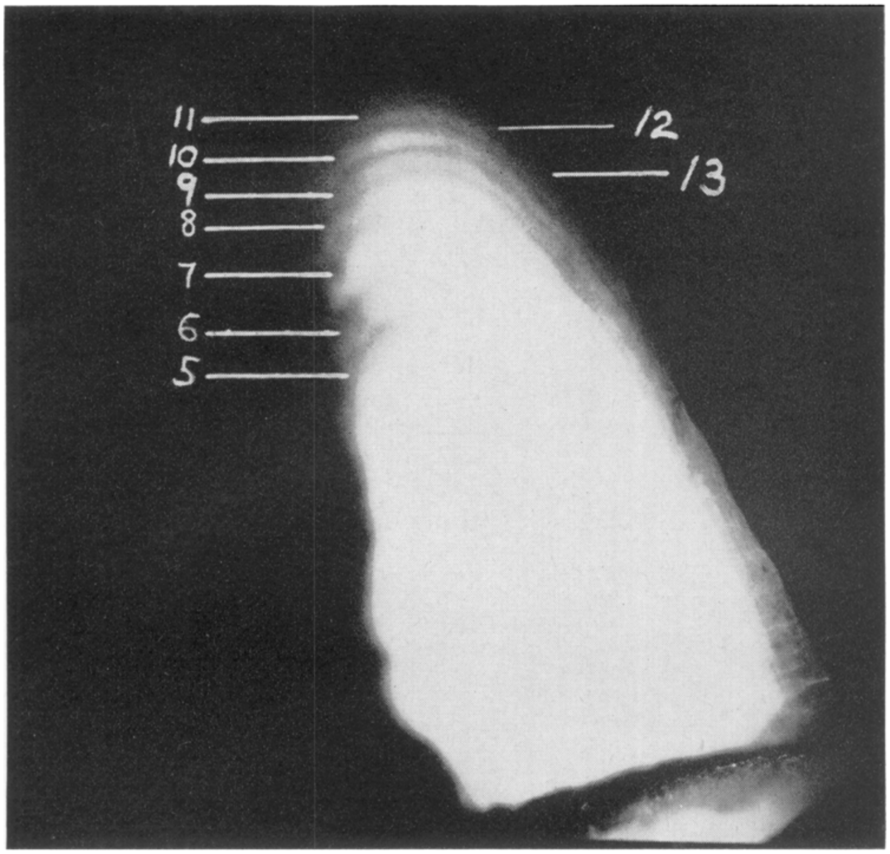

FIGURE 34. Female at 720 mm. aged at 13+. The first four annuli are not visible in the photograph.

FIGURE 34. Female at 720 mm. aged at 13+. The first four annuli are not visible in the photograph

9.3. GROWTH AFTER THE FIRST YEAR

Growth has been expressed in three basically different ways by different workers. Growth of weight in time is probably the best means of expressing the total growth for a species. Relative growth is the best means of expressing growth in form, while absolute linear growth expresses nothing more than the growth in a given direction. Brody (1945) states that: “While the age curve of growth in weight describes the change in the *organism as a whole,* the age curve of growth of some one linear dimension describes the change in only one of many linear measurements, which may or may not be proportional to the change in other linear measurements or to the change in weight.”

The growth of fishes is usually expressed as the change in length with age. While this describes only one dimension of growth, the relationship between this particular dimension and age has been repeatedly demonstrated. For this reason, and also because age-length data are often the only means of estimating population composition and dynamics in fisheries research, the growth of Scorpaenichthys will be expressed in terms of length.

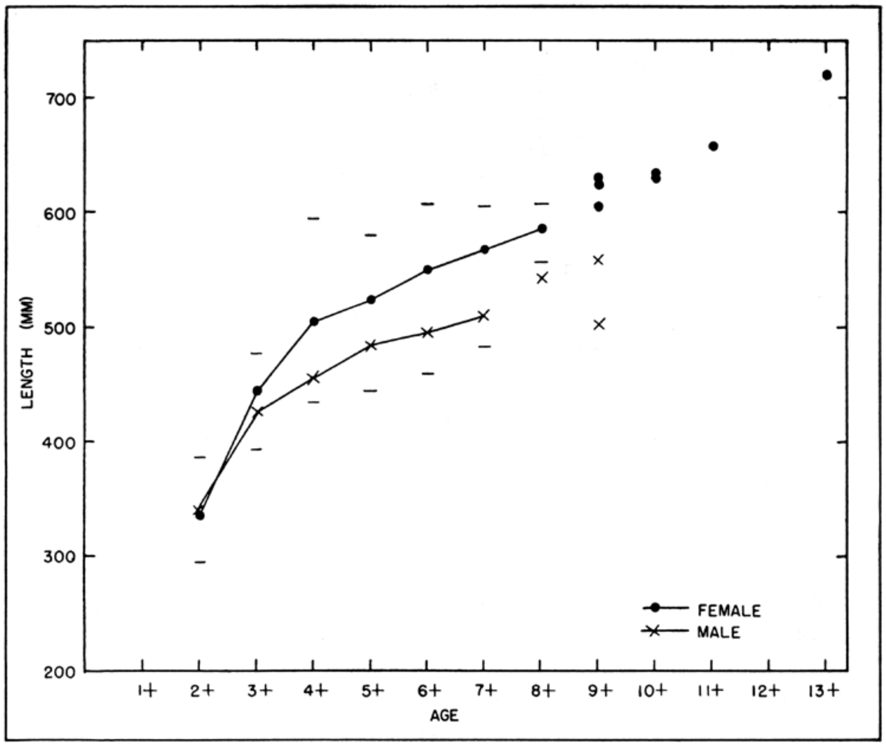

FIGURE 35. Age-length plot for *Scorpaenichthys*. The dashes are range marks.

FIGURE 35. Age-length plot for Scorpaenichthys. The dashes are range marks

In Figure 35 the mean length at each age is plotted separately for the sexes. The short lines above and below each pair of points are the lengths and the smallest specimens respectively. All the maximum points are female and all lower points are males except at 2+ and 8+. Growth during the first few years of life is relatively rapid, tapering off at an age of 3+, where a notable difference between the average lengths of males and females first becomes evident. Beyond the age of 8+ for females and 7+ for males only individual points are plotted. It may be noticed that the few females over eight years old are somewhat larger than might be expected from the length ranges of those under eight years old. No explanation could be found to account for this.

Walford, in 1946, described a simple graphic method of plotting the usual length-on-age data whereby growth could be objectively described by two constants. When lengths at ages *n*+1 are plotted against lengths at ages *n*, the points usually fall in a straight line for that part of the line "above the inflection." The equation of the straight line fitted to these points has the form, in Walford's notation, $l_{n+1} = l_1 + kl_n$ where l_{n+1} is length at age *n*+1, l_1 is the *y* intercept, *k* is the slope of the line, and l_n is length at age *n*. The slope of the line, *k*, is the constant ratio of successive growth increments. The point l[8], at which the fitted line intersects the line of no growth, drawn across the graph at a 45° angle, is

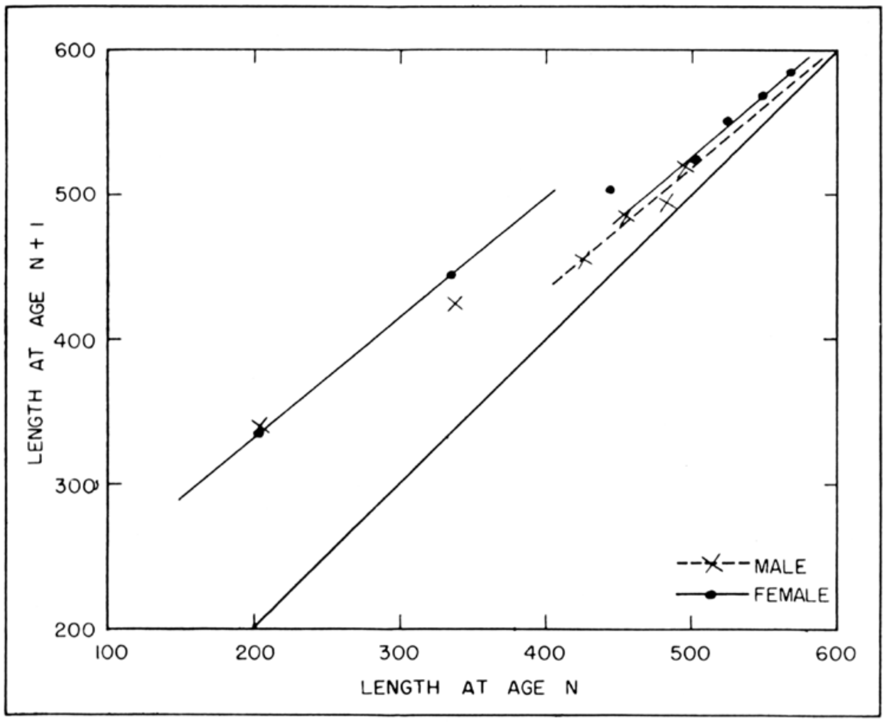

FIGURE 36. Length at age *n* plotted against length at age $n+1$

FIGURE 36. Length at age n plotted against length at age n + 1

called the limiting length by Walford. Once the slope of the line is known, l[8] can be conveniently calculated from the equation $l[8] = l_1/1-k$ It might also be pointed out that the line of no growth has a slope of unity, and that any line representing a constant rate of decrease will have a slope of less than unity. The higher the *k* value, the more slowly is l[8] approached. By definition, l[8] is the growth asymptote of the species.

When the age-length data for Scorpaenichthys were plotted according to Walford's transformation (Figure 36) it was immediately apparent that the points did not conform to a straight line. The two, or possibly the three, lowest points for females, and the lowest point for males, were at variance. Before continuing with this discussion, therefore, it is necessary to determine whether or not these points are to be included in the regression.

To test the hypothesis of a constantly decreasing rate of growth, a graphic method described by Brody (1945) was employed. He used it to evaluate the relationship between age and weight for many organisms, but the method is equally applicable to age-length data. When the difference between length at maximum growth (l[8]) and length at each age (l_n) is plotted as a percentage of l[8] on arithlog paper, the points will fall in a straight line if the rate of decrease is constant. Thus

$$p = \frac{l\infty - l_n}{l\infty}$$

FORMULA

As Brody points out, the line will deviate in a curved manner if high or low values of l[8] are assumed. This is demonstrated on page 512 of his text.

If, on the other hand, more than one rate of decrease (*k*) is inherent in a set of values, there will be a definite break in the line. If the line is distorted by the assumption of an unreasonably high l[8] it may become curved on either side of the break, but the latter will still be apparent. The points can only be made to approximate a straight line by choosing a ridiculously low l[8].

It seemed reasonable, therefore, to choose the convenient asymptote of 1000 for Scorpaenichthys, since the largest specimen taken was 720 mm. The resulting lines for each sex in Figure 37 are deflected in the third and fourth years of life respectively. (These lines are replotted in Figure 38 using the asymptotes derived below from Walford's transformation.)

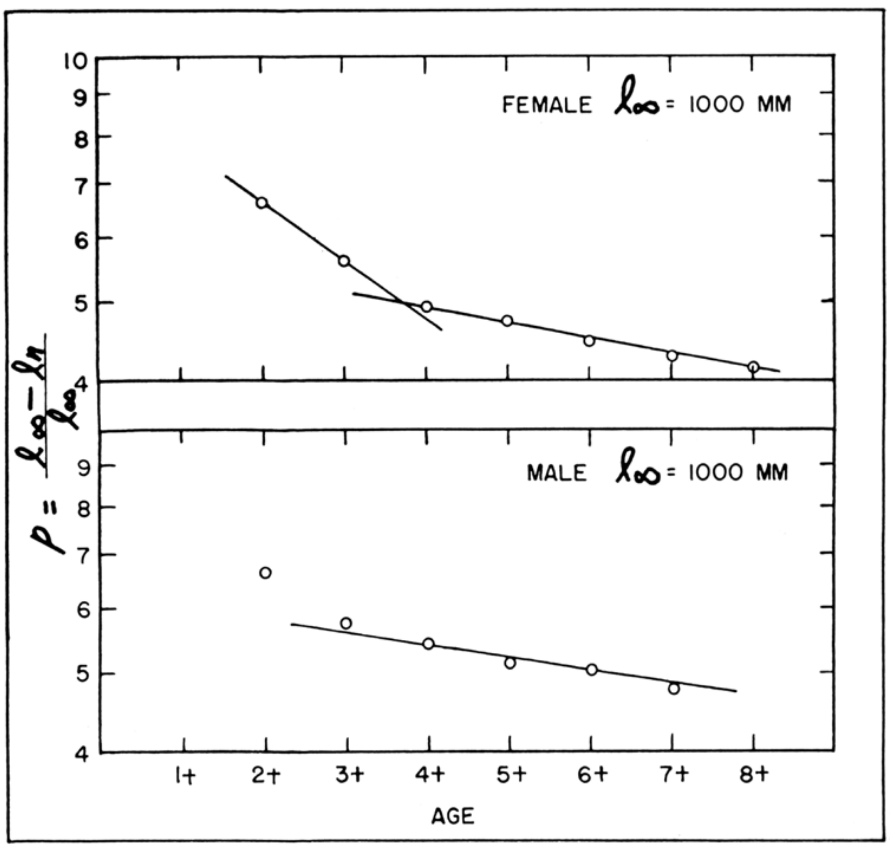

FIGURE 37. Length at each age plotted as *p*, with an arbitrary asymptote of 1000 mm.

FIGURE 37. Length at each age plotted as p, with an arbitrary asymptote of 1000 mm

The assumed mean length of 205 mm. for the 1+ age group was used in conjunction with the mean length of the 2+ age group to plot the lowest point in Walford's transformation (Figure 36). Although the break is apparent in the *p* transformation (Figure 38) without this point, it does lie very close to the plotted line, which means that it is not greatly in error. Since the mean lengths of males and females varied at random during the first year, the 205 mm. is applied to both sexes. The fact that the mean length of males is slightly higher than that of females at 2+, whereas it is lower in all succeeding years, infers that the random variation is extended at least through this age. In the remaining calculations pertaining to juveniles (below the break), the means derived from the female data will be applied to both sexes.

Returning to Walford's transformation, it is now possible to eliminate the transition points for both sexes and fit lines by the method of least squares to (1) the two lower female points, (2) the upper four female points, and (3) the upper four male points. The calculations and resulting constants are set forth in Table 9.

The growth of Scorpaenichthys can now be conveniently described by six constants. Since *k* denotes the proportion of the remaining growth that is not fulfilled during each year, the reciprocal, 1 — *k*, denotes the proportion of the remaining growth that is fulfilled during each year. Converting the *k* values (Table 9) to 1 — *k* values, then, permits the following description of growth for Scorpaenichthys. Juveniles approach an asymptote (l[8]) of 983 mm. at a constant rate of .17. Mature males approach an asymptote of 604 mm. at a constant rate of .17 after the second or third year. Mature females approach an asymptote of 760 mm. at a constant rate of .09 after the third or fourth year.

The meaning of these values can be more readily appreciated when they are used to reconstruct the growth pattern of the species in the conventional length on age plot (Figure 39). For this purpose, the lowest length employed in the calculation of each regression line was used as a base from which to calculate successive l_{n+1} figures. The curve

TABLE 9

Regressions of Length at Age n on Length at Age n + 1. X = n; Y = n + 1; k = slope; l∞ = growth asymptote.

	X	*Y*	*X*²	*XY*	*Y*²	*No. of entries*	*k*	*l*∞
Juveniles								
Sums	541	781	154,921	218,400	310,921			
Means	271	391	8,580	7,139	5,940			
		$Y = 165 + .83X$				2	0.83	983
Females								
Sums	2,147	2,228	1,154,853	1,198,111	1,243,062			
Means	537	557	2,451	2,232	2,066			
		$Y = 68 + .91X$				4	0.91	760
Males								
Sums	1,864	1,957	871,450	914,311	959,521			
Means	466	489	2,826	2,349	2,095			
		$Y = 102 + .83X$				4	0.83	604

TABLE 9

Regressions of Length at Age n on Length at Age n + 1. X = n; Y = n + 1; k = slope; l[8] = growth asymptote

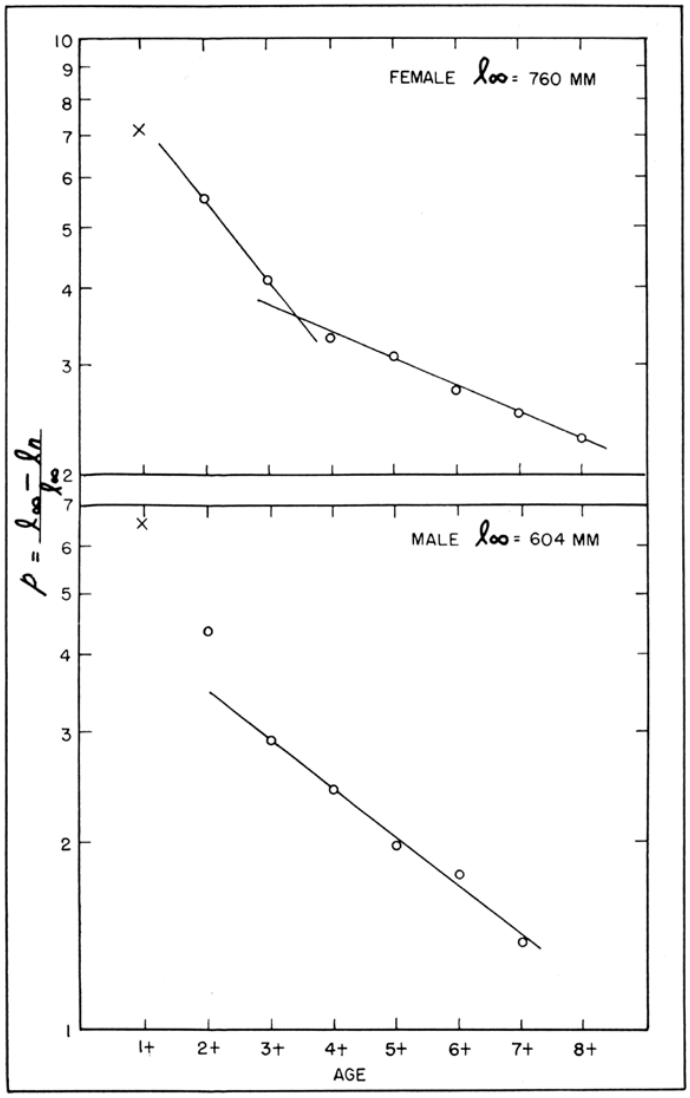

FIGURE 38. Length at each age plotted as *p*, with the calculated asymptotes

FIGURE 38. Length at each age plotted as p, with the calculated asymptotes

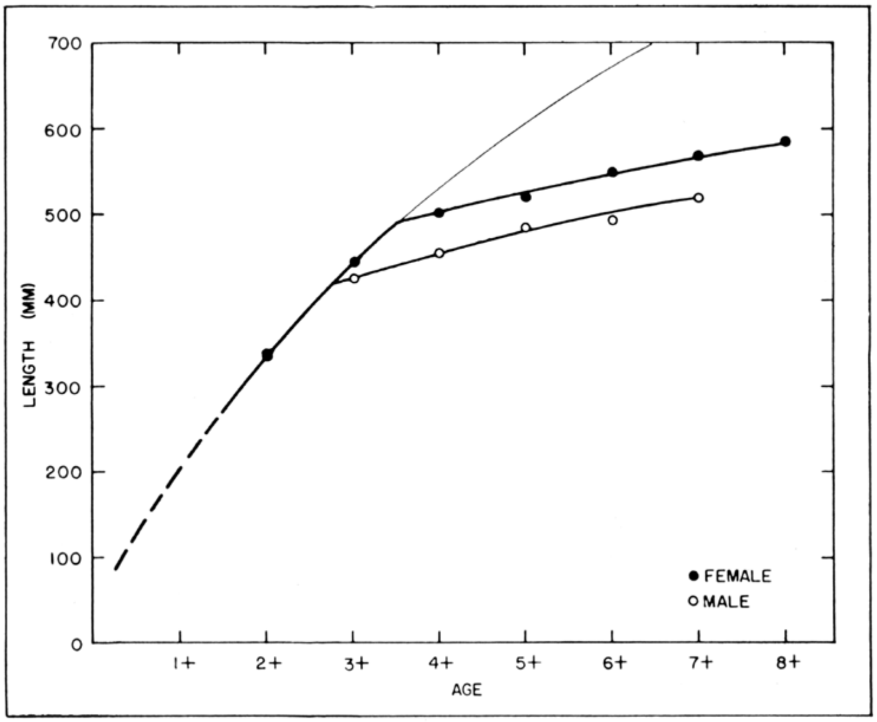

FIGURE 39. Age-length curves for *Scorpaenichthys* derived from the $n+1$ on n regressions. Points are means from original data.

FIGURE 39. Age-length curves for Scorpaenichthys derived from the n + 1 on n regressions. Points are means from original data

for juveniles was extrapolated to indicate the course growth might follow if the rates of deceleration remained constant throughout life. of course, it must be remembered that these are mean values and that the change probably occurs at rather different times for different individuals. Such variations would further multiply the already wide length range apparent among juveniles of a given age.

The cause of the change in growth rates, particularly in regard to the difference of occurrence in time for the two sexes, cannot be readily explained.

The most obvious physiological change after the first few years of life is the advent of sexual maturity. Although the available data do not permit an accurate determination of age at first sexual maturity, they do suggest that the males mature about a year earlier than the females. The 2+ through 5+ fish taken between November 1st and April 20th were recorded as mature or immature. The condition of the gonads was apparent to the naked eye for almost all specimens. Some of those taken in the latter part of the period were verified by microscopic examination and ovarian weights. At 1+ no fish were mature; at 2+ there were 33 percent mature males and no mature females; at 3+ there were 100 percent mature males and 63 percent mature females; at 4+ there were 100 percent mature males and 80 percent mature females; at 5+ all

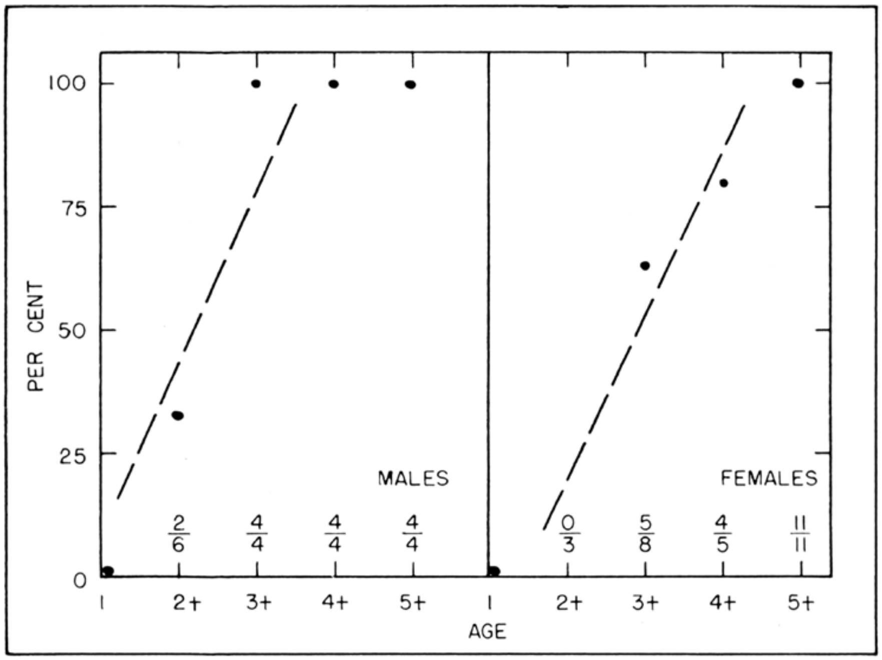

FIGURE 40. The percentage of mature male and female *Scorpaenichthys* at each age. Fractions indicate number of mature specimens over total examined.

FIGURE 40. The percentage of mature male and female Scorpaenichthys at each age. Fractions indicate number of mature specimens over total examined

specimens were mature. In Figure 40, the fractions show the number of mature specimens over the total number available. The lines are only tentative.

With only these data, it is not possible to evaluate exactly the relationship between length at age of first maturity and the change in growth rates. It seems significant, however, that Morrow (1951) notes that the vast majority of longhorn sculpins mature in their third (2+) year of life, with perhaps a small percentage remaining immature until the fourth (3+) year. Plotting the calculated lengths for this species on Walford's transformation yields a picture similar to that found for Scorpaenichthys. The first point is high, and the second point intermediate between it and the line formed by the later points. When all lengths were transposed to *p*, a break was evident between the 2+ and 3+ age groups.

10. COLOR

In describing Scorpaenichthys, several authors note that the color is extremely variable. Jordan and Evermann (1898), Barnhart (1936), Bolin (1944), Clemens and Wilby (1949), Roedel (1948), all note the outstanding blue-green or turquoise-green ground color that occurs in many individuals. Roedel described the lining of the mouth and the flesh as translucent turquoise-green. Barnhart mentions, also, the green color of the flesh. Only the first two works mentioned above note individuals with a red ground color.

The juveniles, when they enter the tide pools at a length of 40 mm., are silvery red in color, the darker color forming five irregular vertical bars. When they reach a length of 60 or 70 mm., however, some variation in the color of individuals becomes apparent. Most are olivaceous, but some tend to be reddish or gold, particularly on the ventral surface, while others are translucent green ventrally. The olivaceous specimens are usually evenly colored. Those tending to be green or red are vaguely mottled with brown, white, lavender and green on the sides.

The mottled condition becomes more apparent in the yearlings. The color of 14 specimens, ranging from 141 to 197 mm. in total length, graded from brown above to gold, yellow, lavender, red, orange, white or green ventrolaterally. The lateral color faded to almost white on the ventral surface. The lateral color often occurred again as spots just above the base of the anal fin, where the background color was different from that on the dorsal parts of the body. The chin and lips were strongly speckled with white and the fins were mottled, barred or spotted. Although mottled, all these yearlings displayed an unmistakable pattern of four broad, irregular vertical bars on the sides and dorsal fins. Four patches of melanophores, two on each dorsal fin, originate at an earlier period of development. This has been fully described in the discussion of larval development. The barred pattern becomes apparent on the body as these patches spread over the dorsal fins. Still obvious on the yearlings, the barred pattern is gradually obscured by its own ramifications as adult proportions are attained.

The ground color varied in both juveniles and adults, but there seemed to be a definite relationship between sex and basic ground color only for the adults. The color of the latter varied from dark brown through various shades of red to light tan and gray with large patches of black. Almost all were mottled, or marbled. Giant marbled sculpin, incidentally, is the common name assigned to Scorpaenichthys by Clemens and Wilby (1949). The ground color is the most outstanding feature of adult coloration, and upon it all individuals, including the juveniles, can be classified as either red, green or white. In the remainder of the discussion, these three colors refer to the diffuse pigment in the integument, visceral lining and muscle tissue. When difficult to detect elsewhere, the lining of the mouth was found to be quite reliable. The green color in most of the females was intense, particularly in the mouth and around the anus. Both sexes showed heightened color during the spawning season, but the red in the males varied considerably and was, on the whole, much fainter than the female color. During the summer months, when the gonads are in the resting phase, the color becomes faint in both sexes, and the white category already mentioned is largely a result of this seasonal loss of color. However, the green is more readily detected than the red even during the summer.

In Table 10, 135 specimens are grouped according to color, sex, sexual maturity and length. The length intervals were arbitrarily chosen. Those individuals classified as immature have not yet spawned for the first time. Those classified as mature had maturing, mature or spent gonads during the 1950–51 spawning season. The 12 specimens classified as white (less than 9 percent of the total) could not be allocated to either of the main categories under discussion. Most but not all were juveniles. The white signifies a faintness of coloration rather than a pertinent condition, and will therefore be dismissed from the discussion.

If the red and green immature individuals of both sexes are summed, there are 26 percent green and 74 percent red, but if the sexes are considered separately, the result is 11 percent green, 89 percent red for males, and 40 percent green, 60 percent red for females. The red color, then, is dominant among juveniles of both sexes, although the females show a somewhat greater tendency towards green than the males.

The adult males show a further shift to the red condition (92 percent), and in females the ratio is strongly reversed to green (97 percent). With such a strong correlation between sex and color, the presence of even 8 percent mature green males and 3 percent mature red females is curious, but cannot be explained. It is worth noting, however, that the three males involved are all over 500 mm. in length. One of these was the smallest and another the largest of the 11 males in the 500–800 mm. category.

Although the literature indicates that the color dimorphism here described would be quite simply explained by the presence of a carotenoid pigment, the green pigment from a female Scorpaenichthys could not be identified as such.

Goodwin (1951) stated that as yet no water-soluble carotenoproteins had been found in fishes. Since the green pigment extracted from Scorpaenichthys was water soluble, I sent a sample of it to Dr. Goodwin, who generously subjected it to spectrographic analysis. He informed me (*in litt*.) that this pigment must be considered an unidentified, green, water-soluble chromoprotein, probably not a carotenoprotein, with an absorption maximum at 662.5 [u] and an inflection at 400 [u]

Similar unidentified green pigments have been reported for at least two other fishes. Willstaedt (1941) noted that Cottus scorpius contains a water-soluble green chromoprotein with an absorption maximum at 681 [u], and von Zeynek (1902) reported a similar pigment in Crenilabrus pavo. Cursory observation in the field disclosed the presence of a green ground color in some of the smaller tide-pool cottids, while the muscle tissue of the lingcod (Ophiodon), examined at the markets, was found to be green in color like that of Scorpaenichthys.

The identification of this pigment and subsequent knowledge of its function in fishes is the province of the physiologists, and was considered beyond the scope of the present investigation.

TABLE 10

One Hundred and Thirty-five Specimens Grouped According to Color, Sex, Sexual Maturity and Length

Length (mm)	Immat. M		Mat. M		Mat. F		Immat. F		White M	White F
	Green	Red	Green	Red	Green	Red	Green	Red		
101-200	–	3	–	–	–	–	1	3	1	6
201-300	–	–	–	–	–	–	–	1	–	–
301-400	–	4	–	6	1	–	–	–	–	2
401-500	1	1	–	20	14	1	3	2	–	–
501-800	–	–	3	8	47	1	–	–	2	1
Totals	1	8	3	34	62	2	4	6	3	9
Percentages	11.0	89.0	8.0	92.0	97.0	3.0	40.0	60.0	25.0	75.0

TABLE 10
One Hundred and Thirty-five Specimens Grouped According to Color, Sex, Sexual Maturity and Length

11. SUMMARY

1. The cabezon is a species of comparatively minor importance in the commercial and sport landings of California.

2. The sport catch has increased at a much greater rate than the commercial catch since 1946, being over five times as great as the latter in 1950.

3. The greatest commercial landings occur during the winter months at Monterey, and the greatest sport landings occur during the summer months at Santa Barbara.

4. Although the increase in the sport catch after the war can be accounted for by increased sport fishing effort, the relationship between effort and catch differs considerably at the six major ports along the California coast. This variation in catch per unit effort is due in part to availability of the species and in part to different types of fishing.

5. In the sport fishery, yield has increased with effort at all ports.

6. Standard length is 0.83 of total length over the whole length range of the species.

7. The cabezon inhabits rocky bottoms up to depths of approximately fifty fathoms, and its recorded range extends from the Queen Charlotte Islands, British Columbia, to Turtle Bay, Baja California.

8. The pelagic larvae, which occur in the plankton from November through March, have been collected as far as 200 miles from the coast. Postlarvae appear in the tide pools when they are about 40 mm. long, then gradually move into deeper water as they grow larger.

9. Crabs of several species constitute one-half of the adult diet, fish and molluscs the other half. Crabs replace other crustaceans in the diet of juveniles when they reach a length of about 140 mm. Fish first appear in the stomachs of juveniles 150 to 200 mm. long, and molluscs in the stomachs of preadults 300 mm. long.

10. Spawning commences in early October or late November, reaches a peak in January and ends in the latter part of March. There is strong evidence that at least some part of the population spawns more than once during the season.

11. The number of eggs spawned increases with the total weight of females. The regression of number of eggs on total weight, $Y = 27.3 + 1.53X$, shows that females weighing 1.4 kg. spawn an average of 48,700 eggs in a batch. This increases by 1,500 for each 100 g. of total weight to an average of 97,600 at 4.6 kg.

12. The newly hatched larva of the cabezon differs from those of other California cottids that have been described in having a more elongate yolk sac, heavier and more general pigmentation, and an extension of the median finfold anterior of the anus. Metamorphosis is gradual, and the young fish approximates the adult form by the time it is 60 mm. long.

13. The length-weight relationship for the species is $W = .00054L^{2.9836}$. The relative growth constants of males and females are not significantly different.

14. In January the one-year-old age group, which includes individuals between nine and fourteen months old, has a mean length of 160 or 170 mm. and a range of 80 to 210 mm.

15. The mean lengths of all age groups except the 1+ were determined from otoliths.

16. The growth of Scorpaenichthys can be described by six constants derived from the equation $l_n+1 = l_1 + kl_n$ and

$$l_\infty = \frac{l_1}{1-k}$$

FORMULA

. Juveniles approach an asymptote (

$$(l \infty)$$

FORMULA

) of 983 mm. at a constant rate of 0.17 (1-*k*). Mature males approach an asymptote of 604 mm. at a constant rate of 0.17 after the second or third year. Mature females approach an asymptote of 760 mm. at a constant rate of 0.09 after the third or fourth year.

17. Although the data do not permit an accurate determination of age at first sexual maturity, they do suggest that the males mature about a year earlier than the females.

18. Although there is considerable variation in the color patterns of individuals, a definite relationship exists between the basic ground color and sex. The red ground color is dominant in juveniles of both sexes, but among adults the males are predominantly red, the females predominantly green.

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