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The Life History of the Starry Flounder Platichthys stellatus (Pallas)[1]

By

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STARRY FLOUNDER, *Platichthys stellatus*. Photograph by J. B. Phillips

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ACKNOWLEDGMENTS

In embarking upon investigations of this kind it is necessary to call upon many persons for assistance in particular problems. During the course of this work the author enjoyed the willing cooperation of many workers, and it gives me pleasure to here acknowledge specific aids extended.

My thanks go to Dr. Rolf L. Bolin for his direction of this work and his suggestions and criticisms during the course of the investigation and the writing of this paper. I am particularly indebted to Dr. Willis H. Rich and Dr. George S. Myers for encouragement and assistance in Dr. Bolin's absence. To Mr. Julius B. Phillips of the California Division of Fish and Game and Dr. Raghu R. Prasad I also extend my thanks for many valuable suggestions, and I take this opportunity to express my sincere appreciation to my colleagues and the staff at the Hopkins Marine Station for their assistance in collections and technical procedures. The cooperation of the commercial fishermen of Monterey and Santa Cruz in securing samples from the commercial catch is greatly appreciated. Special thanks go to Mr. Robert Giho of Santa Cruz Fisheries, Inc., for his aid in securing ripe fish during the spawning season.

HAROLD G. ORCUTT
January, 1950

1. INTRODUCTION

The order Heterosomata, the great group of the flatfishes, has long been of major economic importance in the marine fisheries of the world. Its multiform representatives are the subject of a very extensive and diverse literature which, however, is but a brief prologue to what research can bring to light. This paper is an attempt to contribute to the knowledge of one member of the group, and it is hoped that it may be of some value to intelligent management of the fishery in the future.

The specimens of starry flounder for this study were taken during the last four months of 1946 and throughout the years 1947 and 1948 from the waters of Elkhorn Slough, the mouth of the Salinas River and at various localities in Monterey Bay (Figure 1).

In Elkhorn Slough the fish were caught in a bobbinet seine 255 cm. long and 94 cm. deep, with hexagonal meshes of 3 mm. diameter. At the mouth of the Salinas River a minnow seine was used for monthly collections made from September, 1946, to February, 1947. This net measured 3 m. long, 1 ¼ m. deep, and had meshes 12 mm. in length. During the period from March, 1947, to August, 1947, the samples from the same locality were taken in a modified beam trawl (Figure 2). This gear had a beam 2 m. long, a depth of 50cm. and length of 4 m. The mesh length was graduated from 4 cm. at the lead line to 2 cm. in the sack. A bag of bobbinetting was sewed around the sack to impound all fish small enough to pass through the mesh of the sack.

The fish taken from Monterey Bay were secured from commercial fishermen and wholesale fish dealers. These fish were caught in trammel nets off Santa Cruz; in drag nets off Monterey and Moss Landing; in purse seines off Capitola, Fort Ord, and Moss Landing; and in crab nets off Moss Landing and the Pajaro River.

2. SYSTEMATIC POSITION

Linnaeus placed all flatfishes in a single genus, Pleuronectes. With subsequent increase in knowledge this arrangement proved unsatisfactory and his flatfishes went through the same transformations as so many of his other genera and became first a family and then an order.

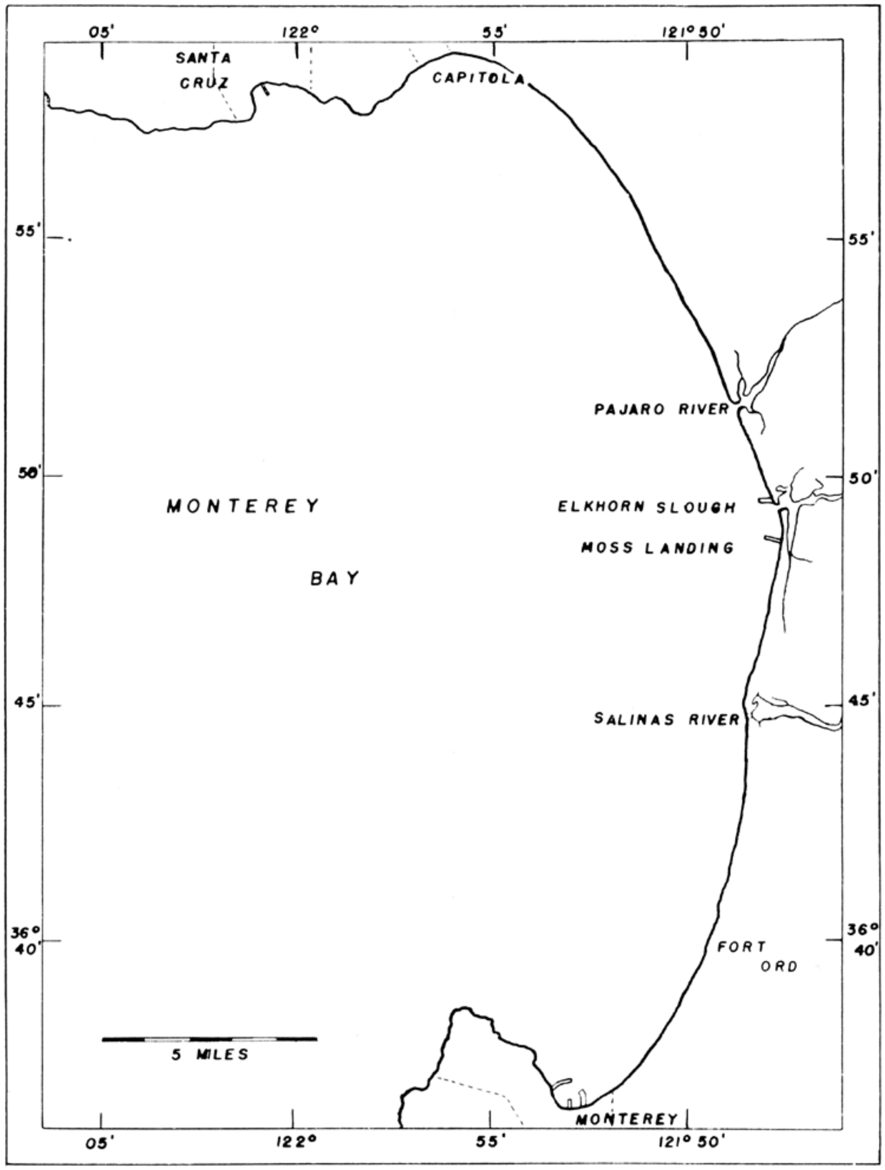

FIGURE 1. Monterey Bay, California

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The most comprehensive recent work on the group is Norman's "Monograph of the Flatfishes" (1934) which is widely accepted. Although several previous authors (Müller, 1846; Günther, 1862; Cope, 1871; and Jordan and Evermann, 1898) considered the group as closely allied to the Gadoids in descent and one author (Kyle, 1921) supports a polyphyletic origin. Norman, following Regan (1910), considers that the flatfishes constitute a homogeneous group derived from a generalized percoid stock. He divides the Heterosomata into five families: Psettodidae, Soleidae, Cynoglossidae, Bothidae, and Pleuronectidae.

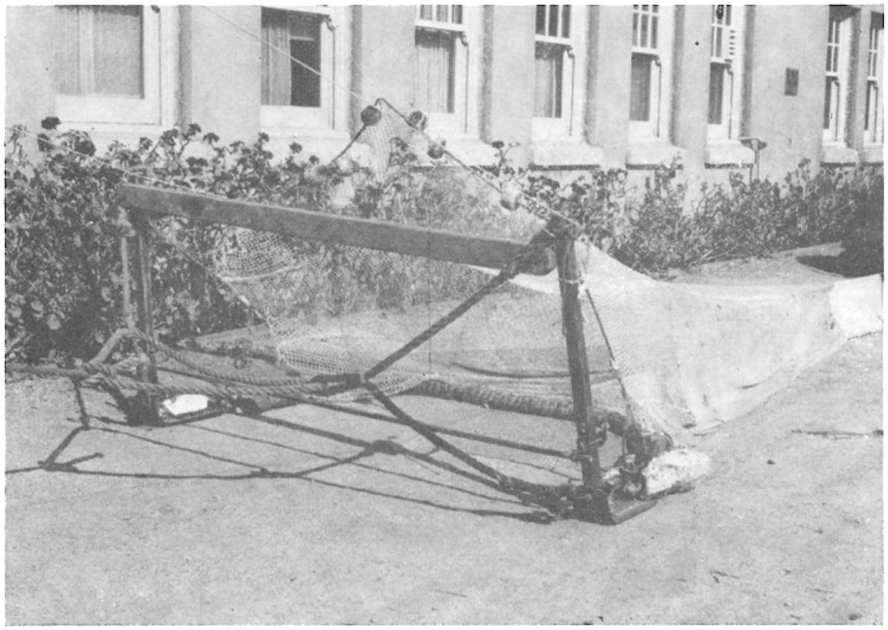

FIGURE 2. The modified beam trawl used for catching samples of *Platichthys stellatus*

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The Psettodidae, represented by a single genus with two species, is distinguished from all other flatfishes by having a dorsal fin which does not extend forward on the head, by the possession of spines in the dorsal and pelvic fins, by the occurrence of a supplemental maxillary, by the presence of teeth on the palatines and by a low number of vertebrae (24 instead of 28 or more). This family is considered the most generalized of existing flatfishes.

From the primitive psettoid stock two divergent evolutionary lines are believed to have arisen. One of these characterized by the possession of a dimorphic optic chiasma, by the lack of ribs and post-cleithra, and by the occurrence of preopercula with margins not free, being hidden by the skin and scales of the head, gave rise to the families Soleidae with the eyes on the right side and the Cynoglossidae with the eyes on the left side. It has been suggested that these two families of "soles" may have an independent origin from the primitive stock.

The other line, characterized by having a monomorphic chiasma, by having ribs and one or two post-cleithra on each side, and by the occurrence of preopercula with free margins, split into the two families of "flounders," the Bothidae and Pleuronectidae. The former is distinguished from the latter by having the eyes normally on the left side instead of the right side, the nerve of the right eye always dorsal instead of ventral and by the occurrence of an oil globule in the yolk of the egg.

It is to the family Pleuronectidae that Platichthys belongs. This genus contains three species: P. flesus, occurring along all of the European coasts; P. bicoloratus from Japan, Korea and northern China; and P. stellatus, widely distributed in the North Pacific and adjacent waters. The European P. flesus has been differentiated into three subspecies and it may be that the Pacific P. stellatus will be similarly subdivided when specimens from widely separated areas of its extensive range have been carefully compared.

Platichthys stellatus first received notice in the pre-Linnaean manuscript of Steller, 1743 (Stejneger, 1936) wherein it is referred to as Rhombus scaber. Pallas redescribed the fish in 1787 as Pleuronectes stellatus. In that work he did not recognize Steller's contribution, but in 1811 he gave another technical description and at this time referred to Steller's manuscript. Girard (1854) redescribed the fish as Platichthys rugosus and assigned it to the new monotypic genus, Platichthys. Later, Pleuronectes stellatus and Platichthys rugosus were recognized as the same species and Gill (1864) used the name Platichthys stellatus. This has been almost uniformly accepted during the present century and modern authors including Jordan, Evermann and Clark (1930) and Norman (1934) have reduced all of the other names listed above to synonymy.

Platichthys stellatus, like most fishes, has had many common names applied to it by scientific workers, commercial fishermen, and sport fishermen. Among the common names prevalent in literature and in usage among fishermen are: starry flounder, rough jacket, diamond flounder, English sole, sole, and swamp flounder. Such names as English sole and sole are definitely inappropriate. of all the common names starry flounder and rough jacket are most generally used in California. While rough jacket is the name favored by fishermen, starry flounder has been used in most written accounts of the fish and is listed as the official common name by the California Division of Fish and Game (Roedel, 1948) and is also the common name accepted by the American Fisheries Society (1948). Starry flounder is the name used in this work.

3. DISTRIBUTION AND HABITAT

Platichthys stellatus is known to occur in coastal waters of the Pacific and Arctic oceans and connecting seas, and rivers within 33 degrees to 73 degrees N. latitude and from 105 degrees W. to 127 degrees E. longitude. Thus it is one of the most widely distributed flounders. In the eastern Pacific the southern limit of its range is at the mouth of the Santa Ynez River at Surf, Santa Barbara County, California. The species becomes more numerous in northern California and is found along the entire Pacific coast of North America from the Santa Ynez River to the Alaskan Peninsula. It occurs along the Aleutian Island chain westward to the Commander Islands and the Kamchatka Peninsula and then extends southward along the east coast of Kamchatka, and Kurile Islands, and the main islands of Japan to Tokyo Bay.

It also occurs in the peripheral seas. It is known from the Sea of Japan south to Obama, Japan and Gensan, Korea; and from the entire Gulf of Tartary. Hubbs and Kuronuma (1942) have mapped it as occurring along all of the shores of Okhotsk Sea although they give no definite locality records and I have been unable to find any elsewhere. Platichthys stellatus has been found along the southern and eastern limits of the Bering Sea and along the northern coast of Alaska and Canada eastward as far as Coronation Gulf. Whether it occurs along the northwestern shores of the Bering Sea is uncertain and there appear to be no records along the arctic coast of Asia. Locality records of P. stellatus are shown

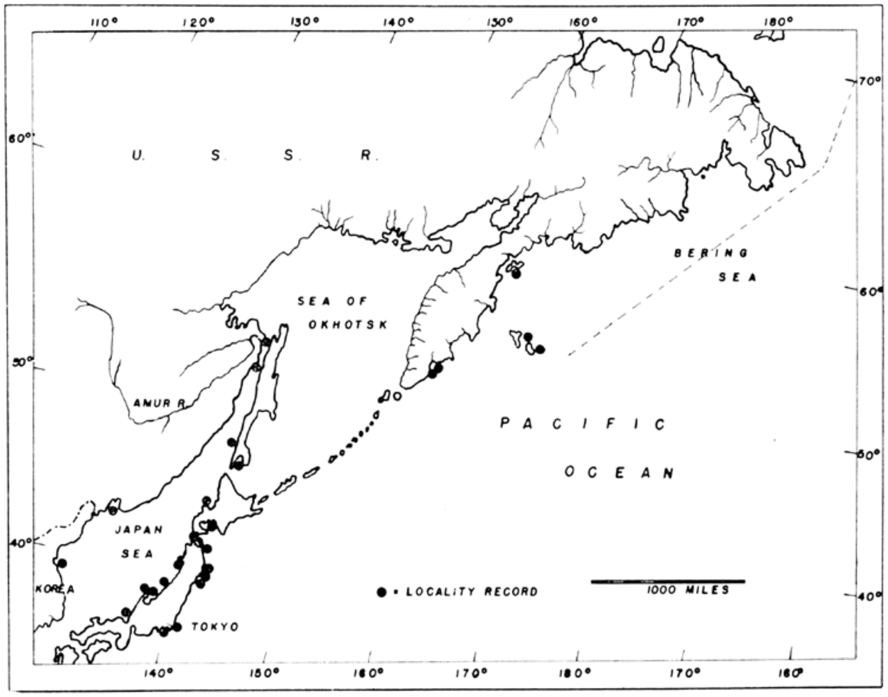

FIGURE 3. Asiatic locality records of *Platichthys stellatus*
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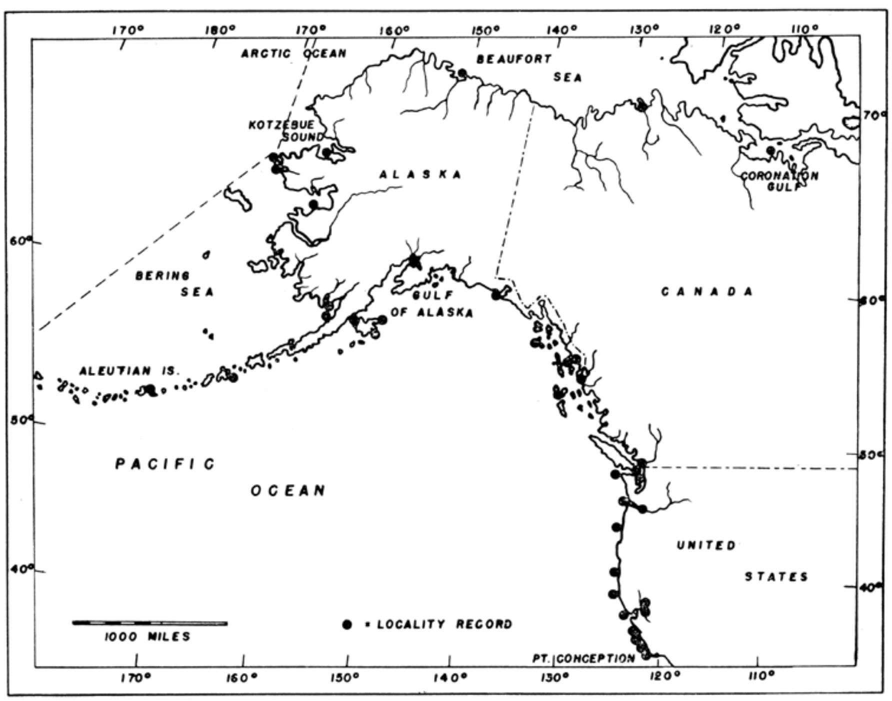

FIGURE 4. North American locality records of *Platichthys stellatus*
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in Figures 3 and 4. These are based upon data published in the works of Pallas (1787, 1811); Günther (1862); Steindachner and Kner (1870); Bean (1884); Jordan and Gilbert (1889); Schmidt (1903, 1904); Jordan and Starks (1906); Evermann and Goldsborough (1907); Gilbert and Burke (1912); Jordan, Evermann and Clark (1930); Norman (1934); Hubbs and Kuronuma (1942); Gunter (1942); and on personal communications from Mr. Leo Erkkila, Mr. Tokiharu Abe, and Dr. Carl Hubbs.

The records of Platichthys stellatus as illustrated in Figures 3 and 4 show that the fish is truly one of coastal waters and frequents the numerous bays, inlets, and sounds of the north Pacific Ocean and adjacent seas. However, its bathymetric range is considerable. Small specimens occur to the shore line in protected places. During the course of the present investigation flounder with standard lengths of 10 to 45 mm. were taken in shallow channels of Elkhorn Slough, where the depth was only 14 inches (Figure 5). Specimens up to 323 mm. in standard length

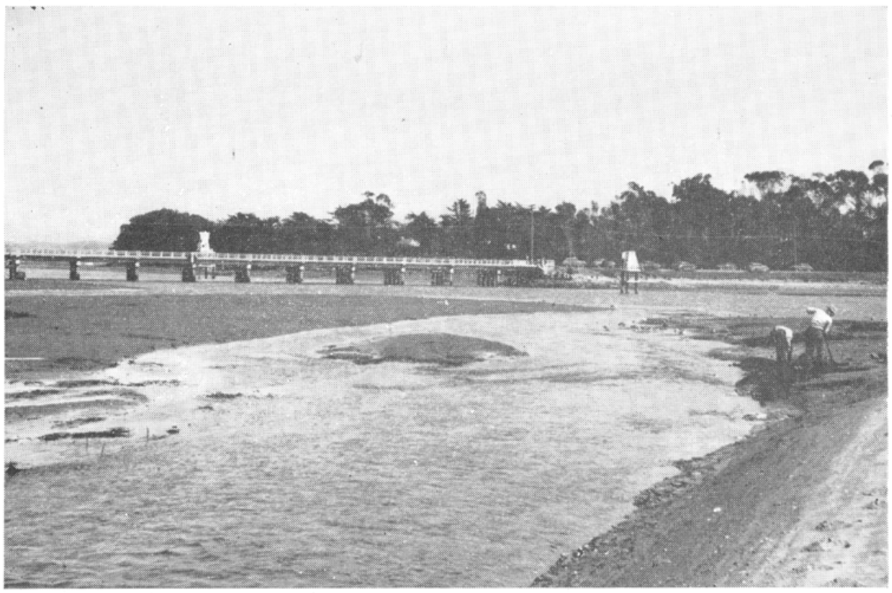

FIGURE 5. The channels of Elkhorn Slough, California, as exposed at an 0.7-foot tide on May 4, 1948

FIGURE 5. The channels of Elkhorn Slough, California, as exposed at an 0.7-foot tide on May 4, 1948

have been caught by hand seine in three to four feet of water in the mouth of the Salinas River. However, the commercial fishing operations yielding this flounder are carried on in waters of 10 to 150 fathoms in depth. In one month (May, 1947) about 2,000 pounds were taken in depths of 150 fathoms or more. Since this poundage is relatively large and fishes tend to become less abundant at limits of their distribution, it can be said without hesitation that P. stellatus occurs at considerably greater depths.

The starry flounder frequents various types of bottom, appearing to avoid only rock. It is taken on gravel, clean shifting sand, hard stable sand, and mud substrata, but fishermen report the largest catches over soft sand. Individuals evidently move freely from one type to another in search of food, since mud inhabiting worms (Sternapsidae) and sand living clams (Siligua patula) and crabs (Cancer gracilis) have been found in the gut of a single fish.

Since the time of its discovery Platichthys stellatus has been recognized as a euryhaline organism. Pallas, in his descriptions, mentioned that it occurs often around the mouths of rivers, streams, and small brooks flowing into the ocean, and in bays and the more clam recesses of the sea. Later work has provided ample proof of its occurence in strictly fresh river waters many miles from the sea as well as in the truly oceanic waters off the open coast. Gunter (1942) reports that the starry flounder has been taken 75 miles upstream in the Columbia River. Such extensive penetration inland may be somewhat unusual but that the occupation of the fresh-water habitat is by no means abnormal is clearly shown by recent results obtained incidentally by the United States Fish and Wild-life Service, while studying the movements of young, seaward-migrating chinook salmon and striped bass. During the course of that investigation in 1947 fyke nets were fished just below the surface of the water one-half mile below the Antioch Bridge in the San Joaquin River and six miles downstream from Rio Vista in the Sacramento River. Although the collecting nets were not designed or set for the capture of bottom fishes, they took, in addition to the salmon and striped bass, 80 starry flounder in the San Joaquin River. At Antioch the salinity varied from about 0.06 to 9.0 parts per thousand during the period from April through September, in which the flounder were caught; a variation from fresh water to brackish water having a salinity about one-quarter that of the ocean. At Rio Vista the salinity varied from 0.02 to 0.5 parts per thousand and the Sacramento River water could be considered nothing but fresh during the entire period of the experiment. Nevertheless 193 starry flounder were caught at the latter station. It should be noted that all the flounder taken in these two rivers ranged from 19 to 101 mm. in length. No large fish were taken, but in all probability this is not due to any difference in tolerance to fresh water between the various age groups but to the tendency of larger fish to frequent greater depths than occur in the rivers and the possibility of larger fish avoiding the fyke nets.

Salinity records are not available for many of the smaller rivers and streams of California; however, Hubbs (1947) found chlorinities ranging from 0.57 to 1.02 for the waters of the lower three miles of the Salinas River in August, 1946, at which time, starry flounder were numerous in those waters. In Japan its common occurrence in the brackish back-waters and salt marshes of Hachiro-gata, Kasumiga-ura, and Hi-numa has given rise to the name "Numa Karei" or swamp flounder.

4. COMMERCIAL CATCH

While the starry flounder is of comparatively minor importance in the fisheries of California it enters the commercial catch at all of the major fishing ports north of Point Conception. Here it is retailed principally in fresh filleted form and the fillets are frequently sold under the inclusive name "sole." Generally, the flesh is not considered to be one of the choicer seafoods in flavor and texture. The young and comparatively small individuals are deemed more desirable than larger and heavier fish. While not widely appreciated in California, Andriashev (1935) reports that in the Bering Sea it is used commercially along the shores of eastern Kamchatka and the Island of Koryak, where it is mainly canned as a high class export item.

The California catch is made by trawlers principally in the San Francisco and Eureka regions: A few boats operate trawl nets in Monterey Bay. This type of gear is fished in depths from 10 to 150 fathoms with about 70 percent of the landings being taken between 20 and 40 fathoms (Table 1). The concentration of the catch in this depth range is

TABLE 1

Total Annual Percentages of the California Trawler Catch of Platichthys stellatus Caught at Various Depths During the Years 1941 and 1947 *

Approximate depth in fathoms	Percent of catch		Approximate depth in fathoms	Percent of catch	
	1941	1947		1941	1947
10-19	5.19	----------	60-69	0.69	10.12
20-29	14.82	43.72	70-79	0.04	0.16
30-39	55.75	27.16	100	1.76	2.13
40-49	20.74	10.09	150	----------	2.82
50-59	1.01	3.68			

*Calculated from unpublished log records of trawl fishermen.

TABLE 1 Total Annual Percentages of the California Trawler Catch of Platichthys stellatus Caught at Various Depths During the Years 1941 and 1947

probably due to fishing effort directed toward more desirable species rather than an abundance of starry flounder occurring only within such a limited area. The nets used in the Eureka region are otter trawls with tapered patterns of 3- to 5-inch meshed webbing strengthened by four to six longitudinal lines known as "rib lines." The nets vary considerably in size; the smaller ones have a length of about 74 feet (including wings), and a throat of 16 feet while the larger ones may measure 280 by 133 feet. The larger otter trawls are operated from vessels about 125 feet in length while the smaller gear is handled on 35-foot boats. The trawl of the San Francisco region is also of the otter-board type but has a rectangular design with mesh of variable size, a carry-over from the two-boat paranzella rig of earlier years. The smaller of these nets are about 25 by 75 feet while the larger ones have a length of 110 feet and a throat 35 feet wide. Effective July 1, 1949, the legal minimum size of the mesh of drag nets became four and one-half inches to insure greater escapement of the smaller fishes. In Monterey Bay the drag boats operate small otter trawls of the northern design. At Santa Cruz, starry flounder are taken in depths of 10 to 25 fathoms by trammel nets 35 to 45 fathoms long and 2 to 3 fathoms deep. The outer guard mesh of these nets is 24 inches while the inner trapping mesh is of 8-inch webbing. This flounder is also frequently taken on hooks of halibut gear in waters off the State of Washington and British Columbia. Sport fishermen take the starry flounder incidentally on hook and line.

The commercial catch from Monterey Bay consists of fish ranging from 8 to 22 inches in standard length with an average length of 13 inches and weight of 1.84 pounds. In the previous century Lockington (1880) reported that those taken in San Francisco Bay attained a weight of eight, ten, or even twelve pounds, while still larger individuals were caught in Humboldt Bay. Jordan and Evermann (1898) suggest that this is one of the largest of the American flounders, reaching a weight of 15 to

20 pounds. However, if specimens of this size were taken today, they would be most outstanding and attract much attention.

The monthly landings made in California during the past years show that this fish is caught throughout the year with no season of consistently highest catch. However, the total landings by months for these years show that catches in February and March, and July and August have been higher than those of the intervening months (Table 2). The winter months of November, December, and January show the lowest total landings. It is very probable that weather conditions and the direction of fishing effort, rather than availability of the fish, are the major factors resulting in the over-all seasonal differences in the catch.

TABLE 2

Total California Catch of Platichthys stellatus by Months for the Period 1930-1947, Inclusive *

Month	Total catch (100,000 lb. units)	Percentage of a year's catch	
		Lowest in any one year	Highest in any one year
January	4.4	0.3	14.2
February	9.3	1.7	41.0
March	9.8	2.5	22.3
April	7.2	1.6	14.7
May	6.1	1.4	18.5
June	8.4	0.8	22.0
July	9.0	1.6	32.2
August	10.7	2.5	31.6
September	8.6	2.6	31.4
October	7.4	1.1	23.0
November	5.4	0.4	16.0
December	4.4	0.4	21.0

* Calculated from landing data in Fish Bull. Nos. 44, 49, 57, 58, 59, 63, 67, California Division of Fish and Game, and unpublished 1947 log records of fishermen.

TABLE 2 Total California Catch of Platichthys stellatus by Months for the Period 1930–1947, Inclusive

TABLE 3

Total Annual Landings of Starry Flounder and of All Flatfish Excluding Northern Halibut in California, 1924 Through 1947 *

Year	Starry flounder (Thousands of pounds)	Flatfish (Except northern halibut) (Thousands of pounds)	Year	Starry flounder (Thousands of pounds)	Flatfish (Except northern halibut) (Thousands of pounds)
1924	379.5	13,516.8	1936	621.2	11,273.6
1925	594.4	13,813.7	1937	974.8	11,076.1
1926	667.7	11,762.8	1938	542.8	10,100.0
1927	590.1	13,256.5	1939	739.3	12,425.9
1928	399.9	12,999.6	1940	804.1	10,041.4
1929	580.6	14,490.7	1941	601.6	6,423.7
1930	391.1	13,036.6	1942	370.1	4,642.1
1931	169.8	11,043.5	1943	505.4	6,952.8
1932	543.8	11,073.1	1944	366.5	7,183.1
1933	516.3	10,371.4	1945	339.3	10,687.3
1934	537.2	11,382.7	1946	509.4	14,308.9
1935	656.1	12,114.1	1947	527.0	13,663.8

* Data compiled from data in Twenty-ninth Biennial Report; Fish Bull. Nos. 15, 20, 30, 44, 49, 57, 58, 59, 63, 67 and Circular No. 22, California Division of Fish and Game.

TABLE 3 Total Annual Landings of Starry Flounder and of All Flatfish Excluding Northern Halibut in California, 1924 Through 1947

The commercial landings of starry flounder reported in California during the years 1924 through 1947 reveal that though the fishery is not of major importance in respect to total poundage of flatfish landed, it is a stable fishery that can probably stand great utilization (Table 3). Figure 6 shows the total catch per year for this 24-year period. The trend

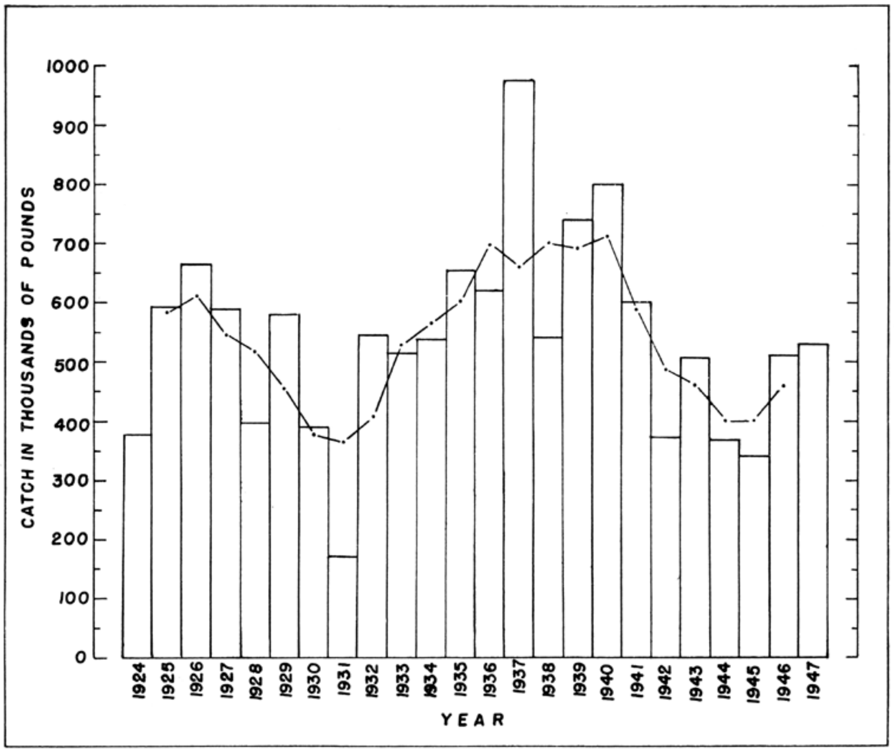

FIGURE 6. California catch of *Platichthys stellatus*, 1924-1947

FIGURE 6. California catch of Platichthys stellatus, 1924–1947

line drawn through the histogram is smoothed once by averaging successive three-year periods. The trends indicate a general decline from 1926 to 1931; however, the decrease was not consistent. The low point in yearly landings occurred in 1931 when the fisheries of California were most affected by the economic depression of the thirties. Following 1931 there was a general increase until 1941. During this period, new developments in gear began to have an effect on total poundage. Larger catches actually resulted from voluntary adoption of increased mesh sizes by fishermen during the period 1934–1939. Introduction of the more efficient otter trawls replacing the two-boat paranzella nets undoubtedly was an important factor in maintaining the high landings from 1938–1940. After 1941 the induction of many fishermen into the armed services and the transfer of trawling vessels to naval duty materially reduced the fishing effort and caused a downward trend until 1945. The return of fishermen and vessels to the industry as well as expansion into the Eureka region has in recent years begun an upward trend in the landings. Evidently starry flounder are available and can probably be subjected to considerably higher fishing pressure than they now endure.

5. HABITS

When Platichthys stellatus is in the normal resting position the dorsal and anal fins are held at an angle toward the lower or blind side. This prevents the body proper from resting upon the substrate. Support is by the fins, the outer margins making contact with the bottom, and thus the fish normally has a cushion of water between it and the bottom surface. This allows for escape of water from the opercular opening on the blind side, and also lessens the effort required for movement. The body of the fish at rest bends to conform with the general curvature of the substrate.

Movement along the bottom is by a method very much like crawling. The first few rays of the dorsal and anal fins are moved caudally, then raised, moved forward and finally lowered to the original position. This results in a rowing movement of the fin rays. The action progresses caudally along successive rays creating a waving movement of the fin which propels the fish forward and it glides across the bottom leaving only a slight trail even on very soft surfaces. In backward locomotion the action of the rays is reversed and the waving movement begins at the caudal end of the fins and progresses anteriorly. This backward locomotion is used when obstacles are encountered, and as a method of escape from danger. In turning, the propulsive wave moves backward along one marginal fin and forward along the other, with the result that the fish turns in the direction of the latter fin. The caudal fin is also used in turning; in this operation the caudal peduncle bends in the dorso-ventral plane and the fin, in contact with the substrate, aids in turning the body of the fish.

When moving upward or downward on the surface of rocks or the side of an aquarium, the dorsal and anal fins are more closely applied to the supporting surface than when the fish rests on a horizontal bottom. This brings the opercular and caudal regions of the blind side of the body in contact with the substrate and a partial vacuum is created which holds the fish on the vertical plane.

The pelvic fin of the blind side is used in conjunction with the anal fin. It gives an added thrust to movements and acts as an additional marginal support anterior to the anal. The pelvic fin of the eyed side moves with that of the blind side.

The pectoral fins are not used in normal slow progression across the bottom. In quick movements, as when the fish is feeding or frightened, they are extended at right angles from the body, expanded like open fans and used as paddles. This movement is most pronounced when the fish leaves the bottom and for a short time swims freely in the water. The pectoral fin of the blind side is extended fully only when the fish leaves a supporting surface. At times it acts as a skid but the fish has never been observed to support itself on this fin.

When slightly disturbed the fish flutters its dorsal, anal, and caudal fins in such a manner as to wave a light covering of mud or sand over the body as it settles into the hollow created by the disturbance; whereupon the position of the fish is discernible only as a gentle rise in the sand with a faint outline of the fish's body. often no rise in the sand is detectable and the fish can be located only by its eyes protruding from the sand and rotating slightly as they follow movements of objects about them. Very close observation will reveal slight disturbances of the sand caused by respiratory movements of the operculum of the eyed side.

When frightened the starry flounder swims very rapidly and will bury itself so deeply that the eyes are completely covered. Gradually the eyes will appear and, as excitement abates, the head will emerge so as to free the posterior margin of the operculum of the eyed side. The burying habit seems to give the fish a sense of security. If the flounder is disturbed when buried it does not move until the disturbance is considerable; sometimes not until the fish has been forcefully displaced. The same reaction has been observed to a lesser degree when the fish is not buried but displays a color pattern which closely matches the surface on which it lies.

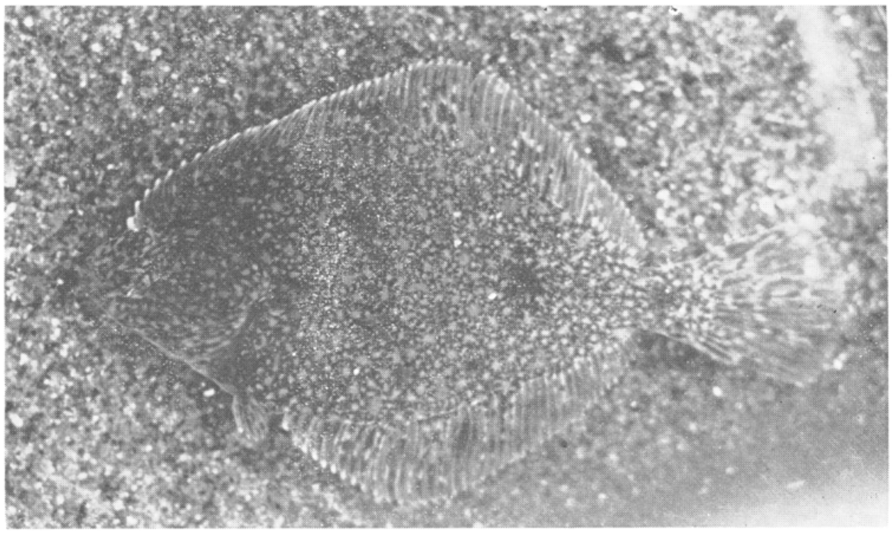

FIGURE 7. A specimen of *Platichthys stellatus* 45 mm. in standard length over a finely mottled substrate

FIGURE 7. A specimen of Platichthys stellatus 45 mm. in standard length over a finely mottled substrate

Adaptive coloration is very pronounced in Platichthys stellatus. The process of changing pigment granule concentration in chromatophores results in differences in the shade of various regions of the skin. That such changes are purposeful can be debated, but the actual simulation of the substrate undoubtedly serves as an advantage to the fish. Individuals taken from clean sandy areas are brownish, those from muddy bottoms are usually very dark; while specimens over a mottled surface have a mottled pigment pattern. If the light and dark areas of the substrate are small, those of the skin are small, and if the contrasting areas are large those of the skin are correspondingly large. Individuals on extremely light bottoms become very nearly grey, and in such specimens the characteristic dark bars of the fins become much less noticeable, but return to darker shades very rapidly when the fish move to dark substrate. Figure 7 shows a specimen of P. stellatus closely simulating a finely mottled background.

6. FEEDING AND FOOD

The young fish, before metamorphosis and assumption of life on the bottom, are dependent upon minute planktonic organisms for food. The demersal life that follows necessitates a change in diet and feeding habits. The younger metamorphosed fish ingest small animals and swallow them whole. In a tank, the young starry flounder, when feeding upon live copepods of the genus Tigriopus, watches the prey and follows it until it settles on the bottom or is slightly above the level of its eyes. Then the fish makes a quick lunge and the food is drawn into the mouth with a small amount of water. At times the fish will rise quickly, take the food and immediately return to the bottom. When feeding in an aquarium, fish 20 to 50 mm. in standard length have been observed to leave the side of an aquarium, catch their prey and settle to the bottom, never returning to the side; but they will graze for food along the sides up to the surface of the water. Never have the fish been observed to swim about well off the bottom in search of food.

When the fish attain about 100 mm. in standard length their jaws and teeth are developed sufficiently to permit a different mode of feeding. Small clams can be crushed and swallowed and worms can be pulled from burrows or bitten off. In stomachs of fish 180 to 250 mm. in length as many as 71 siphon tips were counted in a single individual. These tips were about 10 mm. in diameter, showing that they had come from claims which were too large to be ingested. Evidently the flounder at this stage has a habit of grazing siphon tips from the unfortunate clams.

The food taken by still larger fish consists for the most part of invertebrate animals having very hard exoskeletons, many of them too large to be swallowed whole. The lower pharnygeals of the starry flounder are provided with coarse pavement-like teeth that act as crushing molars in breaking up such organisms as shellfish and echinoderms. Other fishes also form an important food item for the larger starry flounder.

Analyses of the stomach contents of 250 specimens ranging from 10.5 to 536 mm. in standard length clearly show that there are changes in diet which are correlated with increase in size (Table 4). The observations were only roughly quantitative, food items being recorded as numerous, fair in numbers, few in numbers, and single observations. In many instances the organisms in the stomachs were in a condition allowing identification to species; however, in general they were grouped by orders. When particular food items occurred in abundance or when a major category was represented by a single genus these were recorded by genera.

Among the specimens examined, 19.2 percent of the fish two years of age and over had empty stomachs, while only 16.7 percent of the fish less than two years old had no food in the gut. While the differences are not particularly striking, these observations are in agreement with those of Ricker (1946) who says, "There are very few exceptions to the rule that large fish more often have empty stomachs than do smaller ones of the same species . . . ." This is apparently due to the fact that larger fish can endure longer periods without food than can the smaller, more active, and faster growing individuals.

TABLE 4

Stomach Contents of Platichthys stellatus, Monterey Bay, California, 1947-1948

Standard length in mm.	Number of fish	Diatoms	Algae	Protozoa	Nematoda	Crustacea						Polychaeta			Mollusca		Echinodermata		Fish	Paste	Unidentified
						Nauplii	Nebalia	Copepoda	Amphipoda	Decapoda	Other	Nereids	Aphrodita	Other	Siliqua	Other	Dendraster	Ophiura			
10-19	7			○	1	●	x	●													
20-39	4	1		○				●	○												
40-59	7			○				x	●												
60-79	10	○			1				●		x			○							○
80-99	8		1					○	●												
100-119	17								●		○			1	○	○					○
120-139	13		○						●		○			1		1					
140-159	12								●		○	x		○							
160-179	2								●		○										
180-199	3		1						x						●	x					
200-219	6								○	x		x		●							
220-239	13									x	●	x		x		○		○			
240-259	12								○	●		x		●							○
260-279	22								○	●		x			●	1		●		○	
280-299	17									●		●			●	x					
300-319	12									●	●				●	○				1	
320-339	11									●				○	●	○		x			
340-359	10									●					●		x	x	1		
360-379	15									x	○	○	x	○	●	1	x	○		1	
380-399	8									x				1	●				1	1	
400-419	6									x					●	1					
420-439	7									●				1	●	○	●	1	○		
440-459	4									x									○		
460-479	4										1				x	1				1	
480-499	4									●	○				x		●	1		1	
500-519	2												x		●	1		●			
520-539	2															○	●				

● Numerous
x Fair in numbers
o Few in number
1 Single occurrence

TABLE 4 Stomach Contents of Platichthys stellatus, Monterey Bay, California, 1947–1948

Plant material was never very abundant in the alimentary tract. Diatoms of the genus Navicula were found but they could easily have been from the alimentary tracts of ingested copepods. The filamentous alga, Enteromorpha, and the green alga, Ulva, appeared in very few of the fish examined. In all probability they were swallowed accidentally. These few records of plant forms in the stomach reveal beyond any doubt that the starry flounder is not a vegetarian. It may be noted, however, that examination of specimens smaller than 10 mm. in standard length may reveal that the first food of this species is primarily from the plant kingdom. It was an alga that the larvae ingested at the critical period in the laboratory, as discussed later in the section on development, and Lebour (1918) has stated that small specimens of the smaller mouthed flatfishes show indications of a diet including diatoms or other microscopic plants.

The smallest representatives of the animal kingdom found in the stomach contents were a few pelagic marine ciliates, tintinnids. Nauplii occurred in stomachs of fish 10 to 15 mm. in standard length. Fish of 10 to 40 mm. fed principally upon copepods of different species. The harpacticoid genera Canthocamptus and Pseudobradya were the chief forms found. A few calanoids were also present. Another minor food item of the young fish consisted of Nematoda of the genus Metoncholaimus. These nematodes were found only in fish under 75 mm.

The food found in fishes of 40 to 150 mm. consisted primarily of Amphipoda of the genera Gammarus and Corophium. Incidental food items of this size group were a few ostracods, phyllopods (probably Artemia), cladoceres, isopods, and polychaetes. The first evidence of the starry flounder feeding upon Mollusca was the appearance of broken shells of Siliqua lucida, Mya arenaria, and Schizothaerus nuttallii in stomachs of fish of 112 to 126 mm. The shells of these mollusks were from 10 to 20 mm. in length before being broken. Fish of 150 to 190 mm. taken from the waters of the mouth of the Salinas River were found to have fed upon mysids which were present in dense swarms. This is probably due to the fact that although mysids are not bottom forms, the shallow waters of the Salinas River made them available to the flounder there. These organisms did not occur in samples from other localities.

The starry flounder 150 to 200 mm. in length feed primarily upon clams, principally the species Siliqua lucida, Siliqua patula, and Schizothaerus nuttallii. Clams small enough to be taken into the mouth are crushed and swallowed; others, too large for ingestion, suffer loss of the ends of their siphons, as mentioned earlier in this section.

The stomach contents from fish 200 to 250 mm. show that the fish of this size feed upon still different organisms. Razor clam 17 to 50 mm. in length and siphon tips are a major item, but small crabs, chiefly Cancer gracilis, 8 to 35 mm. in width are about as common. The other crabs found, Cancer antennarius, Pinnixia sp., and Pugettia sp., were few in numbers. Polychaeta usually about 30 to 70 mm. in length make up a substantial portion of the diet. In a few stomachs the isopod, Cirolana harfordi, was observed.

The starry flounder of 250 mm. and over have about the same diet. of course, the much larger fish frequently feed upon larger organisms; for example, 80 mm. Siliqua patula are eaten by 400 mm. flounders. The outstanding difference between the food habits of these fish and those under 250 mm. in length is that the larger individuals feed upon other fishes and echinoderms. The sand dollar, Dendraster excentricus, and brittle stars, chiefly Ophiura lütkeni are often found to fill the entire digestive tract. One fish of 355 mm. had eaten 78 Dendraster ranging from 8 to 20 mm. in diameter, and another fish, 525 mm. in length, was literally stuffed with Ophiura lütkeni whose body discs ranged from 12 to 25 mm. in diameter. The fishes found in the stomachs were the sardine, Sardinops caerulea; the sand dab, Citharichthys sordidus; and the shiner perch, Cymatogaster aggregata. The zoarcid fish, Lycodopsis pacificus has also been listed as a food of this species along the coast of British Columbia (Clemens and Wilby, 1946). No fishes were found in stomachs of starry flounder under 350 mm. in length.

Other forms found to be food of the larger fish were:

Food organism	*Standard length of fish in mm.*
Sternapsidae (15–25 mm.)	480–530
Goniadidae (105 mm.)	320–390
Aphrodita (85–103 mm.)	505
Macoma (40 mm.)	475
Tellina (37 mm.)	369
Cardium (12–20 mm.)	280–285
Nuculana (15–20 mm.)	260
Callianassa (125–140 mm.)	466–480

In some cases the stomach contents were so far digested that identification of the type of food was impossible. Frequently the digestive tract contained only a yellowish-white pasty substance in the last stages of digestion. Breder (1923), in his work on the winter flounder, Pseudopleuronectes americanus, remarked that the "paste might well have been the remains of food taken before migration to the spawning grounds, as the peristalsis of fish in winter is usually extremely slow." However, in specimens of Platichthys stellatus from Monterey Bay, this pasty material was found in larger fish throughout the year with no definite higher rate of occurrence in mature fish during the spawning season.

To review briefly: The starry flounder apparently begins to feed on unicellular algae, but in a very few days turns its attention to minute planktonic animals. Upon settling to the bottom after metamorphosis, the diet consists largely of small crustacea, primarily copepods, small amphipods and nauplii. Soon the small copepods are overshadowed in importance by the larger amphipods and at about a standard length of 100 mm. annelid worms and small mollusks are taken. At a length of between 200 and 300 mm. crabs replace the amphipods as the main crustacean item of diet, annelids become less important and bivalve mollusks are of major importance. At this size also echinoderms and fishes appear in the stomach contents and these latter items, together with crabs and mollusks, form the characteristic food of the largest flounders.

7. PARASITES

Platichthys stellatus from Monterey Bay were found to be relatively free from parasites, and diseased fish were rare. Other than the isopod, Livoneca vulgarus, which commonly clings to the gills of most marine fishes, the animals observed using the starry flounder as a host were copepods embedded at the base of fins (more frequently on the blind side); tetrarhynch cestode larvae, plerocercoids of Lacistorhynchus tenuis, encysted within the walls of the stomach and intestines; and acanthocephalan larvae, Corynesoma sp., encysted in the gut and anterior portion of the gonads. Some fish were found to be infected by spherical cyst-like bodies 0.5 to 1.0 mm. in diameter. These were fungal colonies lodged in tissues of the stomach, intestines, and liver. One specimen was noted to have ovoid nodules embedded in the epidermal tissue overlying the fin rays and the inner side of the opercula, as well as in peritoneal tissues of the intestines. Similar infections have been described in European plaice (Johnstone, 1920) as fungus colonies or growths of mycelia with sporangium-like bodies occurring principally in the submucosa of the host.

8. SPAWNING

The spawning season of the starry flounder was established by two methods: (1) the observance of ripe, spawning, and spent fish, and (2) a study of maturing ova from month to month.

Flounder gravid with eggs are visibly distended, showing a rounded triangular shaped swelling with the base between the insertions of the pectorals and the origin of the anal fin and its apex located about on the vertical above the end of the second third of the anal base. These fish, when ripe, yield a stream of transparent mature ova under slight stripping pressure. Individuals from which eggs flow readily without application of pressure are in a condition for immediate spawning. Spent specimens are distinguished by a flaccid condition of the ovaries easily detected by handling. In October some gravid females were noted. Ripe, spawning, and spent fish occurred in November, became more numerous in the middle part of January, and gradually disappeared from the landings in February.

Male fish ripe with sex products yield milt on stripping, and those from which milt flows without pressure can be considered as in the spawning condition. Such fish were found from late November through February. Spent males can be distinguished only by dissection.

The height of the spawning season in Monterey Bay was reached during the period when the surface water temperature approached a monthly average of 11.0 degrees C. This temperature occurs during the winter months of December and January but early spawners are found in November and late spawners in February (Table 5). During the months of March through May all the ova were under 0.15 mm. in diameter (Figure 8).

TABLE 5

Monthly Size Progression of Ova of Mature Platichthys stellatus of Monterey Bay, California, 1948-1949

Maturity	Diameter in micra	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Ripe	900-940									○	●	●	○
	850-899									○	●	●	○
	800-849									○	●	●	
	750-799									●	●	○	
	700-749									●	●	○	
	650-699									●	●	○	
	600-649									●	○	○	
	550-599								○	●	○		
Maturing	500-549								○	○	○		
	450-499							○	●	○	○		
	400-449							○	●	○			
	350-399							○	●	○			
	300-349						○	●	●				
	250-299						○	●	●				
	200-249					○	●	○	○				
	150-199				○	●	○						
Immature	42-149	●	●	●	●	●	●	●	●	●	●	●	●

The extreme range in size of eggs found in any particular month is represented by the columns of circles. The majority of females carried eggs of the sizes indicated by the range of the solid circles.

TABLE 5 Monthly Size Progression of Ova of Mature Platichthys stellatus of Monterey Bay, California, 1948–1949

This general resting stock consists of immature eggs nearly filled by large nuclei and only a few of the largest of these eggs show any yolk accumulations. The size increase and yolk formation in ova destined for spawning at any particular season begins late in June. As maturation continues, two size groups of eggs become distinguishable. In September the larger ova and the general immature stock are, for the first time, found in two groups with no intermediate sizes (Figure 9). The enlargement of the eggs is most rapid in October and November, and by the latter part of November ripe eggs occur in early spawners. Table 5 shows clearly that Platichthys stellatus spawns but once a year at a definite and relatively short season. In fishes having protracted and indefinite spawning seasons there is no sharp separation between the immature stock of eggs and those maturing for spawning, for the sizes of the eggs pass continuously between the two groups. Further evidence of spawning taking place but once a year was found while sampling for growth studies. These samples revealed that recently metamorphosed fish occur only in the months of March, April, and May.

FIGURE 8. Portion of general egg stock from an immature specimen 334 mm. in standard length taken January 6, 1948

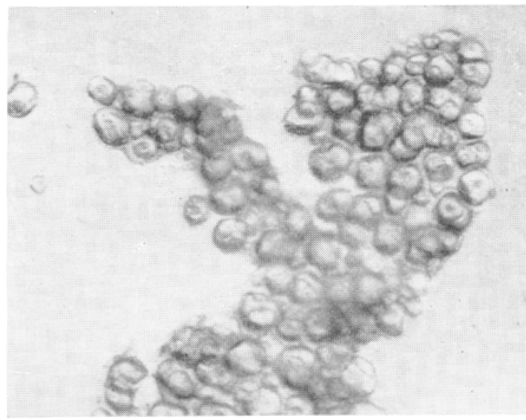

FIGURE 8. Portion of general egg stock from an immature specimen 334 mm. in standard length taken January 6, 1948

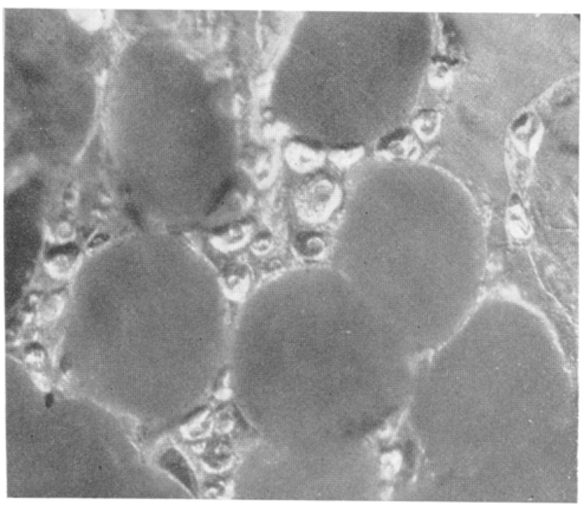

FIGURE 9. Portion of ovary from a mature specimen of 435 mm. standard length showing immature egg stock and nearly mature ova. Specimen taken December 1, 1947

FIGURE 9. Portion of ovary from a mature specimen of 435 mm. standard length showing immature egg stock and nearly mature ova. Specimen taken December 1, 1947

The number of eggs spawned at a season by a fish of 565 mm. standard length with an ovary 262 mm. long was determined to be about 11,000,000 by counting a gram of eggs and multiplying the number by the combined weight of both ovaries. When the eggs of the season have been spawned the ovary is flaccid and nearly empty; the stromata contains no mature or nearly mature eggs, and a few detached dead mature ova remain in the lumen. Figure 10 and Figure 11 illustrate the differences between an ovary

FIGURE 10. Transverse section of a nearly ripe ovary from a specimen 435 mm. in standard length taken December 1, 1948

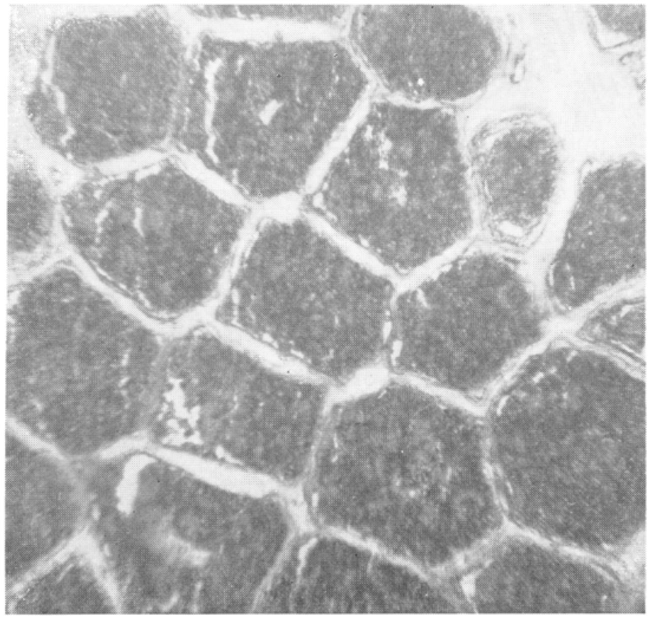

FIGURE 10. Transverse section of a nearly ripe ovary from a specimen 435 mm. in standard length taken December 1, 1948

FIGURE 11. Transverse section of an ovary soon after spawning. From a specimen 425 mm. in standard length taken December 8, 1948

FIGURE 11. Transverse section of an ovary soon after spawning. From a specimen 425 mm. in standard length taken December 8, 1948

shortly before spawning and a spent ovary. It is probable that unspawned eggs are resorbed by the tissues of the ovary. In studies of the European plaice, Pleuronectes platessa, Cunningham (1893) observed that "all the yolked ova left in an ovary after spawning has taken place degenerate and disappear, and the formation of yolk in the succeeding crops of ova does not commence till some time after spawning is over."

There is evidence that the spawning fish seek shallow water near river mouths and sloughs. Trawl boats at Monterey catch starry flounder consistently except during the spawning season at which time mature fish virtually disappear from the catch. Preceding the actual spawning season, fish with maturing gonads are landed in considerable numbers, and after the spawning season spent fish appear in the catch. Inasmuch as dragging in Monterey Bay is legal only at depths greater than 25 fathoms it was suspected that spawning occurred in shallower water. This was proved by a check of the trammel net fishery at Santa Cruz which revealed that fish in a condition for immediate spawning (eggs and milt flowing without stripping) were commonly caught in depths of 16 fathoms and less.

9. EMBRYOLOGICAL DEVELOPMENT

Various stages in the development of a number of the Pleuronectidae have been studied and the main features of their development are well understood. However, the present knowledge is primarily of species having the greatest economic importance, leaving much to be learned of the features of development of many other flatfishes. Adequate bases for differentiation of the embryological and larval forms of the various species would be of great value in problems of taxonomy and zoogeography, as well as in determining the origin of exploitable stocks.

The eggs of pleuronectids are, so far as is known, buoyant and pelagic with the exception of those of Pseudopleuronectes americanus which are said to be demersal and adhesive (Norman, 1934). The yolks are undivided and without an oil globule. In general, the early larvae are very similar to those of ordinary symmetrical teleosts. The permanent post-larval features of the group are assumed during the period of metamorphosis. These include the migration of the eye, growth of the pelvic and caudal fins and deepening of the body.

On January 22, 1948, eggs of Platichthys stellatus were stripped into a clean finger bowl wet with sea water. A few drops of sperm were stripped into 3 cc. of sea water in another clean finger bowl and then distributed over the eggs by means of a pipette. The eggs and sperm were stirred gently in order to facilitate fertilization and after three minutes the eggs were rinsed four times in fresh sea water to remove the excess sperm. They were then distributed into eight one-gallon jars, each jar containing about 100 fertilized eggs. The jars were put in a constant temperature bath operating at 12.5 degrees C. (the temperature of the surface water of Monterey Bay on the day of stripping) and this temperature was maintained for the period during which development was observed. The temperature range of the surface waters of Monterey Bay for the same period was from 11.6 degrees C. to 12.6 degrees C., with an average of 12.1 degrees C.

The freshly stripped eggs of Platichthys stellatus are spherical in form and measure 0.89 to 0.94 mm. in diameter. Their specific gravity is slightly less than that of sea water so that they slowly rise and float at or near the surface of quiet water, but will readily follow slight vertical currents. The eggs, when emitted, appear as a fluid mass but soon float separately and disperse in the water. They are colorless, transparent, and without oil globules. In containers of sea water they are discernible only by the refraction of light as it passes through them. The egg membrane is transparent and very thin, measuring 0.013 mm. in thickness. There is no pattern of sculpturing on the membrane, but under comparatively high magnification a fine vermiculated pattern caused by minute wrinklings of the surface is discernible (Figure 12). It was not possible to locate the micropyle. The protoplasm within the membrane is imperceptible until fertilization occurs.

Almost immediately upon fertilization the protoplasm becomes perceptible as a thin layer investing the colorless yolk. Within three minutes after fertilization it begins to concentrate at the animal pole initiating the formation of the blastodisc. No streaming of protoplasm toward the animal pole was detected as has been observed in the eggs of different species by Ryder (1884), Wilson (1891) and other authors. This may occur but such a movement could not be discerned possibly due to the extremely small size of the protoplasmic granules.

At about one hour after fertilization the redistributed protoplasm, forming the fully developed blastodisc, appears as a rounded cap at the animal pole (Figure 13). The blastodisc is thickest at the center and has rather abruptly sloping edges, the protoplasm of which gradually decreases in thickness to a very thin layer which continues to envelop the entire yolk sphere. The surface of the blastodisc pressing against the egg membrane is gently convex while the surface adjacent to the yolk is very slightly concave. The yolk sphere has become somewhat distorted by the pressure of the accumulated protoplasm and thus has a more flattened surface immediately opposite the blastodisc. This change in shape of the yolk sphere and the abrupt sloping of the blastodisc edges renders the perivitelline space conspicuous in this region, its greatest width being about 0.06 mm.

The first indication of incipient cleavage is a slight lengthening of the blastodisc. At about two hours after fertilization the first cleavage occurs. A furrow appears in a plane perpendicular to the long axis of the blastodisc. This furrow is meridional and deepens to divide the blastodisc into two large approximately equal blastomeres with sides more abrupt than the blastodisc from which they originated (Figure 14). The axis of the blastoderm is now noticeably elongated. Viewed from above, the two blastomeres appear roughly semi-circular in shape and are quite flattened in the region of their adjacent surfaces. The division of the blastomeres is not complete. A thin connection of protoplasm remains at the surface next to the yolk. All the eggs do not divide at the same rate, but the period of time between cleavages is approximately one hour.

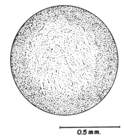

FIGURE 12. Ripe unfertilized egg

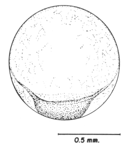

FIGURE 13. Egg one hour after fertilization. Fully developed blastodisc

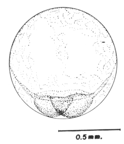

FIGURE 14. Two hours. Two blastomeres

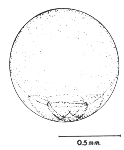

FIGURE 15. Three hours. Four blastomeres

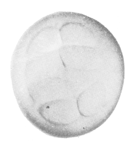

FIGURE 16. Four hours. Eight blastomeres

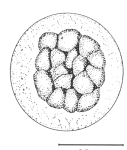

FIGURE 17. Five hours. Sixteen blastomeres

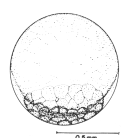

FIGURE 18. Seven and one-half hours. Blastodermal cap

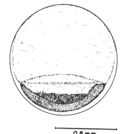

FIGURE 19. Eighteen hours. Enlarged segmentation cavity

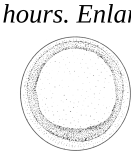

FIGURE 20. Eighteen hours. Enlarged segmentation cavity

The second cleavage is also meridional and at right angles to the first. It occurs about three hours after fertilization and results in four subequal blastomeres about 0.2 mm. in greatest thickness (Figure 15). These four blastomeres restore equality to the two axes of the blastoderm. After the second cleavage the bases of the blastomeres are markedly constricted. However, prior to the third cleavage the bases slope more gradually in relation to the surface of the yolk. The third cleavage occurs at about three and one-half to four hours after fertilization. This cleavage takes place on each side of, and parallel to, the first plane of cleavage. The resulting eight blastomeres are arranged in two parallel rows of four blastomeres each. Thus the blastoderm is again elongated in one axis (Figure 16). The blastomeres in this stage of development vary considerably in size and shape. The fourth cleavage occurs at about five hours after fertilization and results in the development of 16 very irregularly shaped blastomeres (Figure 17). The division furrows of this cleavage do not appear simultaneously, but when the 16 cells have been formed the blastoderm is a roughly circular single layer of cells. The succeeding cleavage forms a blastoderm with two layers of cells in the central region. The individual division planes become increasingly difficult to discern as they follow no definite pattern of cleavage or time interval between divisions. At about seven and one-half hours the blastoderm has passed through six cleavages. The cells are now very much smaller than in earlier stages but are still irregular in shape. They form a blastodermal cap with very abrupt edges (Figure 18). The peripheral cells taper off over the yolk forming a narrow collar of cortical periblast. Subsequent cell divisions produce a large number of very much smaller cells that appear more regular in shape. The walls of the blastodermal cap assume a gentle slope and at about 15 hours after the time of fertilization the cap is a rounded lenticular dome. The perivitelline space is now much reduced. The inner surface of the blastodermal cap presses against the yolk and flattens it considerably. The periblastic wall forms a peripheral collar investing the proximal portion of the yolk. Soon after the blastoderm has developed into the symmetrical shape described above, the segmentation cavity becomes evident and by 18 hours after fertilization it is fully developed (Figure 19). The peripheral cells of the blastoderm have been cut off from the periblastic layer. The shape of the blastoderm has changed by an increased convexity of the outer surface and a concomitant thinning of the central portion producing more pronounced concavity of the inner surface. The segmentation cavity is lenticular in shape and its cellular walls are quite distinct when viewed from the side. When viewed from above, the rim of the blastodermal cap adjacent to the yolk is not as translucent as the thinner roof of the segmentation cavity which thus appears as a lighter area surrounded by a more dense ring of protoplasm (Figure 20). This is the germ ring. At this stage of development the first indication of the main axis of the embryo is evidenced by the rapid proliferation and centripetal growth of the peripheral cells so that the germ ring becomes slightly thicker at one side. The thickened portion marks the posterior pole. As the blastoderm increases in size the germ ring advances over the yolk sphere (Figure 21). Invagination occurs more rapidly at the posterior pole and at this point very rapid proliferation of cells results in the development of a broad tongue-like area of protoplasm, the embryonic shield, which gradually grows forward into the segmentation cavity (Figure 22). As the blastoderm increases in size a definite constriction of the yolk sphere occurs in the region of the advancing germ ring (Figures 19, 21, and 23). At the same time the embryo lengthens and at about 20 hours after fertilization extends nearly half way around the yolk (Figure 23). The embryo at this stage of development has a thickened cephalic region.

At about 23 to 24 hours after fertilization the germ ring has advanced well beyond the equatorial plane of the yolk and is decreasing in diameter. By this time the anterior end of the embryo has become much thicker and the greater accumulation of the relatively heavy protoplasm at the head has caused the egg to rotate somewhat in its floating position so that the anterior end of the embryo is much lower than the posterior end.

About 30 hours after fertilization, considerable differentiation has occurred in the embryo (Figure 24). Marked thickening along the median line has resulted in the development of a dorsal ridge which protrudes into the perivitelline space and a ventral ridge resting in a V-shaped groove in the yolk. Kupffer's vesicle has appeared at about twenty-eight and one-half hours and is partly embedded in the yolk under the posterior end of the embryo. The head of the embryo is quite well formed and the rather small optic vesicles have made their appearance at about 29 hours.

The constriction of the yolk by the germ ring causes the uncovered portion of the yolk to bulge prominently outward. As the germ ring advances further the bulge becomes pinched in more tightly forming the yolk plug at about 31 hours after stripping (Figure 25), and within the next hour of development the blastopore closes. At this period of development the embryo is more thickened and the optic vesicles show an increase in size.

During the next few hours of development differentiation is very rapid. The otic capsules appear as a pair of small vesicles posterior to the eyes at about 32 hours and about an hour later segmentation can be detected. The first pairs of mesodermal somites become evident in the central region of the embryo and successive ones appear progressively to the anterior and posterior. The pupils of the eyes can be seen at about 34 hours after fertilization and at the same time the notochord becomes visible in the region just anterior to the otic vesicles. Within the next hour, the olfactory capsules put in their appearance immediately anterior to the eyes. In this same period of rapid differentiation the heart appears as a bulge into the yolk just under and posterior to the eyes. The embryo at 35 hours after fertilization appears as in Figure 26.

During about the fortieth hour of development the first evidences of pigmentation appear. An extensive irregular series of melanophores develops on the dorsal portion of the body behind the vertical of the heart and another scattered series appears dorsally in and anterior to the region of Kupffer's vesicle.

About 42 hours after fertilization 17 mesodermal somites are evident (Figure 27). Kupffer's vesicle attains its largest size, having a diameter of 0.04 mm. The embryo continues to increase in thickness and the utilization of the yolk has resulted in a greater perivitelline space. The auditory capsules now are larger and an otolith is faintly visible within each one.

FIGURE 21. Nineteen hours. Early germ ring

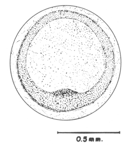

FIGURE 22. Twenty hours. Embryonic shield

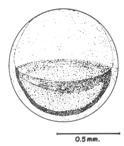

FIGURE 23. Twenty hours. Germ ring nearly at equatorial plane

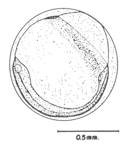

FIGURE 24. Thirty-hour embryo

FIGURE 25. Thirty-one-hour embryo

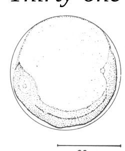

FIGURE 26. Thirty-five-hour embryo

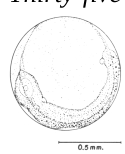

FIGURE 27. Forty-three-hour embryo

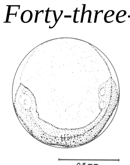

FIGURE 28. Forty-three-hour embryo with two Kupffer's vesicles

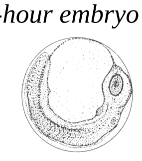

FIGURE 29. Fifty-two-hour embryo

At this stage a peculiarity in the development was observed. In one egg the thickening of the posterior portion of the embryo continued further anteriorly and two Kupffer's vesicles developed (Figure 28). The more anterior of these was slightly larger than the posterior one. The duplication was probably the result of abnormal development, for in 56 embryos observed in this stage only one Kupffer's vesicle was present. The development of two Kupffer's vesicles has been reported to be as high as about 50 percent in the eggs of the labrid fish, Oxyjulis californica (Bolin, 1930).

At about 47 hours, melanophores appear sparsely scattered about the eyes and nasal capsules and the two separate areas of pigmentation on the dorsal regions of the body have spread and united into a single extensive chromatophore field. Kupffer's vesicle is decreasing in size and the tail end of the embryo is becoming rounded. The gut makes its appearance and the heart becomes much more prominent. At about 50 hours of development Kupffer's vesicle has almost completely disappeared and only a slight trace of it remains two hours later. When viewed from the side a tubular heart with a large chamber may be clearly seen in the embryo of 52 hours (Figure 29). At this stage of development the two otoliths are clearly observed in each auditory capsule and the three primary divisions of the brain are distinguishable. The embryo now extends about three-quarters of the way around the yolk. It is still embedded in the yolk in a very deep V-shaped groove but the tail end has become more rounded and is becoming free. The gut can be readily distinguished in the body cavity. Xanthophores have appeared in the dorsal region just posterior to the auditory capsules. The dorsal fin fold has made its appearance as a very low, thin, continuous fold extending from the back of the head around the posterior end of the body.

The heart of the embryo was observed to beat at 57 hours after fertilization. At this time the rate of beating was 40 per minute and minute corpuscles which appeared to be colorless were moved about in the heart chamber during each beat. Within the same hour of development slight quivering movements of the embryo were observed.

A few hours before hatching the tail of the embryo becomes more detached from the yolk and the fin fold extends along the ventral side to the posterior end of the alimentary tract (Figure 30). At this time the embryo twitches its tail and exhibits wriggling movements of its entire body.

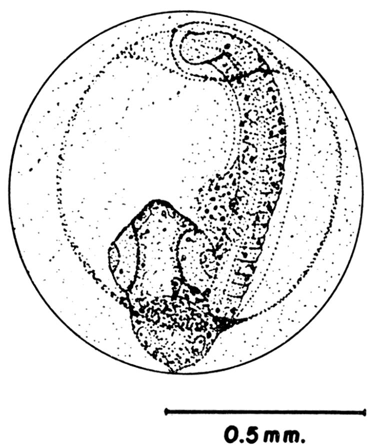

FIGURE 30. Sixty-three-hour embryo

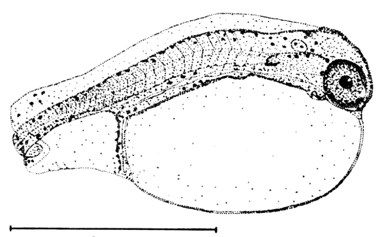

FIGURE 31. Sixty-eight hours. Newly hatched larva

At about 68 hours after fertilization the larvae hatch. By strenuous thrashing movements of the embryo, pressure is intermittently exerted upon the egg case, strong enough to stretch it from its spherical shape. The membrane soon tears and the larva gradually emerges by periodic thrashing movements. The larva in most instances forces itself out, head first, through the initial opening. The yolk sac of the larva is noticeably constricted as it passes through the tear in the egg case. The process of hatching takes approximately five minutes. The newly hatched larva (Figure 31) floats horizontally at the surface and with the yolk sac uppermost. The empty egg case settles quickly to the bottom. Occasionally larvae were observed emerging from the egg capsule tail first. In such cases the egg capsules were elongated considerably; one was observed to be stretched to 1.25 mm. in longest dimension when the larvae straightened with only tail protruding from the egg case.

On January 21, 1949, a second group of eggs was fertilized and the embryological development compared with that observed in the previous year. The temperature of the surface waters of the bay at the time of

TABLE 6

Rate of Embryological Development of Platichthys stellatus at 10.5° C. and 12.5° C., Pacific Grove, California

Stage of development	Hours required for development		Stage of development	Hours required for development	
	10.5° C.	12.5° C.		10.5° C.	12.5° C.
First cleavage	2½	2½	Germ ring, three-quarters distance to closure	30	23½
Second cleavage	3½	3	Notochord (appearance)	57	34
Third cleavage	5	4	Heart (appearance)	70	35
Germ ring, one-half distance to equatorial plane	23	18	First movement	93	53
			Hatching	110	68

TABLE 6 Rate of Embryological Development of Platichthys stellatus at 10.5° C. and 12.5° C., Pacific Grove, California

fertilization was 10.5 degrees C., and the eggs were kept in water at this temperature throughout their development, two degrees lower than during the initial experiment. The only difference between the two groups was in the rate of development which was definitely slower at the lower temperature (Table 6). The times from fertilization to hatching were: 110 hours at 10.5 degrees C., and 68 hours at 12.5 degrees C.

10. LARVAL DEVELOPMENT

The newly hatched larvae vary in length from 1.93 to 2.08 mm. They are slender, delicate, transparent and pelagic, their buoyancy being dependent upon their yolk sacs. Larvae at this early stage characterized by possession of yolk sacs have been termed prolarvae (Hubbs, 1943).

The body of the larva is strongly curved about the large and elongate yolk sac which has a length of 0.95 mm., a depth of 0.55 mm., and a breadth of 0.44 mm. The young fish is symmetrical with a long trunk nearly circular in cross section and tapering gradually posteriorly. The head extends slightly anterior to the yolk sac into which it is strongly deflected. The dorsal profile of the head is regularly rounded since the snout is not yet developed and there is no indication of a mouth or jaws. The eyes are comparatively large. The median larval fin fold originates at the postero-dorsal surface of the head, is continuous about the posterior end of the trunk, and extends anteriorly as a ventral fin fold to the anus. The depth of the fin fold is greatest in the anal region where the dorsal fold is about equal to, and the ventral fold one and one-half times the depth of the body. The pectoral fins appear as minute transparent fan-like structures on the sides of the body just posterior to the otic region. The posterior portion of the gut extends along the posterior margin of the yolk sac to the edge of the ventral fin fold.

Melanophores and xanthophores are most dense along the dorsal portion of the body and the posterior portion of the gut. Large melanophores are scattered on the dorsal fin fold and a few occur on the ventral fin fold slightly posterior to these and near the end of the tail.

The larva, immediately after hatching, remains inactive for one to two minutes, a period in which it seems to be in a resting state. It floats with the yolk sac uppermost and with the head somewhat lower than the tail. At first the tail assumes the laterally curled position that it had within the egg capsule but with increased exercise it remains extended and is curved slightly ventrally. often a sharp lateral flexure appears near the tip of the tail. Periodic thrashing movements occur in which the tail bends sharply at the posterior limit of the yolk sac. These appear to be post-embryonic hatching movements rather than efforts to swim, since the larvae remain in position or roll partially or completely over momentarily without moving forward.

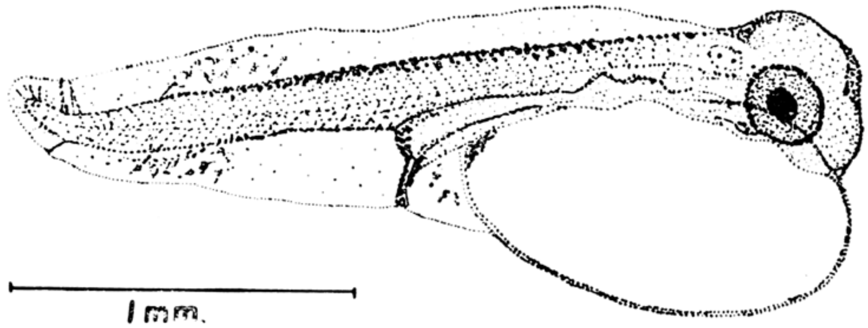

FIGURE 32. Larva of 12 hours

FIGURE 32. Larva of 12 hours

At about 12 hours after hatching the larva still floats with the yolk uppermost but its position is now horizontal. When thrashing or swimming movements occur the body now rolls over so that the yolk sac is below and the larva swims upright. When at rest, however, the position with the yolk sac uppermost is quickly resumed. The larva at this stage of development (Figure 32) differs considerably from the newly hatched larva. Its total length is 2.58 mm. and the yolk sac is now 0.88 mm. long and 0.55 mm. in depth. The posterior portion of the yolk sac slopes more gradually, the head is not deflected strongly into the yolk sac and the body has straightened. The gut has become quite large. The somites display a very regularly chevron-shaped pattern. The pectoral fin has a length of about 0.06 mm. and ceratotrichia or larval rays are beginning to appear as supports in the caudal portion of the fin fold. The posterior tip of the notochord is straight. The pattern of pigmentation is essentially the same as at the time of hatching and the chromatophores of the dorsal and ventral fin folds are characterized by fine thread-like ramifications. The area of pigmentation of the ventral fin fold is concentrated more posteriorly than that of the dorsal fin fold. This is a marking characteristic of the larvae so far as observed.

At 24 hours after hatching the larvae were 2.99 mm. long and very active. In order to study the larvae in detail it was found desirable to anesthetize them, using Panthesine methane-sulfonate sold under the trade name of "M S-222." One part of this vertebrate anesthetic diluted with 6,000 parts of sea water served to anesthetize the larvae in 10 seconds and they became active within five seconds after removal from the solution. No ill effects were observed in larvae anesthetized for a period as long as one hour. The heartbeat of an anesthetized one-day-old larva was 84 beats per minute and this rate is the same as observed for the unanesthetized larvae 12 hours after hatching.

At about one day after hatching a slight depression appears in the profile of the head at the tip of the snout giving evidence of the development of the stomodaeum. Three branching greenish-amber chromatophores appear on the yolk sac which has become noticeably smaller than in the 12-hour larvae. The larval fin rays about the tip of the tail are more distinct and the pectoral fin has a length of 0.22 mm.

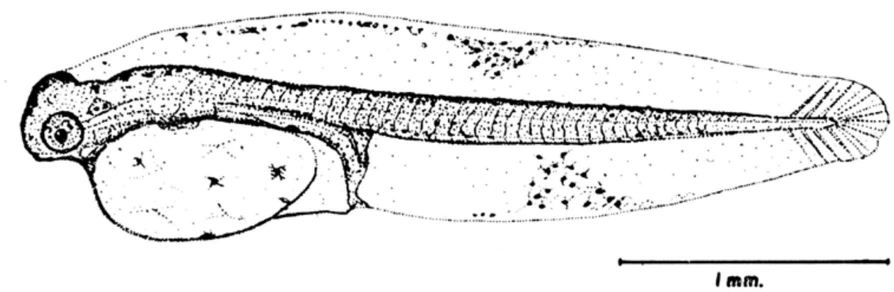

FIGURE 33. Two-day larva

FIGURE 33. Two-day larva

At two days after hatching the larva has a total length of 3.15 mm. and has changed considerably in appearance (Figure 33). The yolk sac has become more elongated and less deep. The head extends free from the yolk sac as far back as the region of the heart. The dorsal and ventral fin folds are about equal in depth. The caudal region has many well-developed ceratotrichia. The pectoral fins are now larger than the eyes and are used actively in swimming. The notochord is clearly visible extending from the posterior portion of the brain to the end of the body. A light green pigmentation has appeared on the tip of the head between the eyes. The margins of the eyes appear greenish-amber anteriorly and amber in color posteriorly. The posterior and dorsal surfaces of the terminal portion of the gut have a light green color and are speckled with melanophores. The chromatophores of the fin folds are concentrated in yellowish-green areas, broadest at the fin margins and thinning out toward the body. The patch on the dorsal fin fold is centered just posterior to the mid-portion of the body and the patch on the ventral fin fold is slightly behind this. A series of melanophores near the margin of the dorsal fin fold extends from the yellowish-green patch to a point about on the vertical of the pectoral fin. Melanophores are also concentrated in separate series along the dorsal and ventral aspects of the body. The mouth and jaws are discernible but not functional at this stage of development. The larvae now float head down with the dorsal margin forming an angle of about 75 degrees with the horizontal. Many were observed to rest in this position on the bottom. At intervals of 15 to 25 seconds they swim energetically for a distance of three or four centimeters and then rest.

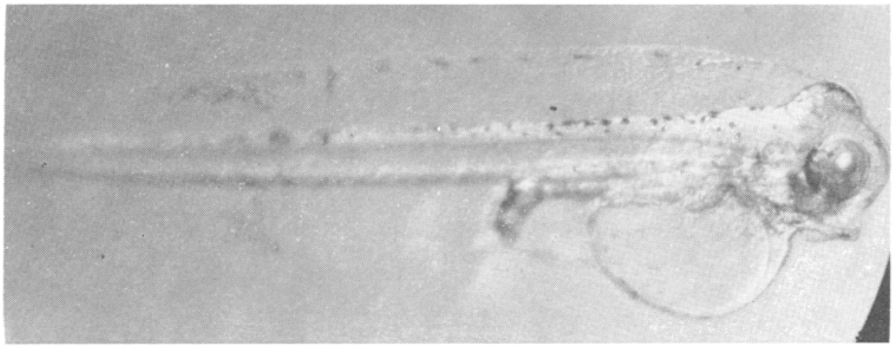

FIGURE 34. Three-day larva

FIGURE 34. Three-day larva

In the three-day-old larva pigmentation between the eyes appear bluish-green. Greenish chromatophores are on the crown of the head and the nape (Figure 34). Dark green pigmentation has developed just behind the eyes and on the walls of the posterior portion of the gut. One large greenish chromatophore is located near the tip of the lower jaw. The larva at this age is 3.20 mm. in length. At about three and one-half days peristaltic movement was observed in the gut.

At four days the larva has a total length of 3.50 mm. and a body depth of 0.19 mm. at the anus (Figure 35). The mouth and jaws are now functional. The two-chambered heart is easily discernible. The yolk sac is now very small, measuring 0.29 mm. by 0.24 mm. Larval fin rays have appeared in the pectorals which are now about 0.29 mm. in length and about 21 ceratotrichia are discernible in the caudal region. Greenish pigmentation is present in the characteristic patches in the dorsal and anal fins; the dorsal wall of the posterior end of the gut; on the crown of the head, the nape, and about the lower half of the eyes. The eyes are now slightly bluish in color. The pigmentation of the iris becomes darker as development progresses. Large stellate melanophores are scattered on the body at the bases of the fin folds. A few are located on the walls of the posterior portion of the gut. The head now has a very angular outline and the terminal mouth and jaws appear to be functional. The larvae at this age use the pectoral and caudal fins in typical swimming movements and they maintain themselves at all levels in the jars in which they are kept.

The fourth or fifth day after hatching can be called the "critical period" for it is at this time that the reserve of the yolk sac becomes exhausted and the fish is entirely dependent upon ingested food for nutrition. The larvae after the absorption of the yolk are often called postlarvae to distinguish them from the yolk-bearing prolarvae.

In an attempt to carry the prolarvae through the critical period and give them a good start in their postlarval life, several different types of food were offered. These were: newly hatched nauplii of the copepod, Tigriopus fulvus; newly hatched nauplii of phyllopod, Artemia salina; motile blastulae of the echinoid, Strongylocentrotus purpuratus; motile cells of the volvocaline alga, Platymonas subcordiformis; the diatom, Nitzschia closterium, forma minutissima; and fine planktonic material collected in eight daily plankton hauls. The larvae were placed in several separate jars and those in each jar were continuously provided with one of the above listed types of food beginning with the third day. No feeding occurred on the third or fourth day, but on the fifth day, when the yolk sac was completely absorbed, all fish offered Platymonas had fed upon it. No other type of food was taken by any of the larvae.

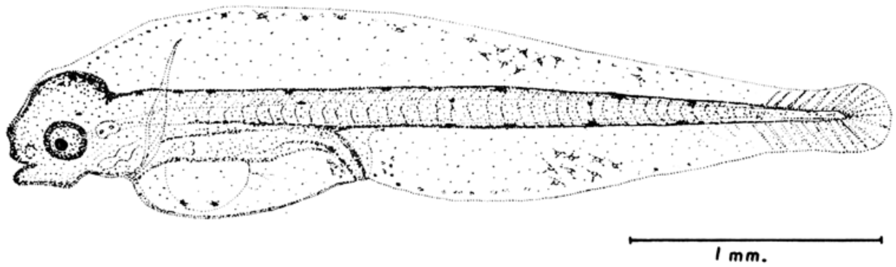

FIGURE 35. Four-day larva

FIGURE 35. Four-day larva

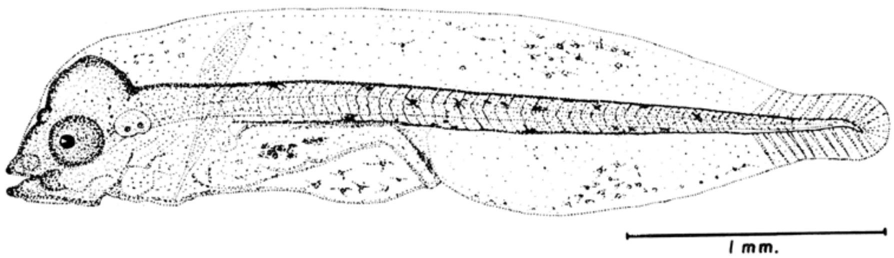

FIGURE 36. Seven-day larva

FIGURE 36. Seven-day larva

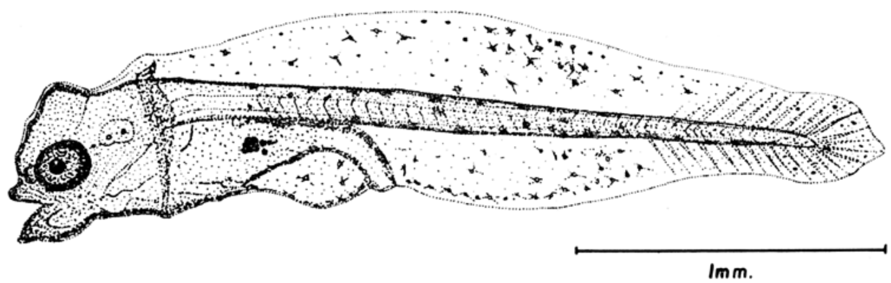

FIGURE 37. Ten-day larva

FIGURE 37. Ten-day larva

By the seventh day the larva has developed a large deep head with a high crown and a very pointed snout and terminal mouth (Figure 36). The jaw has lengthened and is very angular. The eyes and auditory capsules also show an increase in size. Larval fin rays are more strongly developed, those of the caudal region being about 25 in number.

The larvae at this age showed indications of starvation although they were feeding upon the Platymonas. Just posterior to the pectoral fins the belly had become strongly concave and the total length of the larvae was only 3.4 mm., slightly less than that of the four-day larvae. Larvae began to die rapidly on the seventh day, evidently due to lack of proper food. It is quite probable that they received little or no nourishment from the Platymonas. This alga, being a spray pool form, could scarcely be a natural food of the larvae.

On the tenth day only 14 of the 466 larvae that had hatched were alive. They had an average total length of only 3.0 mm. and a very emaciated appearance (Figure 37). The pigmentation pattern on the body had not materially changed. The large chromatophores had disappeared from the head. The caudal region showed the appearance of large melanophores scattered at the base of the ventral fin fold and small pigment spots occurred in the fin about the posterior end of the larvae. About 28 ceratotrichia were discernible and the caudal fin had a pointed outline posteriorly.

All larvae were dead on the eleventh day. It is unfortunate that complete lack of material prevents any description of the striking changes that take place during metamorphosis and that there is little evidence as to the age and size at which this occurs. This stage, which marks the end of pelagic existence and the assumption of life on the bottom, is of primary importance. Intelligent conservation measures must frequently be based upon information about this detail. If the pelagic period is short the spawning grounds and nursery areas must be close together or even continuous to make possible survival of the young. However, if the period is long the two areas may be separated by considerable distances. Such features as larval mortality and consequent size of recruitment in the parent stock may be profoundly influenced by the age at which metamorphosis occurs.

The smallest metamorphosed specimen of Platichthys stellatus taken during the present study was an individual 10.5 mm. in standard length collected on March 20, 1948, in Elkhorn Slough. This fish had assumed bottom-living habits and had, in general, acquired adult characteristics

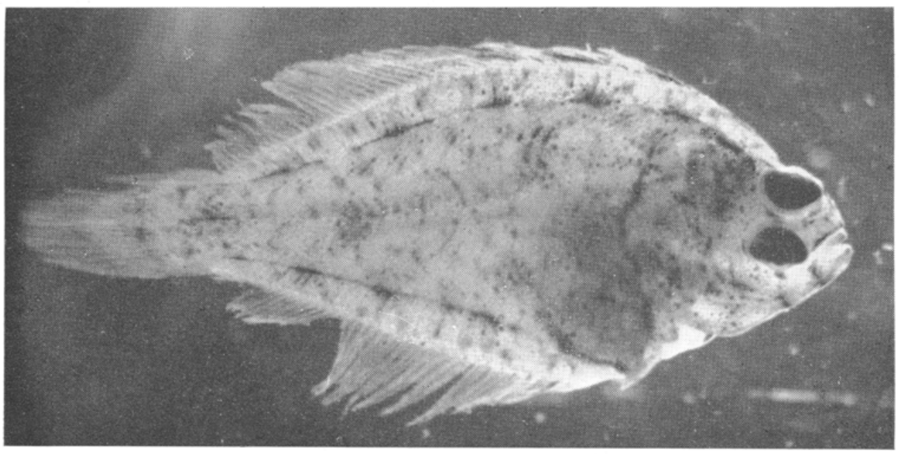

FIGURE 38. A juvenile *Platichthys stellatus* of 10.5 mm. standard length taken at Elkhorn Slough, California, March 20, 1948

FIGURE 38. A juvenile Platichthys stellatus of 10.5 mm. standard length taken at Elkhorn Slough, California, March 20, 1948

(Figure 38). The migration of the eye had occurred so that both eyes were on the same side of the head. The body depth had been greatly increased by the development of pterygiophores, the skeletal elements supporting the median fin rays. The sigmoid myotome arrangement was well developed. The characteristic adult pigmentation pattern of vertical black bands in the dorsal and anal fins and longitudinal black bands in the caudal fin had appeared. Pigmentation was entirely lacking on the blind side of the body. The pelvic fins were well developed and functional and lepidotrichia had replaced larval rays in all of the fins.

Gradual changes in form occur as the young pass through the juvenile stage. The head and eyes are proportionately larger, the snout is much shorter and the mouth appears smaller in the young than in the adult. The actual proportionate increase in the size of the mouth is very slight, the apparent difference being due mainly to the relative decrease in the size of the eyes, and to a rather marked posterior shifting of the upper one with the concomitant lengthening of the snout. The ratio of maximum depth of body to standard length is less and the deepest part is located more anteriorly in the very young than in the larger individuals.

Pronounced changes occur in the structure of the scales with increased body size. Fish about 25 mm. in standard length possess minute embedded cycloid scales which, as the fish become larger, tend to develop into stellate plates with spinous tubercles. In specimens 100 mm. in standard length these stellate plates are present on the eyed side of the head and on both sides along the bases of the dorsal and anal fins. In addition numerous small pits indicating the location of embedded cycloid scales are scattered everywhere on the body.

In fish of 200 mm. standard length broad bands of rough scales are found just above and below the smooth lateral line on the eyed side. The scales have a general alignment with the underlying myomeres and are smoother near the margins of the body. A few scattered rough tubercles have appeared on the dorsal and anal fins themselves. Rough scales on the blind side are limited to the head, bases of fins and double lines above and below the anterior half of the lateral line.

In individuals about 250 mm. in standard length and over very rough scales in the form of spiny plates, often stellate in shape, are scattered over the body. The largest and roughest scales are at the bases of the dorsal and anal fins and on the head. Only a few embedded cycloid scales remain on the posterior part of the eyed side. On the blind side the rough scales are predominant only on the anterior portion of the body, while posteriorly they are sparsely scattered among many embedded cycloid scales. The rough tubercled, stellate scale-plates have been the bases for this fish receiving such common names as starry flounder, rough jacket, emery wheel and grindstone. The skin of a two-year-old fish when dried can be used as a coarse emery which resists tearing and can be used in the rasping of wood.

11. AGE DETERMINATION

In the determination of age of fishes the method of plotting frequency distributions of various size groups is often used. When this statistical method is applied to the data certain size groups within the range of the sample tend to appear as modes which in many instances correspond very closely to age classes. Two hundred and ninety-eight specimens of starry flounder from the commercial catch of Monterey Bay taken during the months of November, December, and January (1948–1949) are represented in the frequency polygon of Figure 39. Unfortunately the data are not truly representative of the population in Monterey

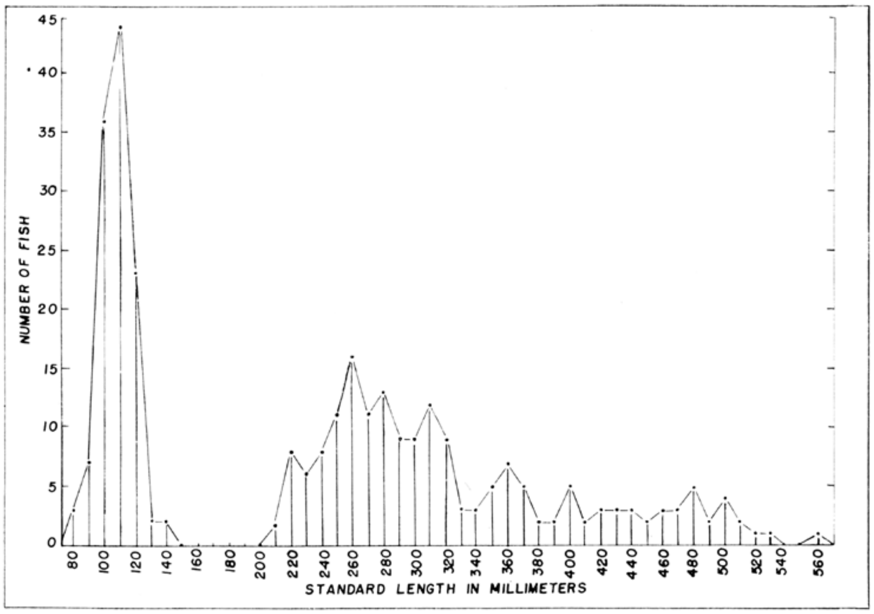

FIGURE 39. Frequency polygon of *Platichthys stellatus* taken November-January, 1948-49. Class interval is 10 millimeters and the data are plotted over the lower limits

FIGURE 39. Frequency polygon of Platichthys stellatus taken November–January, 1948–49. Class interval is 10 millimeters and the data are plotted over the lower limits

Bay because adequate facilities for proper sampling were beyond the resources of the author. However, the first year class appears in the graph as a very distinct and separate curve including fish of standard lengths ranging from about 80 to 150 mm. By simple inspection the mode is found to fall at about 110 mm. Other far less conspicuous modes appear among the larger fish but their correspondence to age classes is open to some question. It might be assumed that the peaks at 260 and 310 mm. are centers of clusterings of the second and third age classes. However, the minor peaks at 220 and 280 mm. as well as the pronounced discrepancy between the distances of the modal progressions during the second and third years casts grave doubt upon the validity of the assumption. The low frequency of observations based upon larger fish, plus probable variation in growth rates, makes further age class identification on the basis of modes impractical. Since size alone, as expressed by the frequency polygon, did not serve as a satisfactory segregation of the fish into age groups, other methods of determining age were applied.

Although, as mentioned in an earlier section, the scales of Platichthys stellatus tend to develop into spinous, stellate plates, there remain many small cycloid scales embedded in the skin on fish of all ages. Since the thickness of the stellate plates obscures the circuli, the small cycloid scales were used for age determination.

To determine the most desirable area of the surface from which to select scales each side of the fish was arbitrarily divided into three areas above the lateral line and three below it; these being designated as dorsal or ventral anterior-, mid-, and posterior-body regions. Scales from each of the 12 areas were carefully compared and it was found that those from the dorsal posterior-body region of the blind side were most satisfactory.

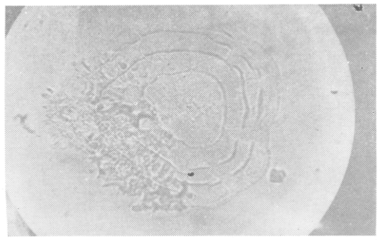

FIGURE 40. Scale from a female Platichthys stellatus 25.9 mm. in standard length taken April 7, 1947

FIGURE 41. Scale of a male Platichthys stellatus 99.5 mm. in standard length taken September 4, 1946

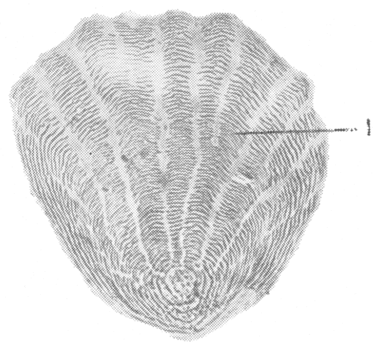

FIGURE 42. Scale of a female Platichthys stellatus 128 mm. in standard length showing an annulus (1) and a wide marginal increment. Specimen taken June 4, 1947

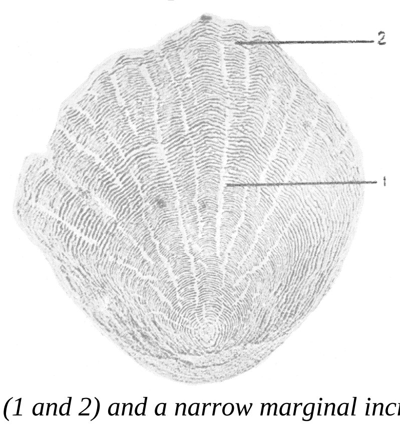

FIGURE 43. Scale showing two annuli (1 and 2) and a narrow marginal increment. Scale from an immature female 250 mm. in standard length taken February 4, 1947

They were the most regular in shape, the least apt to bear spiny tubercles, the most easily cleaned of epidermal tissue and pigment, and showed the circuli most clearly. The scales were cleaned and mounted on slides in a solution of glycerin and gelatin (Van Oosten, 1929) to which a few crystals of carbolic acid had been added for preservation. The scale reading was done both through a compound microscope and by projecting the image through the scale projection apparatus of the California Division of Fish and Game at the Hopkins Marine Station (Felin and Phillips, 1948).

When the starry flounder are about 25 mm. in standard length the scales show two or three concentric rings, the circuli, enclosing a central clear area, the focus (Figure 40). Each cycloid scale of fish about 100 mm. in standard length has many irregular and often branched circuli interrupted by four to nine pronounced radiating clear lines, the radii, extending from the margin almost to the focus (Figure 41). The spaces between the circuli are greatest anterior to the focus, decrease laterally, and converge toward the apex of triangular scales while in rounded scales many completely surround the focus. The scales of considerably older fish are roughly triangular in shape and have additional radii originating at various distances from their foci (Figures 42 and 43).

In the examination of the scales concentric zones appear which are distinguishable due to areas of different spacing of circuli. The innermost area encircling the focus consists of circuli less closely spaced than in the next encompassing band which is characteristized by circuli that become more crowded toward the margin. These two concentric areas of differently spaced circuli comprise the inner zone of growth. Enclosing this is another such zone also consisting of two bands of growth, the first with widely spaced, and the outer with increasingly more closely arranged circuli. The number of these similar growth zones increases in proportion to the size of the fish from which the scales are taken. The scales in Figures 42, 43, and 44 show one and one-half, two, and three such zones respectively.

Scales of fish taken in December and January had the bands of closely spaced circuli at or near their margins, and those of fish caught in February invariably showed a narrow marginal increment of circuli which were farther apart. This suggested that an area of the more closely arranged circuli was an annual growth band or annulus. To check this, a study was made of scales taken monthly for a period of one year (September 1946, through September 1947). These scales were from fish collected from an isolated population at the mouth of the Salinas River. It was found that recently formed circuli at the scale margins had characteristic spacings at different seasons of the year: (1) the widely spaced circuli representing comparatively rapid growth occurred only during the period from late January through early summer; (2) from late summer to fall the circuli became progressively more closely spaced; (3) in the months of November and December the circuli became most closely crowded. The bands of more closely spaced circuli being laid down but once a year and at a definite season are annuli and can be relied upon for determining age.

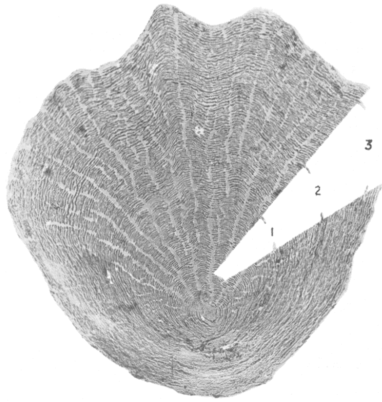

FIGURE 44. Scale from a female Platichthys stellatus 325 mm. in standard length taken February 20, 1947. The figures 1–3 indicate outer limits of annual bands

FIGURE 45. Right otolith from a female Platichthys stellatus 325 mm. in standard length taken February 20, 1947. (Taken from same fish as was the scale of Figure 44.)

Figures 42, 43, and 44 show scales that have one, two and three annuli respectively and are thus from fish that were in their second, third, and fourth years. Not only can the age be determined in years but the experienced reader can estimate the age in months by giving consideration to the marginal increment surrounding the last annulus. For example, the scale in Figure 42 has a marginal increment which, although wide, is not wide enough to be interpreted as resulting from the growth of an entire year. Furthermore, the fact that all circuli at the margin are widely spaced indicates that the fish was taken before late summer. The actual date of capture was June 4th and the specimen was about 18 months of age. Similarly, the fish represented by the scales of Figures 43 and 44 which have very narrow marginal increments had just completed two and three years of life respectively. Both of these fish were taken during the month of February.

Otoliths are structures frequently used in determining the age of fishes and a study was also made of these bones to see if they had annual zones of growth. The otoliths were removed from 161 specimens and examined for features that would indicate age. When viewed in glycerin against black mats in reflected light they show dark (translucent) and light (opaque) concentric rings surrounding an inner light area, the focus (Figure 45). These concentric markings are more widely separated at the ends of the otoliths than at the mid-region and are most distinct in the anterior portions. The lateral or concave surface is the most easily read because the convex median face is deeply scarred by the sulcus acousticus.

Observation of the development of marginal increments of otoliths for a one-year period revealed that the foci are formed during the early part of the first year of life and that the innermost encircling dark rings appear during the first winter. Succeeding rings form during the same season in succeeding years. In all cases translucent, dark concentric rings agreed in number to the annuli on scales from the same fish. These translucent rings are, therefore, considered the annuli of the otoliths. Thus a zone consisting of an inner opaque area with its surrounding translucent ring represents a year's growth. At ages beyond five years the otoliths become so thick and opaque that it is practically impossible to distinguish annuli by transmitted or reflected light and since scales are more easily prepared for examination the latter were used primarily as indicators of age.

12. RATE OF GROWTH

When a method of determining the age of individual fish is established the rate of growth can also be determined. The growth rate of a commercial species is an important factor in the estimation of the natural production of the fishery. The present discussion presents the rate of growth of Platichthys stellatus in Monterey Bay, California as calculated from specimens collected from September, 1946, through December, 1948. The fish taken from the commercial fishery were usually dead and were measured immediately. The fish collected in the field were killed at once in a 2 percent solution of formaldehyde in sea water and measurements were made within three days. Samples from both sources were permanently preserved in a 4 percent solution of formaldehyde in sea water. Measurements of the fish from the commercial catch were determined to the nearest millimeter and those from all other samples (usually smaller specimens) were made by the use of needle point dividers and a ruler graduated in half-millimeter units.

During the first year and one-half of life there is a marked seasonal variation in the growth of the starry flounder. This seasonal variation also occurs in older fish, but the rapid increase in size of the younger individuals exhibits the phenomenon more clearly. The sampling of juveniles for 18 consecutive months indicated that shortly after metamorphosis, which evidently occurs for the most part during the months of January and February, the increase in length maintains a relatively rapid rate throughout spring and early summer. During the months of July through October the rate becomes considerably less. A very marked acceleration occurs in January and rapid growth continues through the second spring.

TABLE 7

Standard Length Data of Monthly Samples of Platichthys stellatus Taken at the Mouth of the Salinas River, California, 1946-1947

Month	N	$\bar{x} \pm$ S.E.	σ	M	D_1	D_9
March	26	26.6±1.56	8.00	29.5	10.8	34.8
April	16	33.4±2.62	10.48	38.7	14.4	44.2
May	10	42.7±3.38	10.69	42.8	23.8	55.0
June	0					
July	12	74.9±2.18	7.54	77.5	62.7	82.4
August	21	82.6±3.12	12.99	82.0	65.0	103.8
September	54	90.9±1.00	7.38	91.8	80.1	100.2
October	100	93.9±0.64	6.35	94.0	86.4	101.0
November	101	101.1±0.68	6.83	100.6	92.6	109.5
December	21	107.7±2.44	11.18	107.6	92.0	121.1
January	92	114.5±1.08	10.26	115.0	103.0	126.1
February	105	134.6±0.98	10.00	134.9	121.7	145.8
March	41	144.2±1.31	8.36	143.0	132.0	154.5
April	84	152.7±1.07	9.77	152.8	139.0	166.5
May	132	154.3±1.28	14.71	154.0	138.3	167.5
June	126	152.2±1.24	13.86	152.2	138.0	167.7
July	99	150.3±1.19	11.82	149.6	138.5	165.6
August	98	151.1±1.33	13.11	149.8	135.5	168.3
	1,128					

Key:

N = Number

$\bar{x}$ = Arithmetic mean

S.E. = Standard error of mean

σ = Standard deviation

M = Median

D_1 = 1st decile

D_9 = 9th decile

TABLE 7 Standard Length Data of Monthly Samples of Platichthys stellatus Taken at the Mouth of the Salinas River, California, 1946–1947

The tabular and graphic presentations of the monthly samples (Table 7 and Figure 46) do not represent fully the seasonal growth that actually occurs. Several factors have contributed to a distortion, but fortunately these may readily be explained. First of all, the negative skewness for the first three months (apparent in the position of the first and ninth deciles) is probably due to size selection by the collecting net. Continued recruitment of large numbers of very young and small individuals undoubtedly occurred and while numerous smaller fish were present they were not taken in numbers indicative of their true proportion in the population until they attained a size sufficient to be held in the gear used in sampling. Secondly, the apparent decline in rate of growth during April followed by a rapid increase during the following two months is undoubtedly due to inadequacy in the size of the May sample (only 10 fish were collected) and the lack of any sample whatsoever in June. Scales of fish taken in July show circuli rather widely and

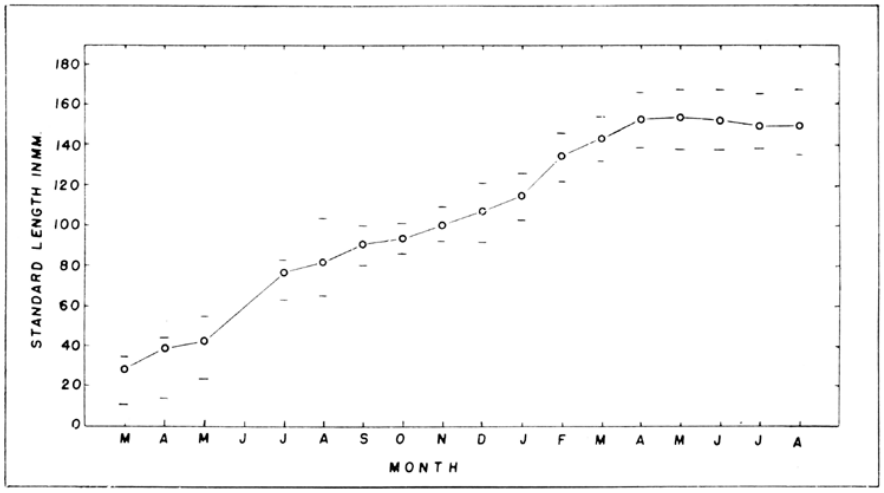

FIGURE 46. Progression of standard length medians for juvenile *Platichthys stellatus*. Salinas River Mouth, California, 1946 and 1947. Dashes above median points (o) are 9th deciles; those below, 1st deciles

FIGURE 46. Progression of standard length medians for juvenile Platichthys stellatus. Salinas River Mouth, California, 1946 and 1947. Dashes above median points (o) are 9th deciles; those below, 1st deciles

evenly spaced from the foci to their margins. This indicates that during the period from March through July the rate of growth was in general uniform with no periods of marked acceleration or retardation. There can be little doubt, therefore, that a truly representative growth curve, based on much more extensive material, would be more smoothly rounded, showing initial rapid growth until July followed by a retardation persisting until about the month of January when a marked acceleration in growth is evident. Finally, the data presented for the second summer show no growth; in fact, a slight decrease in size is indicated. This is certainly a distortion and is undoubtedly due to the method of sampling. All of the collecting was done in shallow water by means of hand-operated seines and trawls. The larger fish tend to frequent deeper waters and due to lack of proper equipment for sampling this habitat they were not fully represented in the samples. Had it been possible to secure adequate samples there is little doubt that the curve would have shown rapid growth until June or July.

The determination of the growth rate of Platichthys stellatus through seven and one-half years of life was possible by means of data obtained through examination of specimens from Monterey Bay. The fish is undoubtedly longer-lived but no older fish were observed during this study. After separation into age classes the fishes were segregated into 12 groups on the basis of the month of capture, and within each of these groups the arithmetic means of the standard lengths were computed separately for the two sexes. The plotting of these mean standard lengths against age gives a graphic illustration of the rate of growth (Figure 47). A comparatively sharp change in growth rate occurs during the latter part of the second year. Prior to that time the growth is very rapid, but after the beginning of the third year it is slower and displays a slight but steady decline as the fish become older.

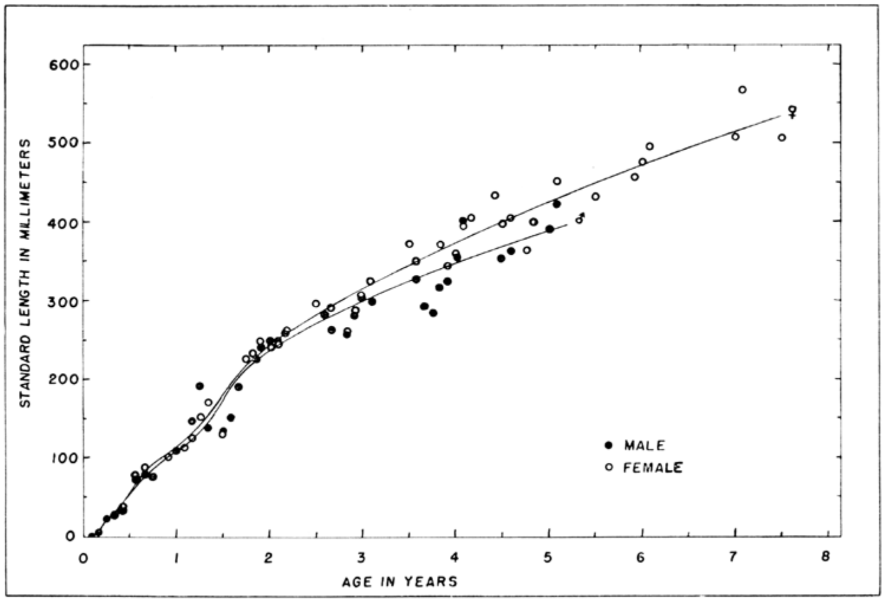

FIGURE 47. Growth rate of *Platichthys stellatus*, from Monterey Bay, California. Data of 1946-1948

FIGURE 47. Growth rate of Platichthys stellatus, from Monterey Bay, California. Data of 1946–1948

Even a casual examination of the plotted means reveals that, beginning with the second year, the fishes taken during late summer and early fall averaged smaller than those which constituted the samples of the previous months. This apparent annual shrinkage is, of course, not to be considered as a phenomenon of growth. It is the result of obtaining samples from different sources. During the period from October to April most of the material was derived from the trawl fishery which operated in depths of 25 fathoms or more—depths inhabited by larger fish. On the other hand, during the slack period of the trawl fishery it was necessary to obtain practically all of the samples from incidental catches of the gill net fishery for crabs which, operating in lesser depths, caught fish averaging somewhat smaller in size. The sampling thus made the representation of the size ranges within age groups more complete, but the seasonal concentration on fish of different sizes also produced the above-mentioned irregularities in the curve.

The growth curves for the two sexes, drawn by eye, show no apparent significant difference in size between the sexes until the second year when the females appear noticeably larger. To show this difference between sexes more clearly the mean lengths of the age groups of males and females are presented in Table 8. Since spawning and annulus formation occur during the same season, this period can be considered as the time when the fish are completing full years of life. For this reason the data of the table are based upon specimens taken during the months of November, December, and January. The difference of 5.6 mm. between the mean lengths of males and females at two years of age increases to 34.4 mm. at five years indicating that the differential in growth rate persists throughout life and that the disparity in size between the two sexes becomes greater with advancing age. Figure 47 and Table 8 also show

TABLE 8

Mean Standard Lengths of Platichthys stellatus Taken During the Months of November, December, and January of 1947-1948 and 1948-1949, Monterey Bay, California

Age in years	Males			Females		
	Number	Mean length in mm.	Range	Number	Mean length in mm.	Range
1	58	105.7	82-142	59	108.7	92-129
2	22	235.0	213-276	11	240.6	228-273
3	45	298.7	248-366	32	315.0	239-362
4	13	345.4	306-370	17	375.1	300-405
5	5	390.8	350-425	14	425.2	365-476
6				19	474.3	425-530
7				3	508.1	478-565

TABLE 8 Mean Standard Lengths of Platichthys stellatus Taken During the Months of November, December, and January of 1947–1948 and 1948–1949, Monterey Bay, California

that in the commercial catch of Monterey Bay the largest fish are females six or seven years of age. Males greater than 425 mm. in standard length and five years old were not found in the sampling although they may occasionally occur.

It is advisable to mention that, inasmuch as the specimens of this study were largely from the commercial catch made by various sizes of different types of gear, such as trammel nets, trawls, and gill nets, the data do not represent the age composition of the population of Monterey Bay. They may be considered as selected for the purpose of showing rate of growth only.

The scales of most fishes are in imbricated overlapping rows which must, if they continue to cover the body, have a rate of growth in direct proportion to that of the entire fish. This is not necessarily true in fishes having scales spaced separately from one another. Since the scales of Platichthys stellatus are embedded and separate rather than overlapping, it was of interest to determine if the relationship between scale and fish growth could be used as a means of establishing the rate of growth. If scales and fish grew proportionately throughout life the mathematical equation for the relationship could be written: $L/L' = 1/1'$, where L equals the standard length of the fish, L' equals the length of the radius of the scale as measured from the center of the focus along a line to the anterior margin, 1 equals the length to be computed and 1' equals the radius of the scale through the annulus for the corresponding period of development.

The existence of such a proportional relationship was first suggested by Lea (1910). Actually, the scales do not appear until after the fish has attained some length, but it is now generally believed that, once formed, the scales grow relatively faster than the fish for a short time after which the rates of growth of both become practically equal. This has been demonstrated in the sockeye salmon (Oncorhynchus nerka) by Dunlop (1924) and in the yellow perch (Perca flavescens) by Hile and Jobes (1941). In the same papers these authors have shown that in older fish growth rate of scales is exceeded by that of the body. These factors would lead to a curvilinear relationship rather than a strictly linear one as suggested by Dahl (1910). The variations, however, occur very early and very late in the life of the fish. Except for special purposes it is practical in fisheries biology to omit the corrections of the equation for these slight differences because the bulk of the fishery is based upon fish at ages when scale and body growth rates are most nearly equal. The simple equation was used in this study.

The distances from the focus centers to the outer margins of each year's growth were measured by means of an ocular micrometer in a compound microscope. All measurements were made at the same magnification and as consistently as possible along the median axis from the foci to the anterior margins of the scales. Fish ranging from 70 to 510 mm. in standard length were used. The mean lengths for the various ages were computed separately for each sex (Table 9) and, for comparison, were plotted together with the mean lengths of Table 8 (Figure 48).

The two methods of determining the rate of growth give results that are very similar, demonstrating that, for this species, both methods are valid and scale and body growth are very nearly proportional. Thus, on the basis of scales from a large specimen, it is possible to calculate the length of that particular individual at the end of each year of its life.

TABLE 9

Standard Lengths of Platichthys stellatus Age Groups as Computed From Scales, Monterey Bay, California, 1947-1948

Age in years	Males			Females		
	Number	Mean length in mm.	Range	Number	Mean length in mm.	Range
1	35	102.8	70-145	41	110.2	81-161
2	34	213.7	158-270	38	225.5	162-290
3	18	308.3	270-366	26	314.5	238-375
4	9	351.7	330-378	16	394.3	342-445
5	4	383.5	350-425	12	435.3	365-476
6	----------	----------	----------	3	486.7	455-510

TABLE 9 Standard Lengths of Platichthys stellatus Age Groups as Computed From Scales, Monterey Bay, California, 1947–1948

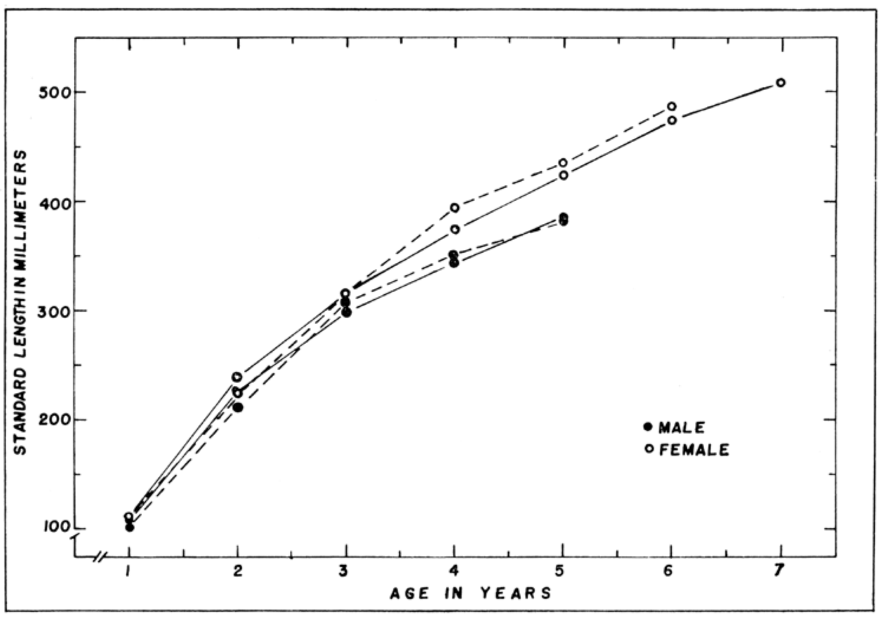

FIGURE 48. Rate of growth of *Platichthys stellatus* as shown by averaged actual lengths and lengths calculated from scales. (Broken line represents calculated lengths.)

FIGURE 48. Rate of growth of Platichthys stellatus as shown by averaged actual lengths and lengths calculated from scales. (Broken line represents calculated lengths.)

Another important relationship in the growth of fishes is that of weight and length, for a knowledge of the size at which the fish increases most rapidly in weight is of value in determining the size at which it may be most profitably harvested. Weight and length of fishes are very closely correlated, and the mathematical relationship can be expressed by the basic formula which, assuming that weight (W) is proportional to volume, can be written $W = kL^X$ in which L represents length, k a constant, and x a power closely approximating 3. The values for k and x are determined empirically for different species. This relationship has been demonstrated for other species by Clark (1925), VanOosten (1929), Hile and Jobes (1941), Marr (1943) and by many other authors.

Inasmuch as there is, in the starry flounder, considerable overlap in the ranges of the length of the different age groups, all of the ages were combined in the study of the relationship between weight and length but males and females were considered separately. Within each 10-milimeter interval of standard length, mean lengths and mean weights (Table 10) were determined. Since the weight-length ratio is a power relationship, the logarithms of the natural numbers were used in the mathematical operations. The logarithms of weight and standard length are shown plotted in Figure 49. The regression lines of log weight on log standard

TABLE 10

Mean Standard Lengths and Weights of Platichthys stellatus for 10 mm. Intervals of Standard Length, Monterey Bay, California, 1948

Intervals of standard length (mm.)	Males		Females	
	Mean standard length (mm.)	Mean Weight (grams)	Mean standard length (mm.)	Mean weight (grams)
100-109	101.0	28.3	106.0	35.4
110-119	----------	----------	112.0	42.5
120-129	126.0	31.9	----------	----------
180-189	186.0	170.1	----------	----------
190-199	192.0	226.9	----------	----------
210-219	212.0	235.0	----------	----------
220-229	224.0	226.9	224.0	226.9
230-239	233.6	340.3	235.5	311.5
240-249	242.0	340.3	246.0	340.3
250-259	252.1	418.9	258.0	453.7
260-269	264.0	444.1	269.0	510.4
270-279	274.0	491.5	274.0	491.5
280-289	282.0	567.1	283.5	538.8
290-299	291.0	661.3	295.0	567.1
300-309	302.7	586.5	303.0	635.2
310-319	312.0	652.2	313.0	794.0
320-329	323.6	793.9	323.5	567.2
330-339	333.5	751.5	334.0	907.4
340-349	343.0	964.1	342.1	860.2
350-359	352.0	998.1	353.0	1,058.6
360-369	365.0	1,134.3	362.0	1,140.8
370-379	371.0	1,191.0	373.0	1,349.6
380-389	385.0	1,190.9	381.0	1,276.1
390-399	----------	----------	392.5	1,550.1
400-409	----------	----------	403.0	1,474.2
410-419	----------	----------	415.0	1,785.9
420-429	425.0	1,814.8	421.0	1,739.1
430-439	----------	----------	435.0	2,344.1
440-449	----------	----------	442.0	2,268.5
450-459	----------	----------	450.0	2,268.5
460-469	----------	----------	463.0	2,111.8
470-479	----------	----------	475.5	2,608.8
480-489	----------	----------	480.0	3,204.8
490-499	----------	----------	495.0	3,289.3
500-509	----------	----------	505.0	3,289.3
510-519	----------	----------	510.0	3,289.3

N = 59 for males, 80 for females.

TABLE 10 Mean Standard Lengths and Weights of Platichthys stellatus for 10 mm. Intervals of Standard Length, Monterey Bay, California, 1948

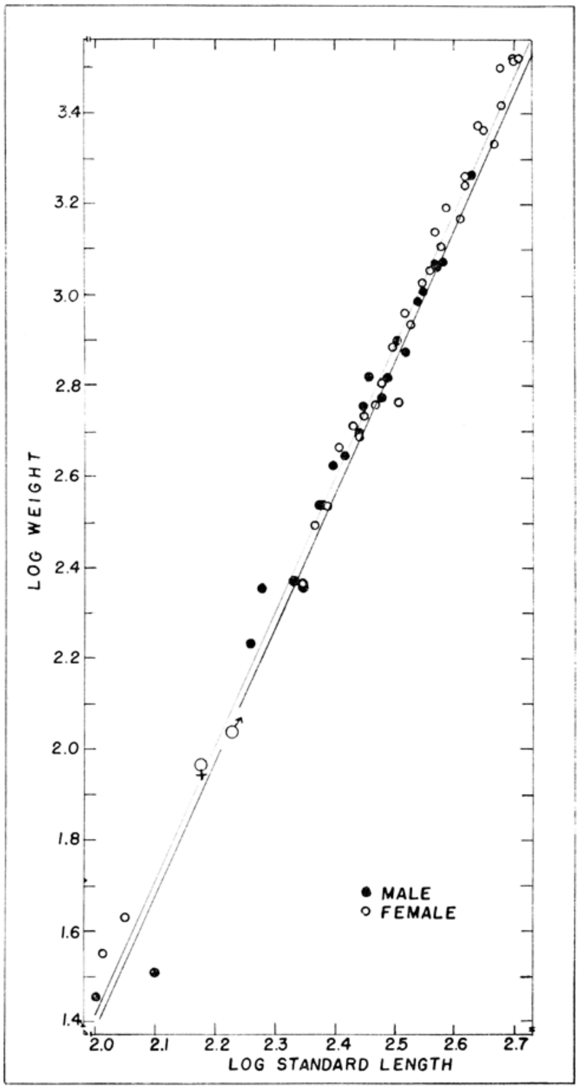

FIGURE 49. Logarithms of weight and length of *Platichthys stellatus*, Monterey Bay, California

FIGURE 49. Logarithms of weight and length of Platichthys stellatus, Monterey Bay, California

length were calculated by the method of least squares. The regression coefficients are 2.96 for the males and 2.95 for the females. The resulting graphic presentation shows that in general the lines fit the data, indicating that the log weight and log length of this species have a relationship that is very nearly that of a straight line. The antilog equations of the weight-length curves for the two sexes were found to be: for the males $W = 0.00002959L^{2.96}$, and for the females $W = 0.00003284L^{2.95}$. The weight-length data of Table 10 are shown plotted in Figure 50, and the

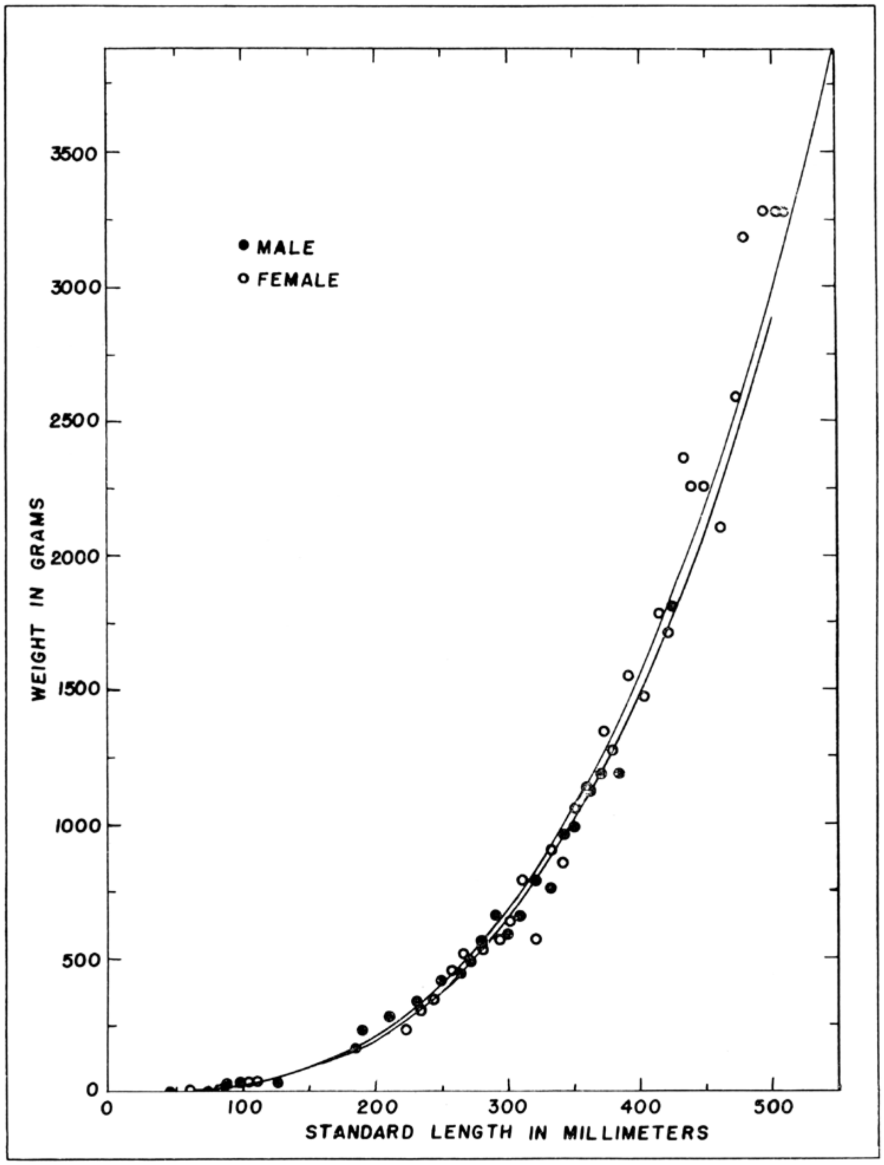

FIGURE 50. Length-weight relationship of *Platichthys stellatus*, Monterey Bay, California, 1948

FIGURE 50. Length-weight relationship of Platichthys stellatus, Monterey Bay, California, 1948

curves are drawn using the above equations. The very slight differences between the k values and of the regression coefficients indicate that for a given size the two sexes do not differ appreciably in weight.

In comparison with increase in length, the rate of the proportional total weight increase is small during the first years of life for, while more than one-half of the maximum length observed is attained at the end of the third year, more than five years are required in order to attain 50 percent of the maximum weight. Over 100 percent increase in weight occurs during the third year in contrast to about a 57 percent increase during the fourth year and about 48 percent in the fifth year. From the commercial standpoint it would not be profitable to catch fish under three years of age and lose the benefit of the rapid gain in weight. As mentioned earlier, the fishery in Monterey Bay is based primarily on

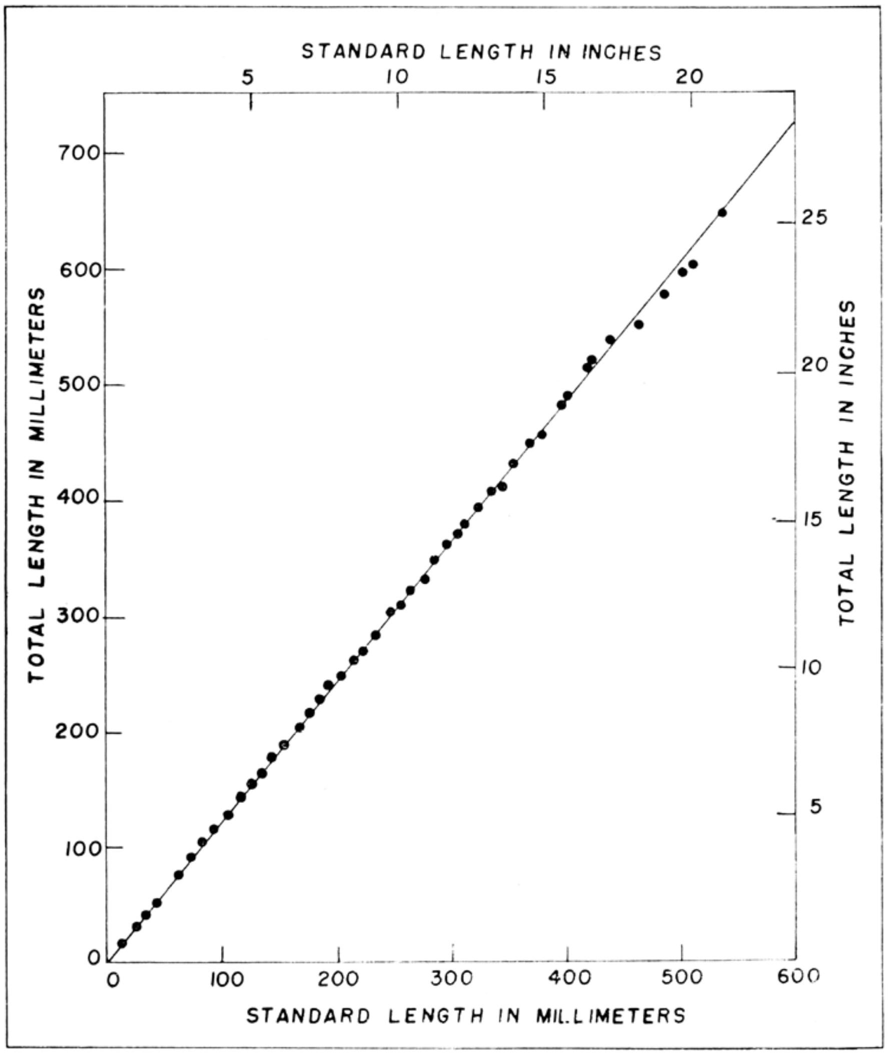

FIGURE 51. Total length—standard length relationship of *Platichthys stellatus*

FIGURE 51. Total length—standard length relationship of Platichthys stellatus

fish about 13 inches (330 mm.) in standard length and since fish of that size are in their fourth year of life and, as will be brought out in the following section, these fish have enjoyed at least one spawning, such commercial operations alone should not deplete the stock.

Frequently researchers record the lengths of fishes in terms of standard length or a comparable measurement. However, regulations of a fishery are usually based upon total length, a measure more readily accepted by fishermen. Since standard lengths are used in this work, the data in Figure 51 are presented for use in converting these measures of the starry flounder to total lengths. The standard length of this species was found to be 81.95 percent of its total length and displayed no appreciable variation in different size groups. In the graph the diagonal line passes through points which represent this relationship.

13. AGE AND SIZE AT FIRST MATURITY

The study to determine the size of the starry flounder at first maturity involved an investigation of the development of the gonads and the growth of the eggs. In the very young fish (10 mm. in standard length) the gonads are so little developed that macroscopic observation for sex determination is not reliable. The gonads of fish more than 20 mm. in standard length show morphological differences between the sexes. The ovaries begin to elongate posteriorly, passing along each side of the haemal spines and interhaemal bones which mark the posterior limit of the main central portion of the body cavity. The testes, in their development, do not extend posteriorly. They remain closely approximated to the posterior wall of the body cavity and enlarge to become elongated kidney-shaped bodies.

As has been explained in an earlier section of this work, the distinction between immature, maturing, and ripe eggs ready for spawning was made on the basis of size. (See Table 5.) The immature eggs appearing in young and adult females measure up to 0.15 mm. in diameter. Maturing eggs are considered to be those measuring from 0.15 to 0.89 mm. in diameter. The third group, eggs about ready for spawning, are those ranging from 0.89 to 0.94 mm. in diameter. In male fish the milky color of the testes and appearance of milky seminal fluid were the indicators of sexual maturity. Fish that have never spawned are considered immature; maturing fish are those having sex products ripening preparatory for their first spawning; and fish that have spawned are considered fully mature.

Since it was impossible to obtain a representative sample of all age groups during the spawning season, the percentage of males and females maturing in each year of life was not established. However, sampling from the commercial catch did yield data of value in the determination of age and size at first maturity (Table 11). The data of this table show that males and females, with few exceptions, become sexually mature during the winters of their second and third years respectively. The one two-year-old immature male fish was the smallest individual of its age group, being only 213 mm. in standard length and the immature three-year females (six in all) ranged from 283 to 340 mm. in standard length. All males of three years of age and females of four years of age that were examined showed clear indication of sexual maturity.

TABLE 11

Ages and Sizes of the Two Sexes of Platichthys stellatus of the Commercial Catch Found to Be Mature During the Spawning Seasons of 1947-1948 and 1948-1949, Monterey Bay, California

Age in years	Males			Females		
	Total number	Mature		Total number	Mature	
		Number	Size range (mm.)		Number	Size range (mm.)
1	58	0	82-142	59	0	92-129
2	22	21	220-276	11	0	228-273
3	45	45	248-366	32	26	239-362
4	13	13	306-370	17	17	300-405
5	5	5	350-425	14	14	365-476
6	----	----	----	19	19	425-530
7	----	----	----	3	3	478-565

TABLE 11 Ages and Sizes of the Two Sexes of Platichthys stellatus of the Commercial Catch Found to Be Mature During the Spawning Seasons of 1947–1948 and 1948–1949, Monterey Bay, California

It is the opinion of the author that as long as the average size of individuals of starry flounder taken in the commercial fishery does not fall below a standard length of 330 mm. a sufficient spawning stock will remain to sustain the fishery.

14. SEXUAL DIMORPHISM

Platichthys stellatus does not exhibit outstanding sexual dimorphism and there are no easily noticeable secondary sex characters. During the breeding season the sexually mature females can be differentiated from the males by the distention of the body posterior to the origin of the anal fin which is caused by the enlargement of the ovary with ripening eggs. Males do not show such a distention of this portion of the body. No differences in color pattern were observed during breeding seasons.

For a given age there is a significant difference in the length of the two sexes. This difference is shown in Figure 47 in the discussion of rate of growth. Other characters, such as maximum depth of body, length of head, distance from tip of snout to insertion of pectoral fins, and minimum depth of caudal peduncle (Figure 52), were studied for possible sexual differences. For these studies a total of one hundred specimens with standard lengths ranging from 19 mm. to 565 mm. were measured. These one hundred fish included fifty specimens from each sex. The correlation coefficients and linear regression coefficients were calculated separately for the characters of the two sexes. In both sexes the characters compared showed very nearly straight line relationships. The significance of the difference between the correlation coefficients was tested by the z test of Ronald Aylmer Fisher as presented by Simpson and Roe (1939). The significance of the difference between regression coefficients of each character of the two sex groups was calculated, using the formula given by Simpson and Roe (1939), to ascertain whether any of these characters show sexual dimorphism. The different values obtained by the above calculations for the characters considered are given in Table 12. The values of P for the differences between all correlation coefficients and for the differences in the regression coefficients of maximum depth and length of head are significant whereas those of distance from snout to pelvic insertion and minimum depth of caudal peduncle are not. This means that in Platichthys stellatus, within the size range studied, body depth and length of head of the females is significantly greater than those of the males. However, the actual differences are slight and in general field observations these evidences of sexual dimorphism are not discernible.

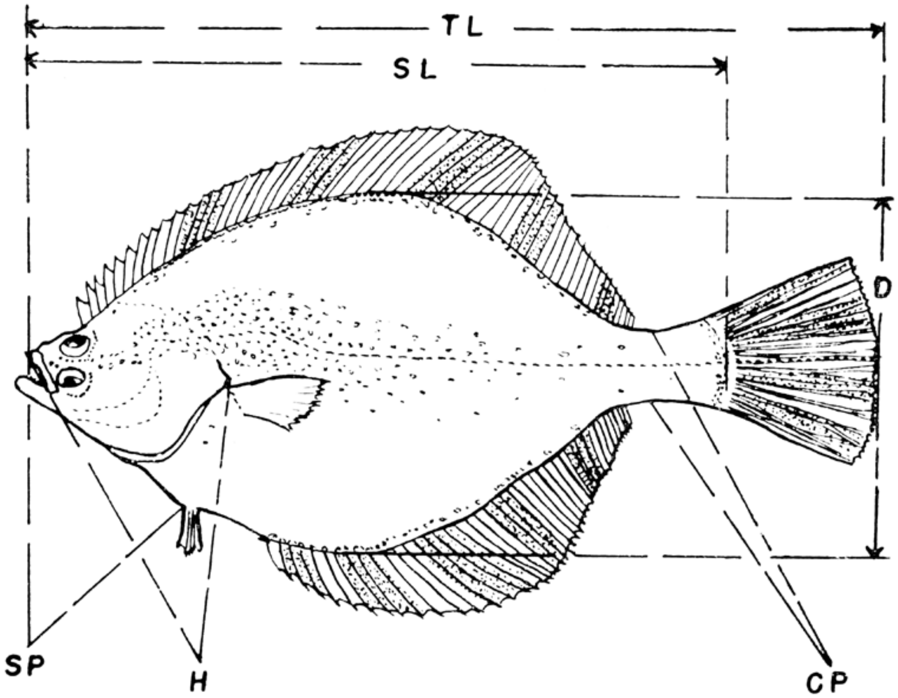

FIGURE 52. The measurements of *Platichthys stellatus* used in this work. TL is the total length; SL, standard length; D, maximum body depth; SP, distance from tip of snout to insertion of pelvic fin; H, length of head; and CP, the minimum depth of caudal peduncle

FIGURE 52. The measurements of Platichthys stellatus used in this work. TL is the total length; SL, standard length; D, maximum body depth; SP, distance from tip of snout to insertion of pelvic fin; H, length of head; and CP, the minimum depth of caudal peduncle

TABLE 12

Data for the Tests of Significance of Differences of Characters Compared in Fifty Male and Fifty Female Platichthys stellatus Ranging From 19.5 mm. to 565 mm. in Standard Length, Monterey Bay, California

Characters*		r		$t=\frac{d_z}{\sigma_{d_z}}$	P	b_{yx}		$t=\frac{d_b}{\sigma_{d_b}}$	P
X	Y	Male	Female			Male	Female		
SL	D	0.985	0.994	2.53	<.016 >.012	0.497	0.530	2.162	<.036 >.028
SL	H	0.940	0.989	2.64	<.01	0.268	0.294	2.248	<.028 >.021
SL	SP	0.877	0.989	6.08	<.01	0.290	0.315	1.235	<.239 >.190
D	CP	0.971	0.997	5.64	<.01	0.187	0.183	0.840	<.420 >.370

* SL = Standard length.
D = Maximum body depth.
H = Length of head.
SP = Distance from tip of snout to pelvic fin insertion.
CP = Minimum depth of caudal peduncle.

TABLE 12 Data for the Tests of Significance of Differences of Characters Compared in Fifty Male and Fifty Female Platichthys stellatus Ranging From 19.5 mm. to 565 mm. in Standard Length, Monterey Bay, California

15. GEOGRAPHICAL VARIATIONS

Studies of geographical variations have an important place in modern fisheries research. Biometrical analyses make possible the distinguishing of different populations within a species. Differing environmental factors or average differences in genetic constitution may effect morphological variations that give rise to geographical forms often called "races." Recognition of these variants is especially valuable in studies of the range and movements of local populations within the total area of distribution of the species and in the formulation of intelligent conservation measures. Although the present study was confined to a single population within a limited area and, thus, did not provide material for direct comparison of geographically distinguishable forms, there are differences between the stock in Monterey Bay and other populations which have been described in the literature.

Platichthys stellatus belongs to a group normally having the eyes on the right side (dextral), but reversed individuals having eyes on the left side (sinistral) are very common in this species. There is evidence that the incidence of reversed individuals of Platichthys stellatus shows geographical differences. Hubbs and Kuronuma (1942) reported that in Japan P. stellatus is invariably reversed, all individuals of a sample of 476 being sinistral. Through personal communication with Dr. Abe of the Central Fisheries Station of Japan, the author has been informed that Dr. Kuronuma has taken a dextral specimen near Akita, that Dr. Tanaka reports another at the Science Museum of Tokyo, and that dextral forms of P. stellatus seem not to be rare in Japan. Townsend (1937) found 67.1 percent of 3,196 specimens of this species from Alaska to be sinistral while 52.1 percent were reversed in 530 specimens from Puget Sound. Lockington (1880) found 54.6 percent of 282 individuals of this species in fish stalls at San Francisco to be sinistral. of 1,439 specimens collected from Monterey Bay, California, the author found that 59.5 percent were sinistral. It is evident that dextral forms are most abundant on the eastern shores of the north Pacific, decrease in relative numbers in Alaska, and are not common in Japan. Although, in general, the proportion of the sinistral specimens decreases southward along the American coast, there is strong evidence of a reversal of the trend between Puget Sound and Monterey Bay, since the percentage of reversed individuals in the latter area was found to be higher than that reported for San Francisco which in turn was higher than that in Puget Sound. These differences may be brought about by various environmental conditions or may be genetic. If the former is true, the differences are not important from the conservational point of view, but if there is a genetic basis and there exists a number of relatively small local stocks which do not interbreed extensively, any future conservation measures should be planned with this in mind.

Townsend (1937) found no significant differences between the proportions of sinistral and dextral forms in the two sexes. Specimens from Monterey Bay showed reversed individuals in the sexes to be 58.6 percent in males and 60.4 percent in females. It is, therefore, probable that variations of percentages of dextral or sinistral individuals in various samples are not due to differential capture of the two sexes.

Work on the European flounder, Platichthys flesus, from the Baltic Sea has developed some evidence that dextral forms of Platichthys are more viable than sinistral forms. Duncker (1900) wrote that among 90 young specimens (19–66 mm. long) from Neustadter Bay 34.4 percent were sinistral and, among 225 individuals of 200 mm. or over from near the mouth of the Obe River only 23.6 percent had both eyes on the left side of the head. From data furnished by Dr. E. V. Smith, it has been reported that: "His extensive data appear to show that the Puget Sound form of the starry flounder; . . . is slightly oftener sinistral (reversed) when young than when adult" (Hubbs and Hubbs, 1945).

The data in Table 13 show the relation between age and sinistrality in Platichthys stellatus from Monterey Bay, California. The data of the fish in their first and second years (O and I age groups) in the table are from a single population and the same year class, that of the winter

TABLE 13

Relation Between Age and Sinistrality in Platichthys stellatus From Monterey Bay, California

Age group	Number of individuals			Percent sinistral		
	♂	♀	♂+♀	♂	♀	♂+♀
0	165	177	342	57.6	52.5	55.0
I	369	426	795	59.6	64.3	62.1
II and over	143	159	302	57.3	58.5	57.9
All ages	677	762	1,439	58.6	60.4	59.5

TABLE 13 Relation Between Age and Sinistrality in Platichthys stellatus From Monterey Bay, California

1945–1946. The data for these groups are not in agreement with the observations of Duncker and of Hubbs and Hubbs referred to above. The fish in the second year of life show a higher percentage of sinistral individuals than the O age group. The samples of the European species were taken at different localities and are definitely not of the same spawning season so that the differences found by Duncker may be dependent upon factors other than age. This may also be true for the Puget Sound samples since they were collected over a four-year period from three different localities and data included specimens from several year classes.

In comparing the three studies, the data for the older age groups show better agreement since after the second year the Monterey Bay fish display a lower percentage of sinistrality than do younger specimens. This decrease in relative numbers of sinistral individuals with age may possibly show a greater viability for the dextral forms, but so many other factors may be advanced to account for the differences reported that it will be necessary to follow a year class from the time of metamorphosis through several years in order to have conclusive data.

According to Townsend (1937) the number of rays in the dorsal and anal fins differ significantly between Platichthys stellatus samples from Alaska and Puget Sound. He found the mean number of rays in the dorsal and anal fins of Alaskan specimens to be 60.58 and 42.96 respectively. For Puget Sound the mean numbers were 58.53 for the dorsal and 42.12 for the anal. In 580 Monterey Bay specimens the values are 58.49 for the dorsal fin rays with a range of 52–64, and 42.52 for the anal fin rays which range from 38–47 (Table 14).

TABLE 14

Data of Fin Ray Counts of Platichthys stellatus, Monterey Bay, California

Dorsal fin		Anal fin	
Number of fin rays	Frequency	Number of fin rays	Frequency
52	1	38	2
53	1	39	16
54	1	40	62
55	23	41	100
56	83	42	161
57	85	43	138
58	98	44	68
59	107	45	29
60	84	46	2
61	61	47	2
62	22		
63	11		
64	3		
	580		580

TABLE 14 Data of Fin Ray Counts of Platichthys stellatus, Monterey Bay, California

The dorsal ray counts demonstrate a higher count in northern samples. The significance of the differences of the means of the samples was tested using the formula presented by Simpson and Roe (1939). The means of dorsal ray counts of Alaska and Monterey samples have a significant difference, indicating statistically that the sampling could have been from different populations. The difference of the means of Puget Sound and Monterey dorsal ray counts was not significant. These two samples could have been from the same population. The anal counts of the Monterey fish occupy an intermediate position between those from Alaska and Puget Sound. The difference between the means of Monterey and Puget Sound specimens shows statistical significance, but this same relationship between Alaska and Monterey specimens borders significance, $[d/D_d] = 0.065$.

16. HYBRIDIZATION

Naturally occurring intergeneric and interspecific hybrids among fishes are not rare. However, hybridization has been recorded much more frequently between fresh-water than between marine forms.

Species of the genus Platichthys appear to be marine fishes which tend toward occasional hybridization with species of other genera. The European flounder, Platichthys flesus, is cited (Norman, 1934) as a parent in crosses with the dab, Limanda limanda, and the plaice, Pleuronectes platessa. The fish described as Pseudoplatichthys oshorensis in Japanese waters is recognized (Hubbs and Kuronuma, 1942) as a hybrid between Platichthys stellatus and Kareius bicoloratus. This hybrid was found to be intermediate in all characters that differed between the parents, and to agree in characters which the parental genera had in common. Furthermore, Schultz and Smith (1936) present data indicating that the rather rare flounder, Inopsetta ischyra, is a hybrid between Platichthys stellatus and Parophrys vetula.

The author, in the winter of 1947, artificially fertilized eggs of the flounder, Parophrys vetula and observed the embryological development and the growth of the larvae through nine days after hatching. All stages agreed in detail with the descriptions and figures presented by Budd

(1940). The eggs are very similar to those of Platichthys stellatus in appearance and size, and the cleavages and early development of the embryos of the two forms have a very close resemblance. However, the embryonic development of the latter species is completed in only about 75 percent of the time required by the former at similar temperatures; at 12.5 degrees C. Platichthys stellatus hatches at about 68 hours, Parophrys vetula at about 90 hours after fertilization. Although the larvae of the two species may be readily distinguished by the characteristic pigmentation of the fin fold in Platichthys stellatus which is entirely lacking in Parophrys vetula and by the somewhat greater length of the latter form, they are very similar in shape. These observations on the close similarity of the earliest stages added to those of Schultz and Smith, which were largely based on adult material, make stronger their convincing argument that Platichthys stellatus and Parophrys vetula hybridize. The data presented by Schultz and Smith show that the hybrid is intermediate between the proposed parent species in many meristic characters, proportionate measurements, and position of the eyes, and that it has the same occurrence and spawning time as both parent species.

17. SUMMARY

This paper presents contributions to the knowledge of the starry flounder, Platichthys stellatus and is summarized as follows:

1. Platichthys stellatus occurs in coastal waters of the Pacific and Arctic oceans and connecting seas, and in rivers (as far as 75 miles upstream) within 33 degrees to 73 degrees N. latitude and from 105° W. to 127°E. longitude.
2. The fish is a euryhaline organism which frequents various types of bottom, appearing to avoid only rock, and moves freely from one type of habitat to another. It is found in depths from a few inches to around 150 fathoms.
3. Commercially, the starry flounder fishery is not of major importance in California, but it is stable and can probably be subjected to considerably higher fishing pressure than it now endures.
4. The fish is carnivorous and its food habits vary with increasing size of the fish, the principal items of diet changing progressively from small copepods to amphipods and annelid worms, and then to crabs, bivalve mollusks, and echinoderms.
5. Platichthys stellatus from Monterey Bay were relatively free from parasites and diseased fish were rare.
6. The starry flounder of Monterey Bay spawn once a year during the period from November through February with greatest spawning activity in December and January. The spawning is carried out in depths less than 25 fathoms.
7. Embryological development covers a period of about 68 hours at 12.5 degrees C. It follows the general teleost plan but the eggs may be specifically recognized by detailed differences at the various stages. Larval development is also typical until the time of metamorphosis. It was impossible to report on the latter phenomenon due to failure to carry the material beyond 10 days after hatching.

8. The scales and otoliths show annual zones of growth which can be used in age determination.

9. The rate of growth of the starry flounder as determined from average lengths of age groups shows variation between the two sexes. Growth of the fish is directly proportional to the growth of the scales. Two-year-olds averaged 107.2 mm. in standard length; four-year-olds, 360.3 mm.; and six years of age, 474.3 mm.

10. The equations for the curves of the weight-length relationship were calculated to be: $W = 0.00002959L^{2.96}$ for the males and $W = 0.00003284L^{2.95}$ for the females.

11. Sexual maturity is first attained in the males at the end of their second year when they have reached a size of about 300 mm. in standard length; in the females at three years of age when about 350 mm. in standard length.

12. Although for a given age female starry flounder are larger and have statistically significantly greater head length and body depth, the actual differences are slight and in general field observations these few evidences of sexual dimorphism are not discernible.

13. There is a marked geographical difference in the proportion of sinistral individuals and there appears to be a decrease in relative numbers of sinistral specimens with age, possibly indicating a greater viability for the dextral forms.

14. Monterey Bay specimens compared with more northerly samples show a tendency toward fewer fin rays in the median fins.

15. Platichthys stellatus is known to hybridize with two species, Kareius bicoloratus in Japanese waters and Parophrys vetula of the eastern Pacific.

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