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The Biology of the Dover Sole, Microstomus pacificus (Lockington)

By
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1952

THE DOVER SOLE, *Microstomus pacificus* (Lockington)

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FREDERICK B. HAGERMAN
March, 1952

INTRODUCTION

The Dover sole, Microstomus pacificus (Lockington) is a fairly large flatfish belonging to the family Pleuronectidae. It is not a true sole, but a flounder. However, through continued common usage of the term "sole" for most of the flounders along the Pacific Coast, this appellation has become recognized by the fishing industry and the different government agencies concerned. It has been known along the Pacific Coast under several different common names, such as slippery sole (California and Puget Sound), lemon sole (Vancouver), smear dab (Puget Sound), rubber sole and short finned sole (San Francisco), slime sole (California and Puget Sound), tongue sole, and Dover sole (Pacific Coast).

The common name of Dover sole was first suggested by Mr. Stewart, employee of the New England Fish Co., Astoria, Oregon, around 1939 according to the Eureka fishermen. He probably associated Microstomus pacificus, the only representative of its genus along the eastern Pacific Coast, with Microstomus kitt Walbaum, which ranges from the White Sea into English waters and is probably taken off the Dover coast. The two species are very similar in general appearance and might well appear identical to an untrained observer, but in meristic counts and morphometric measurements they differ significantly.

In 1946, Clemens and Wilby used the name Dover sole in their *Fishes of the Pacific Coast of Canada*, and in 1948 it was adopted as the official name in California by the Department of Fish and Game. It is evident that the name Dover sole has a greater marketing value than some of the other names, such as slime sole, slippery sole, etc., with their rather unappetizing connotations.

Although the range of the Dover sole extends from Southern California to Alaska, it is important commercially only from San Francisco northward along the Oregon coast. Small amounts have been landed in Washington and British Columbia, but the centers of fishing are at Fort Bragg and Eureka in California, and at Newport and Astoria in Oregon. South of Monterey it is not found in great abundance.

In developing a management program for the conservation of a fisheries resource, a knowledge of the biology of the species concerned is important. Full utilization of the population is desirable, but a balance must be maintained between the recruitment and the total mortality. Regulation of fishing areas, closed seasons, restrictions on destructive gear, and limitations on total catch are tools that may be used in the maintenance of a fisheries resource at the most productive level, but their use should be based on sound reasoning and biological facts. It is in the hope of providing a few of the required facts that this study is presented.

In the course of this investigation approximately 3,200 specimens of Dover sole were examined during the period from July, 1948, to October, 1949. The bulk of the material was gathered from commercial fishermen and dealers in the Eureka region, although a small amount of sampling was conducted at Fort Bragg.

Some of the equipment used for the sampling is shown in Figure 1. After the fish are taken from the vessel during normal commercial handling, they are weighed by the dealer and dumped in a pile near the end of a conveyor system. The measuring board was placed on a fish box or bench as close to this source of supply as possible, and specimens were taken at random from the pile. Each fish was weighed, laid on the board with the nose against the end plate and the total length measured. The abdominal wall was cut to determine the sex and to obtain gonad samples. Stomach contents were sampled in some cases. If scales were required they were taken by means of a pair of forceps and either placed in an envelope or put directly on a slide. Otoliths were taken by holding the fish firmly with the left hand (thumb in the lower eye orbit) and making a diagonal cut into the head exposing the brain and inner ears. Otoliths were taken from both sides, placed in an envelope, and preserved dry. All data were recorded on a white plastic sheet with a lead pencil. In this way, the sampler, with wet slimy hands, could write down the necessary information and by washing the sheet in water have a clean neat record. After transferring the information to paper, the plastic sheet was washed with a cleanser to remove the pencil marks.

FIGURE 1. Sampling Dover sole in the Eureka fish markets. A typical fillet line is visible in the background. *Photograph by Chet Schwarzkopf, 1949.*

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1. THE FISHERY

Since the inception of trawling along the California coast in 1876 the Dover sole has been caught along with the many other flatfishes. Lockington (1878) in surveying the San Francisco fish markets recorded Dover sole being sold during the summer months. The trawling for bottom fishes at this time was conducted by lateen sailboats using paranzellatype (two-boat) nets. According to Lockington the early fishing grounds for Dover sole were 4–5 miles from Pt. Reyes in "tolerably deep waters."

During the second decade of this century the fishing spread to ports south of San Francisco—to Santa Cruz, Monterey, Santa Barbara, San Pedro and San Diego, but it was not until 1929 according to Clark (1935) that the paranzella fleet invaded the virgin trawl grounds off Eureka. The expansion of the trawl fishery to the southern part of the State was curtailed by legislation but by 1938 the California trawl fishery had extended to its present range from Santa Barbara to southern Oregon. Eureka became the center of the trawl fleet, at first a seasonal port, later the home for the majority of the fleet, and now is by far the principal port for trawl caught fish, particularly Dover sole.

During the years in which the trawl fishery expanded from its small beginning in San Francisco Bay to encompass the entire coast of California, the trawling vessels underwent a profound evolution. In 1885 steam power was introduced in competition to sail and soon supplanted it. In 1909 the gasoline engine met with some success and achieved great popularity during the period 1915–1922. However, it was soon replaced by diesel engines.

As the type of boats in the fishery changed, so did the type of nets. Briefly, a trawl or drag net is a funnel-shaped net with two wings that extend forward and laterally from the mouth on each side. The mouth of the net is held open by floats attached along the top, and the bottom leading edge is weighted. The conical net tapers back to the sack, or cod end, where the fish are finally trapped.

The original paranzella net was a drag net which required two boats to pull it, one attached to each wing of the trawl. With the boats towing parallel to each other a short distance apart, the wings were spread to a distance of from 50 to 70 feet. This wasteful method, which employed two boats to pull a single net, was used in California until 1940, but the paranzella was eventually replaced by the more efficient otter trawl which was introduced from Oregon and Washington and soon became the predominant gear of the California fleet.

The otter trawl's superiority over the paranzella net is due to the fact that it can be operated by a single boat instead of by two. The wings of the net are held apart by two otter boards that are set at such an angle to the direction of pull that water pressure against them pushes the boards outward and spreads the wings of the net. Otter trawling developed rapidly in 1935 off the coast of Washington, and by 1941 the method was universal along the entire Pacific Coast.

The mesh size of the nets has changed markedly in recent years. In 1915, a cod end of 1 ½ inches was used; by 1948, the majority of the fleet was using commercial five-inch mesh. By using the larger mesh the amount of small fish, trash, rocks, and mud taken is considerably decreased, and the work of sorting the catch is much easier. Clark (1936) states that the free flow of water allows faster movement of the net at the same engine speed, increasing efficiency, and that there is less damage to the net by snagging, which lowers the cost of webbing and mending.

During this expansion there was no demand for Dover sole. Occasional catches were landed, but with the abundance of the more desired species of flatfish the Dover sole was not marketed and was considered a trash fish to be discarded. Thus, the Dover sole suffered through the exploitation of other more valuable species. Taken incidentally, large numbers of individuals were shoveled overboard dead or in a moribund condition. The trawl gear is not selective for desired species, and it must be remembered that although the catch records show that the Dover sole was not landed at all, nevertheless there was a constant fishing mortality exerted on the stocks within the fishing areas.

Less than 10 years have elapsed since the Dover sole ceased to be considered as a trash fish by the industry and became a sought-after article of commerce. The phenomenal rise in the importance of this species in comparison to other flatfishes is an outcome of the efforts of the fishing industry to supply the unlimited demands of the government and the civilian markets during the period of World War II. New techniques of fish handling, packaging and freezing, introduced during the early war years, were very important in the development of a market for the Dover sole. It was learned that by the quick-freeze method the soft tissues of the fish would harden and produce a marketable fillet. Furthermore, since other species of flatfishes were becoming less abundant necessitating

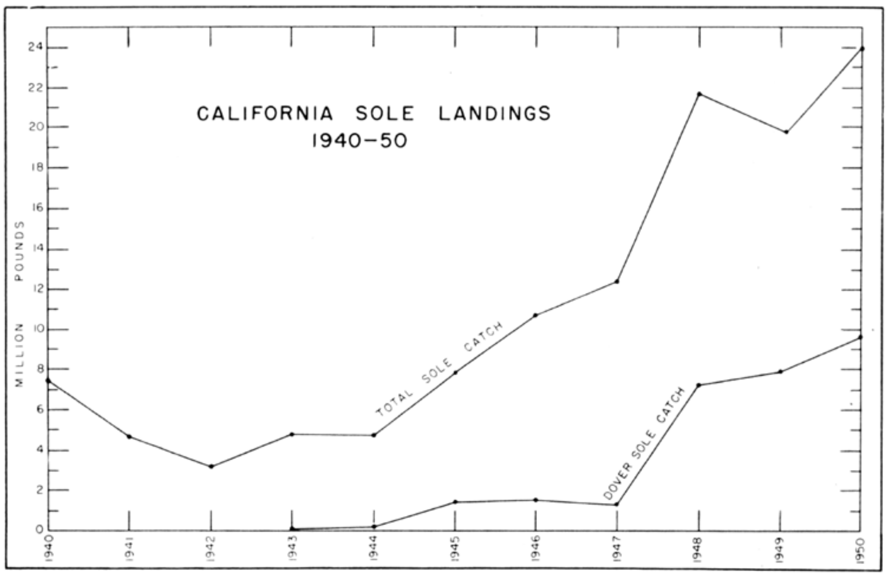

FIGURE 2. The California sole catch from 1940 to 1950. The Dover sole catch from 1943 to 1950 is shown and is included in the total catch.

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longer trips and greater effort on the part of the fishing fleet, the trawlers were glad to turn their attention to the large population of Dover sole which ranged along the northern coast of California in depths greater than those usually frequented by other commercial flatfishes. Dover sole was landed in small quantity at California ports in 1943. The catch has steadily increased until in 1950 the landings in the Eureka and Fort Bragg areas totaled over 9,600,000 pounds. It is now taken in greater quantities than any other flatfish in California, and represents about 38 percent of the total sole catch. (Figure 2). Most of the catch is filleted and

FIGURE 3. A pound carton of Dover sole fillets

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packed in one-pound cartons (Figure 3) or wrapped in cellophane and quick frozen. A small amount is packed in five or twenty-pound boxes and iced for the fresh fish markets.

Figure 4 shows the ocean off Northern California and southern Oregon divided into numbered rectangles or "block areas," in accordance with the system adopted by the fisheries agencies of the three Pacific Coast states. The inshore blocks represent 10 minutes of latitude and 10 minutes of longitude and are roughly 10 nautical miles square. The use of such a system of block areas, designed to identify certain fishing grounds, is not new in fisheries management. By the use of block areas, the actual origin of the fish catch is obtained; and by comparing the catch of the same productive blocks at different times, relative abundance can be determined, as well as indications of migrations.

In California it is required by law that the trawlers keep a daily record of all their fishing activities. The trawlers' logs are in duplicate and record the date, name of vessel, port of landing, name of captain, number of block area fished, depths fished, number and direction of drags, and the time that the net was down on each trawl. An estimate of the poundage taken by each drag is also recorded. The duplicate is then sent to the California Department of Fish and Game. The dealer who buys the fish from the trawler makes out a receipt showing the exact poundages of

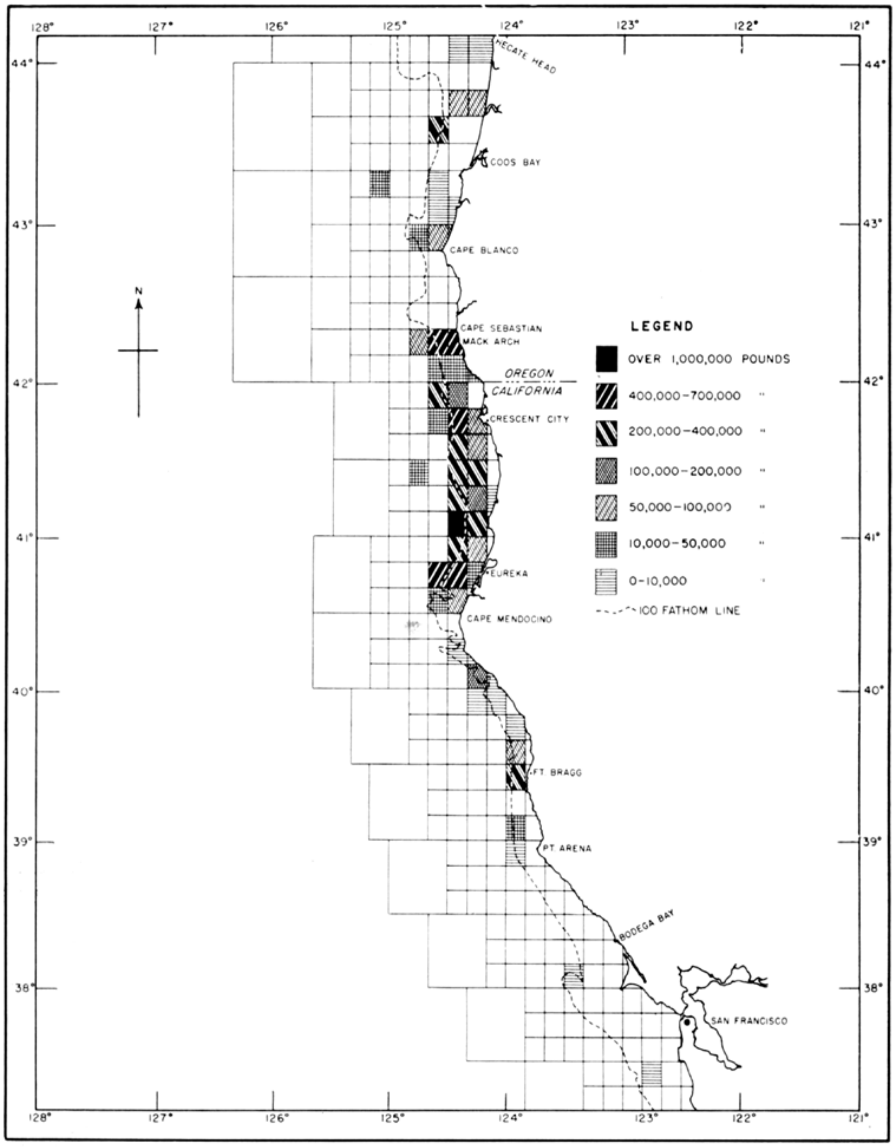

FIGURE 4. The origin of the 1949 catch of Dover sole landed by the California trawler fleet

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each species. The State also receives a copy of this. By combining the log of the vessel with the fish receipt, a fairly accurate picture is presented.

Based upon the trawler logs and market receipts, the amounts of Dover sole taken per block area and landed in California in 1949 are shown in Figure 4. The California boats have ranged as far north as Hecate Head, Oregon. The bulk of the trawlers that fish these northern waters operate out of Eureka and seldom range south of Cape Mendocino. The areas of heaviest fishing are from Cape Mendocino on the south to Cape Sebastian

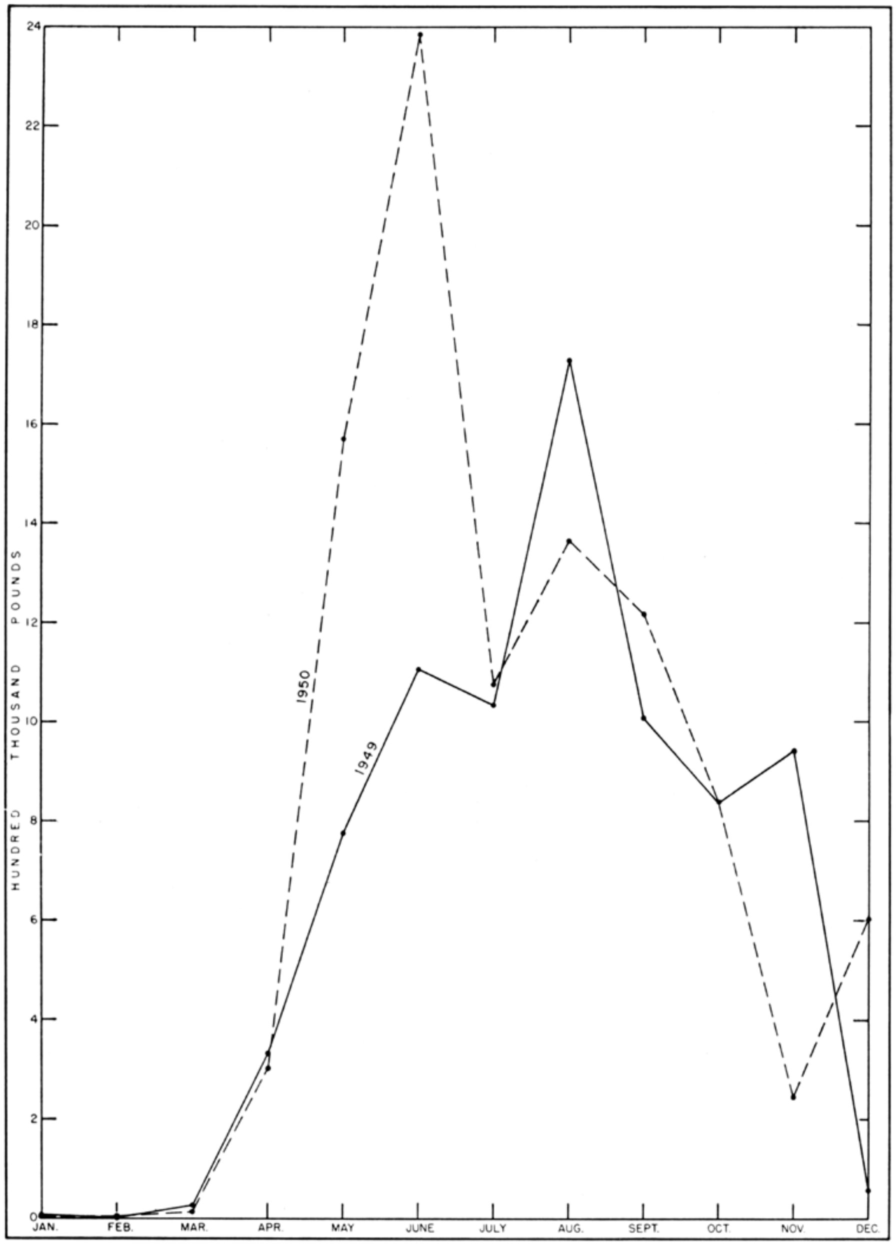

FIGURE 5. The California Dover sole catch per month for years 1949 and 1950

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on the north. The most productive areas tend to fall approximately on the 100-fathom contour line. Records of bottom conditions in areas of light and heavy landings show that the Dover sole is found in greatest quantities over muddy bottoms. The area between Cape Mendocino and Point Arena contributes a minor amount to the annual catch. A small fleet of boats based at Fort Bragg fishes these grounds. Trawlers operating out of Bodega Bay and San Francisco land an insignificant quantity of this species.

The productivity of particular areas and, consequently, the landings vary widely at different times of the year. During the winter months the catch drops to practically nothing. In 1949 the catch of January and February together totaled only 8,800 pounds, whereas the catch for August of the same year was 1,728,657 pounds. Again in 1950 the January and February catch was only 6,049 pounds compared to the August take of 2,383,961 pounds (Figure 5).

There are three main reasons why the Dover catch is exceedingly low during the winter months. First, the Dover sole, at this time of year, moves out into depths that are not fished by the present types of gear. Some fish are caught during this period, but they represent the fringe of the main population. Second, there is a reduction of fishing effort due to the winter storms that produce poor fishing conditions on the Dover sole grounds. These grounds, particularly at this season, are far from shore and exposed to the rough conditions of the open sea. Third, two other flatfishes, each more highly priced than the Dover sole, the petrale sole, Eopsetta jordani, and the English sole, Parophrys vetulus, move into shallow fishing areas close to shore during the winter and spring. The availability of these more expensive flatfishes in comparatively protected areas relatively close to port diverts the major portion of the trawling effort from the Dover sole.

2. DESCRIPTION OF THE SPECIES

A general description of the Dover sole is here presented, but for those interested in a more complete detail, the work of Norman (1934) is highly recommended.

The Dover sole is invariably dextral. It is a slender flounder; the depth of body is 2.8–3.2 in standard length. Head 4.1–4.7 in standard length. Mouth slightly asymmetrical; maxillary extending to below anterior part of lower eye. Teeth developed on blind side only, close set to form a continuous cutting edge (Figure 6). This character will serve to differentiate the Dover sole from Embassicthys bathybius, its closest California relative, which differs in having teeth equally developed on both sides. Diameter of eye 3.0–4.0 in head; lower eye somewhat in advance of upper one. Gill opening barely extending above base of pectoral fin. Dorsal rays 90–116; anal 80–96. Caudal 0.6–0.7 length of head. Pectoral shorter than head. Pelvics 6. Scales imbricated, cycloid, embedded, very fine and small, 137–146 along lateral line. Lateral line practically straight except anteriorly where it is slightly curved over pectoral fin; a short supratemporal branch, not connected with main lateral line. Mucous secretion excessive, the fish very slimy. On the eyed side, the color varying to some extent; some specimens either a light or a dark uniform brown while others indistinctly mottled. A pattern of two yellowish-brown spots along the lateral line, the first just posterior to the pectoral fin, the second half way

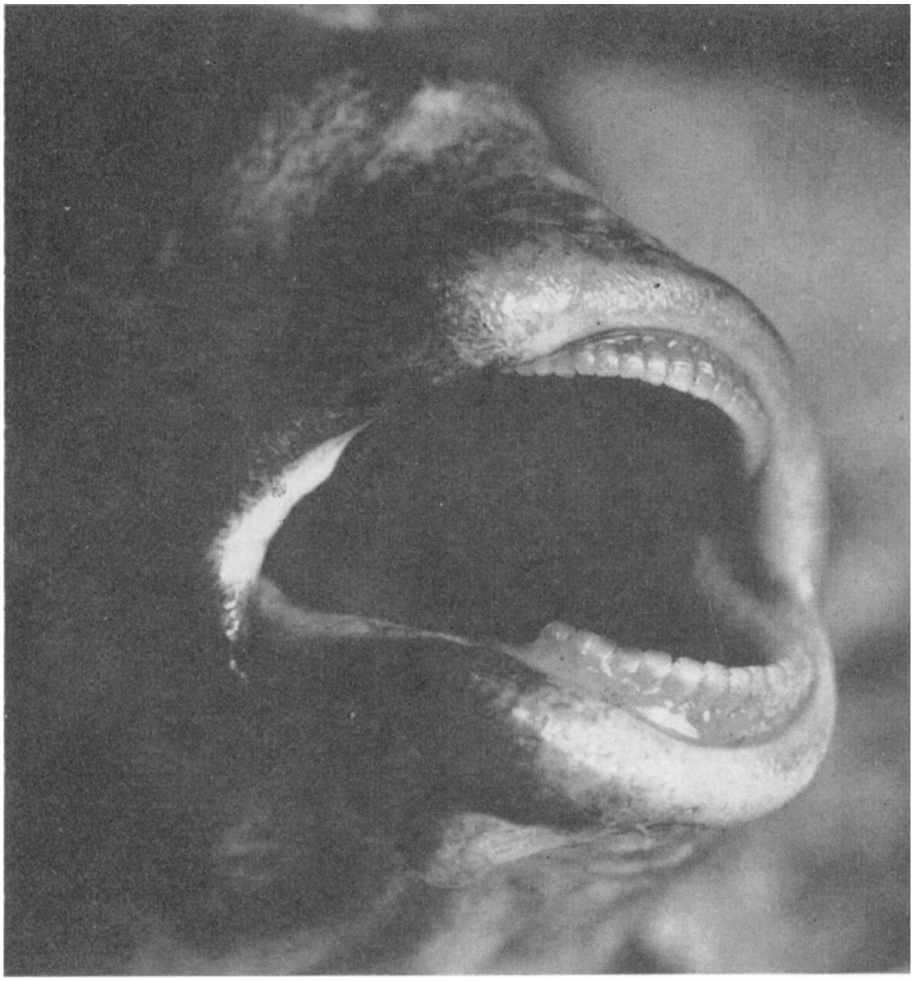

FIGURE 6. Mouth and teeth of the Dover sole. Blind side to the right.

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between the first spot and the posterior edge of the caudal fin (Figure 7). This pattern, most pronounced in small immature specimens, becoming obscure with advancing age, but discernible in some individuals of large size. Some immature fish with five to six small spots equally spaced along the dorsal and anal fin margins. Blotches of a dull blood-red color common

FIGURE 7. Note the shiny mucus condition on the surface, and the two distinct spots along the lateral line

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and usually found on the larger fish. Color on the blind side ranging from a light smoky gray to dark gray. Blotches of the dull red color sometimes found.

There is a tendency for sexual dimorphism in the coloration of the fins in the adults; the males usually have black fin rays while the females show a dark brownish coloration. With experience the two sexes can generally be separated on this basis, but occasionally a female will have black fin rays. Also, the general coloration of the males tends to be darker.

Two different aberrant forms of Dover sole have been observed in the Eureka region. (1) Xanthochromism, a condition in which only the orange and red pigment is developed, has been seen several times. McCormick and Baldwin (1952) reported one specimen taken near Redding Rock, California, July 27, 1951, in 80–85 fathoms. The fish had a bright golden color. Norman states that this is fairly rare in heterosomatous fishes. (2) a ventrally directed branch from the lateral line on the eyed side was observed in one case. It branched off about in the middle of the fish, curved slightly posteriorly and then arched forward to end abdominally a short distance above the base of the anal fin.

3. LENGTH FREQUENCIES

The fish markets of Eureka and Fort Bragg were sampled from July, 1948, to July, 1949, inclusive. In general only one sample of 50 fish was taken from each load. The fish were measured to the nearest millimeter from the tip of the snout to the ends of the longest caudal rays. The amount of sampling reflected the general fishing conditions; many in the summer and fall, and few in the winter and spring. Dragboat skippers were questioned about the areas and depths of fishing, and gear used.

Length frequency distributions are often used in estimating growth rates and age determinations of fish, but this method has been found

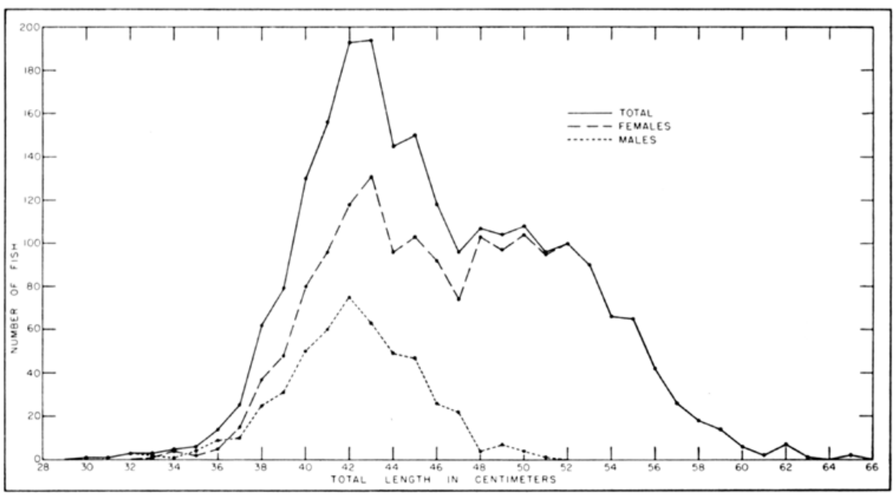

FIGURE 8. Length frequencies distributions from the random market samples taken at Eureka and Fort Bragg, 1948-49

FIGURE 8. Length frequencies distributions from the random market samples taken at Eureka and Fort Bragg, 1948–49

unsatisfactory for the Dover sole because the more apparent age groups are the younger ages which are not in the fishery. Also the fishery is taking at least 10 age classes from several geographical areas, and possibly with varying growth rates.

Figure 8 is a frequency polygon of 2,147 males and females grouped by centimeters, and of 1,651 females and 496 males. The sex ratio in the commercial catch is about 3:1. The females fall into two size groups and the males into one which corresponds closely to the smaller of the two female groups. Any males over 50 centimeters are uncommon in the catch.

Figure 9 comprising the length frequencies of 136 females caught off Fort Bragg, Eureka, and southern Oregon in October, 1948, indicates a general tendency for larger fish to be taken to the north. A modal group occurs at 40.0 cm. at Fort Bragg, at 41.0 cm. at Eureka, at 42.5 cm. in southern Oregon. Fish larger than 50 cm., lacking in the Fort Bragg sample, are more numerous in Oregon than at Eureka. Fishermen state that Dover sole caught from Monterey to Point Reyes are smaller than those caught to the northward. Small Dover sole have been observed at Bodega Bay. The depths fished in the northern waters are much greater than those to the south, and this may have some bearing on the catch composition.

The progression of age groups through the Dover sole fishery over a period of one year is difficult, if not impossible to follow by the length frequency method demonstrated by Figure 10. Here the lengths of females have been plotted for the period July, 1948, through July, 1949. In general the fishery is taking fish representing several age groups but varying in abundance in the trawler catches.

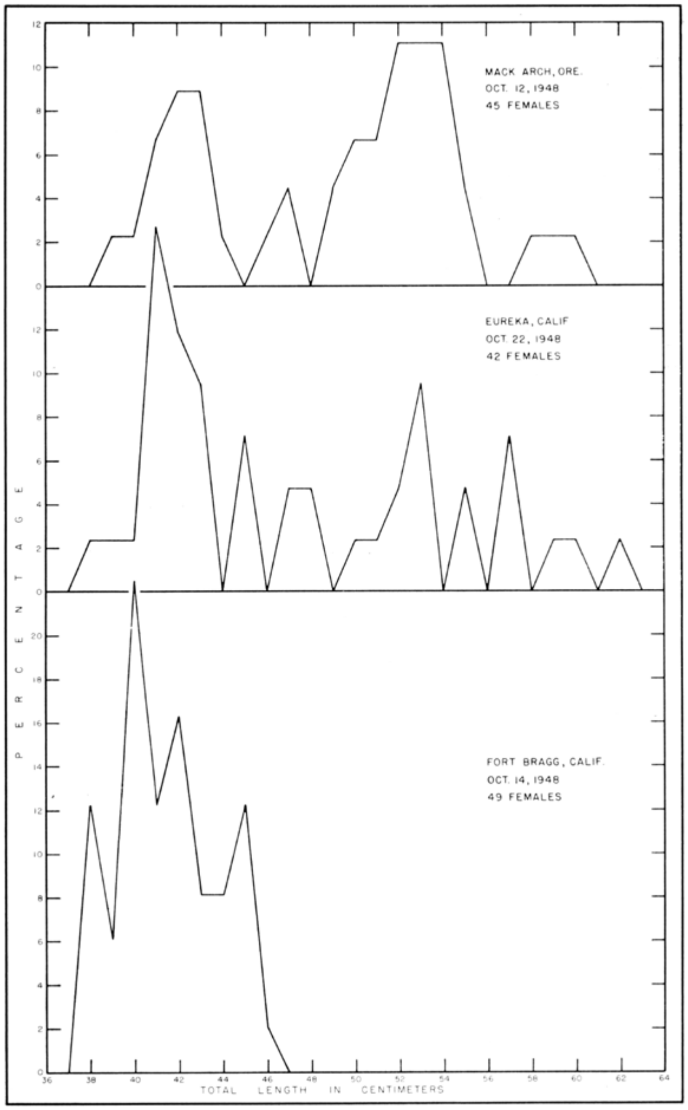

FIGURE 9. A comparison of the length frequencies for fish caught off Fort Bragg, Eureka, and southern Oregon

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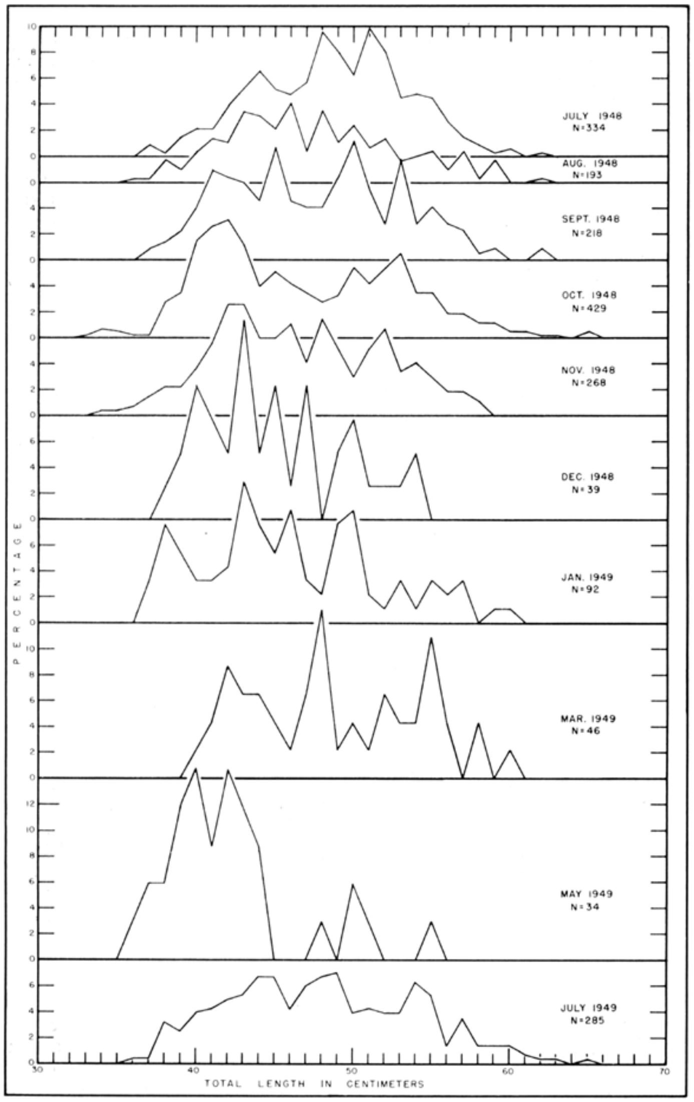

FIGURE 10. Length-frequencies of females taken from market samples from July, 1948, through July, 1949

FIGURE 10. Length-frequencies of females taken from market samples from July, 1948, through July, 1949

4. LENGTH-WEIGHT RELATIONSHIP

It has been established repeatedly that the weight of a fish increases appromixately as the cube of its length. Some species deviate from this "cubic law," but the Dover sole, both male and female, closely approximate this general rule.

The data for this study were taken from 2,226 fish, 1,738 females and 488 males. Each fish was weighed on a spring scale graduated in pounds and tenths and its total length was measured to the nearest millimeter. The sex and condition of the gonads were determined, and scales and otoliths were collected after the fish had been measured and weighed. These data were collected over a twelve-month period and discrepancies in weight due to gonad enlargement over the spawning period or to the subsequent emaciated condition of spent fish may, therefor, be considered to have been cancelled or averaged.

The fish were grouped in one centimeter classes and the average weights of these classes were first plotted on log-log paper by months. The resulting points gave a straight line relationship. There were slight differences for the various months but no attempt was made to work out the statistical significance of these.

The average weights are shown in Table 1, and the length-weight curve in Figure 11 was determined arithmetically for both sexes.

TABLE 1

Length-Weight Relationship

Intervals of total length (mm.)	Mean weight in pounds and tenths		Intervals of total length (mm.)	Mean weight in pounds and tenths	
	Males (N=488)	Females (N=1738)		Males (N=488)	Females (N=1738)
330-339	.75	.90	500-509	2.63	2.80
340-349	.85	.85	510-519	2.65	2.84
350-359	.92	1.05	520-529		2.99
360-369	.92	1.10	530-539		3.27
370-379	1.06	1.09	540-549		3.42
380-389	1.13	1.20	550-559		3.66
390-399	1.28	1.29	560-569		3.78
400-409	1.38	1.40	570-579		4.09
410-419	1.48	1.55	580-589		4.10
420-429	1.57	1.62	590-599		4.37
430-439	1.68	1.74	600-609		4.61
440-449	1.75	1.86	610-619		5.05
450-459	1.86	2.04	620-629		5.36
460-469	2.00	2.13	630-639		5.00
470-479	2.09	2.23	640-649		
480-489	2.36	2.40	650-659		7.40
490-499	2.30	2.57			

TABLE 1 Length-Weight Relationship

Figure 12 shows the regression of weight on length for both males and females determined by the method of least squares. The exponential equation $Y = aX^b$ was used in its logarithmic form, $\log Y = \log a + b \log X$. Y is the weight expressed in pounds and X is the length in centimeters. The regression line for 1,738 females was fitted from the equation:

$$\text{Log } Y = \bar{4}.3782 + 2.97 \ (\log X)$$
$$Y = .0002389X^{2.97}$$

TABLE 1—Cont'd.

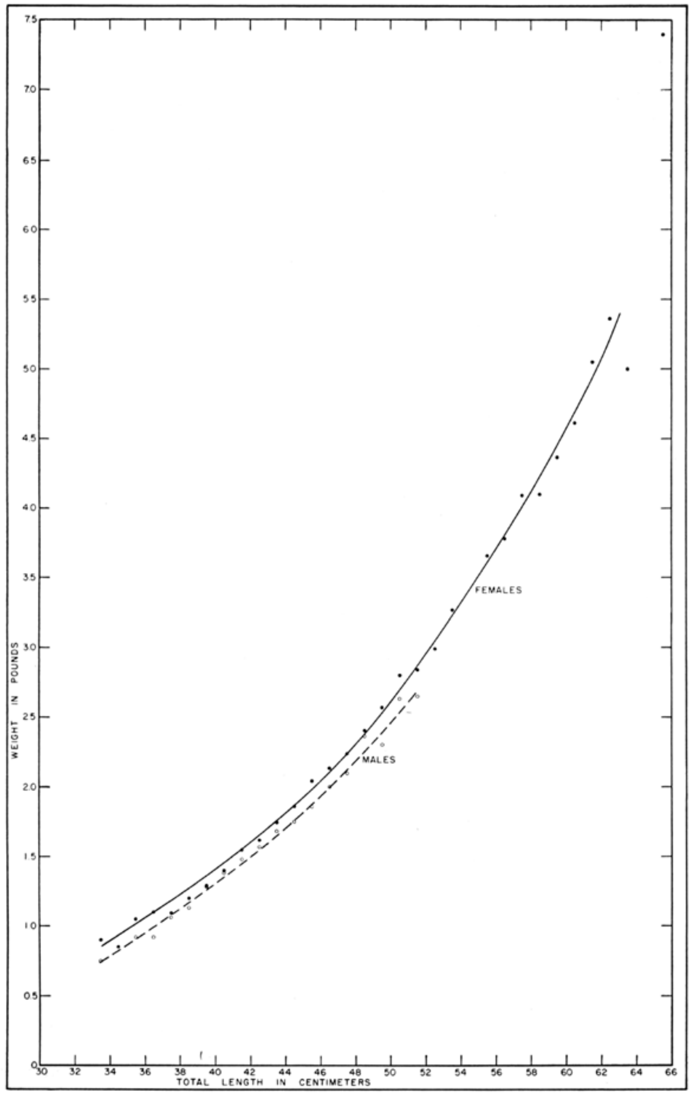

FIGURE 11. Length-weight curve plotted from average weights for one centimeter groups

FIGURE 11. Length-weight curve plotted from average weights for one centimeter groups

The weight of males tends to increase at a slightly lesser rate in relation to length. The regression coefficient "b" is 2.95 as compared to 2.97 for females. The equation for 488 males is:

$$\text{Log } Y = \bar{4}.3874 + 2.95 \ (\log X) \text{ or}$$
$$Y = .000244X^{2.95}$$

FIGURE

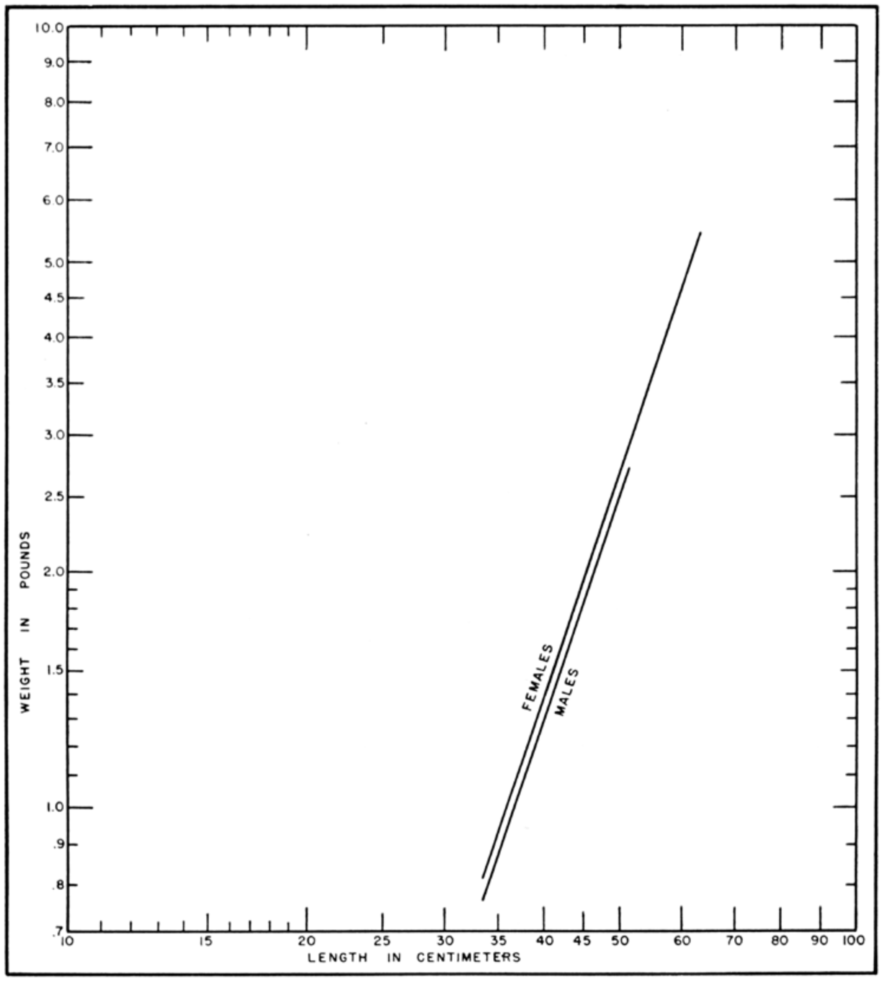

FIGURE 12. The regression of weight to length calculated by the method of least squares. Y is the weight in pounds and X is length in centimeters. The formulas for the curves are: Males, $Y = .000244X^{2.95}$; Females, $Y = .0002389X^{2.97}$.

FIGURE 12. The regression of weight to length calculated by the method of least squares. Y is the weight in pounds and X is length in centimeters. The formulas for the curves are: Males, Y = .000244X$^{2.95}$; Females, Y=.0002389X2.97

5. AGE AND RATE OF GROWTH

It is of prime importance in fisheries management to know the ages and the rate of growth of the species being exploited. These can be established in three ways: by marking experiments, by length frequency investigations, and by a study of annual marks laid down in skeletal structures. Except in very long range studies, it is usually not practical to attempt a solution by the first method, and length frequencies were not satisfactory in the present study. An investigation of annual markings demonstrated that both otoliths and scales provided satisfactory indicators of age and growth.

The sagitta, the largest otolith, was the only earbone used. It is located in the sacculus of the inner ear, where it functions as part of a balance organ. It is roughly oval in shape with one convex and one flat or slightly concave surface. Size, shape, and structure are important factors influencing the readability of otoliths. Those of the Dover sole are quite suitable for age analysis, but because of greater thickness, they are not nearly as legible as the otoliths of the Pacific halibut. For the purpose of age determination the right otolith was superior to the left one, being somewhat flatter. Only the convex side was examined in reading because the other surface was grooved and modified for the passage of the auditory nerve.

The otolith is composed of opaque layers of calcium carbonate secreted during periods of rapid growth over a matrix of translucent organic material. One year is normally represented by an opaque band formed during the summer growing season and a translucent area bordering it laid down during the semidormant winter period. Under magnification the otolith displays a series of light and dark concentric bands (Figure 13). In reflected light, the calcified bands are white and the organic bands are dark, but this condition is reversed when transmitted light is used.

Glycerin, clove oil, and cedarwood oil were tried as preserving and clearing agents, but these liquids impaired the reading qualities, and the otoliths were, therefore, simply cleaned and kept dry. Decalcifying, sectioning, and staining proved to be valueless, but embedding otoliths in plaster of paris and then grinding thin cross-sections produced fair

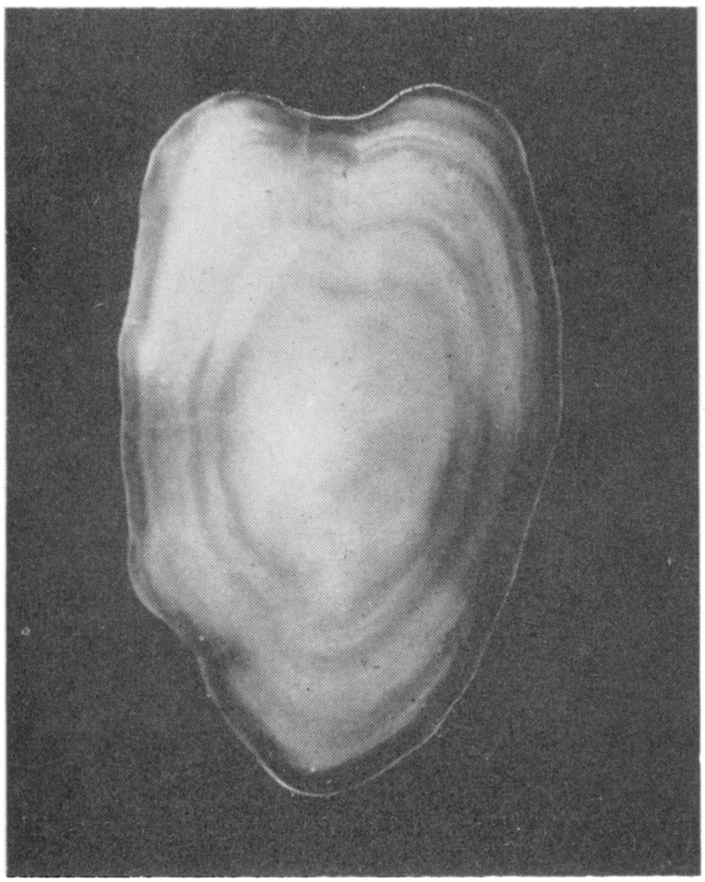

FIGURE 13. The otolith from a five-year-old Dover sole (reflected light)

results. However, this technique was discontinued because the results did not justify the amount of labor involved. The final method used, and by far the best one, was simply to place the whole otolith in a watch glass with enough water to cover and to read them under a binocular microscope.

An adjustable lamp of 100 watts, set at an angle of approximately 20 degrees, provided adequate lighting. According to the characteristics of the otolith being read, the source of the light was varied to produce the best results. This adjustment of the light played by far the most important part in securing good readings. By using a dark background and focusing the light from a small aperture to strike the watch glass just under the otolith, the circuli differentiated well. Less than 1 percent of the fish sampled had otoliths that were unreadable due to a crystalline or granular structure. The age zones were read to the outer edge of the last calcified, or summer, band; complete or incomplete translucent borders (winter checks) were noted.

The scales of the Dover sole are cycloid, very thin, somewhat deciduous, and embedded deep in the dermis of the skin; only a small portion of the posterior part (heavily pigmented in Figure 14–18) is exposed. Scales from the pectoral axilla differ from those found on the more posterior exposed surfaces of the body; they are circular or triangular in shape (Figures 14, 15) instead of in the form of an elongated oval (Figures 16 17 18).

As was pointed out by Villadolid (1927), the scales of the Dover sole display excellent characters for age determination. Concentric ridges, called circuli, are very distinct and by their spacing clearly show variations in the rate of growth. Widely spaced circuli indicate a period of rapid growth, and crowded ones represent an interval of retardation. A close grouping of the circuli, such as occurs each winter, forms a dark

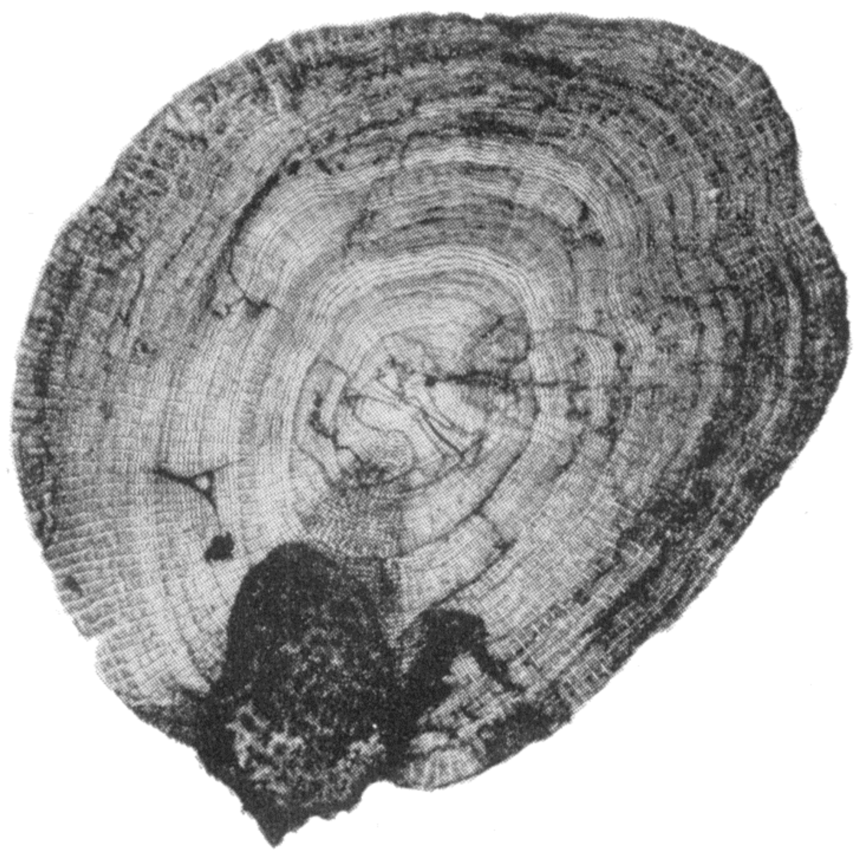

FIGURE 14. Type of scale found in the axilla region directly posterior to the pectoral base. These scales are usually small and difficult to read. Ages were not determined from them

FIGURE 15. The slightly triangular type of scale found in the axilla region, but somewhat posterior to the pectoral base. The readability is fair. The seventh winter check is forming. Taken October 27, 1949, off Blunts Reef

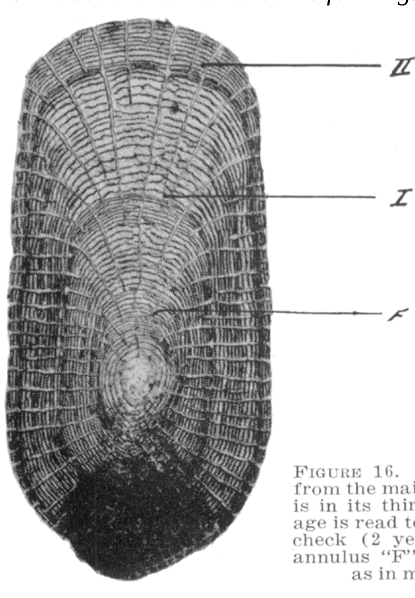

FIGURE 16. A scale taken from the main body. The fish is in its third year, but the age is read to the last winter check (2 years). The false annulus "F" is not distinct as in most scales.

FIGURE 16. A scale taken from the main body. The fish is in its third year, but the age is read to the last winter check (2 years). The false annulus "F" is not distinct as in most scales

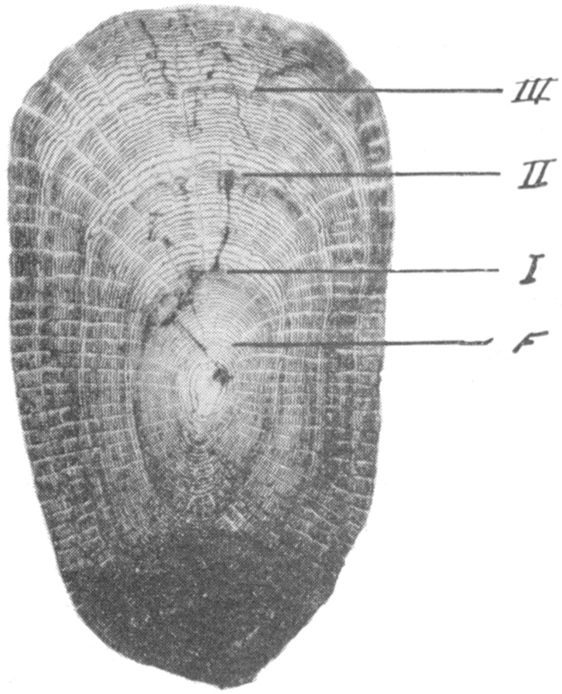

FIGURE 17. The fourth winter check is being formed. Taken in late October off Eureka

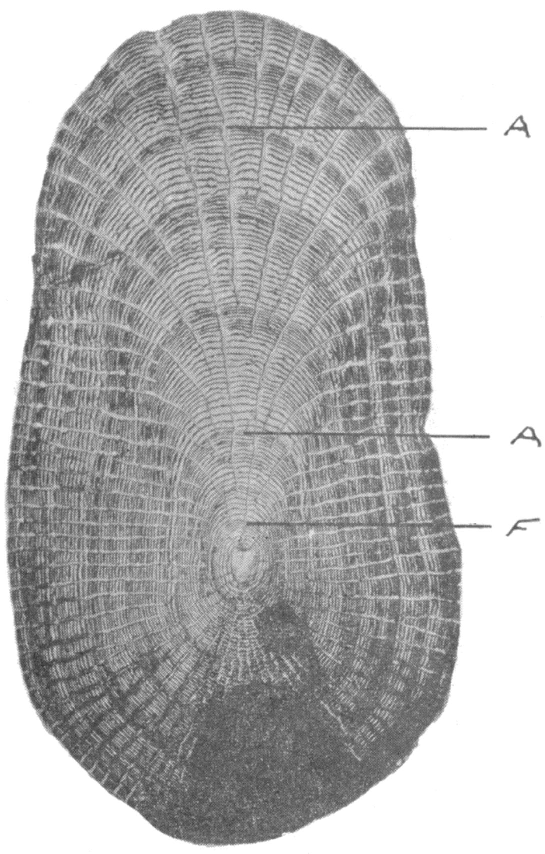

FIGURE 18. Five completed years, and the sixth winter check being formed. Note the false annulus in the first year "F," and the true annuli "A."

band which marks the end of a year of growth; this is termed an annulus. These true annuli begin to form in October and are completed by February.

The formation of the annulus is, in all probability, due primarily to a decreased metabolic rate brought about by the lower temperatures of winter. However, growth is also reduced as a result of the utilization of the fish's energies in the production of sex products. Since the spawning does not always coincide exactly with the period of coldest water, a second false annulus, or spawning check, is sometimes formed close to the true winter check, and care must be taken not to interpret the double annulus as indicative of two years' growth. Other false or accessory annuli are sometimes found. They are not constant in their appearance and probably reflect periods of unusual environmental conditions. In some cases a false check is shown within the first year's growth (Figures 15, 16). Arora (1951) in his study of the California sand dab, noticed the same condition and he states, "It is undoubtedly due to some unfavorable condition and may be formed during the migration of the larvae from a pelagic to a demersal environment and subsequent drift inshore." This reasoning seems plausible and probably fits the Dover sole as well, since larval specimens have been taken near the surface many miles from shore, and fish nearly a year old have been caught at the bottom inshore. The migration indicated by these facts would probably be marked by unfavorable factors in many instances. Many scales have to be read before these unusual conditions become apparent.

Regenerated scales are extremely common, often totaling 60 or even 70 percent of the scales removed from very large and old fish. These scales are of no value in age determination since the central nucleus and early annuli are missing and are represented by an area of uniformly and widely spaced circuli. Fortunately they are readily recognized under the microscope, although not distinguishable by the naked eye.

Scales for use in age determinations were removed from the fish with a pair of small forceps and mounted dry between two glass slides. About six to ten scales from different parts of the body were mounted on each slide, and the best ones selected for reading. They were taken from the eyed side and primarily from the middle of the body, but not from the region immediately adjacent to the lateral line, since this area was found to have a very high percentage of regenerated scales.

The scales were projected through a typical scale-reading apparatus consisting of a regular microscope with a prism over the ocular and a mirror to reflect the image, enlarged to 30 diameters, on a white surface. A separate white card was used for each scale, and the different winter checks (annuli) and the total length as projected were marked off. Since the card was graduated in millimeters, a permanent record of the size and of the distances between annuli was secured, representing the growth of the fish throughout its life. Care was taken to avoid counting false annuli, and all checks not consistent in all of the scales from a single individual were ruled out.

Ages of individual Dover sole were determined both by means of the otoliths and scales. In the large majority of cases these two different structures gave the same result, although there were some discrepancies. On the basis of otolith age determinations, the average age of each centimeter size group of both males and females was calculated (Table 2).

TABLE 2

Age Groups

	O	I	II		III		IV		V		VI	
10 mm.	♂ + ♀	♂ + ♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
50–59												
60–69	1											
70–79	5											
80–89	1											
90–99												
100–109												
110–119												
120–129												
130–139												
140–149												
150–159		1										
160–169												
170–179												
180–189												
190–199		2										
200–209		1										
210–219												
220–229												
230–239												
240–249												
250–259			1									
260–269				4	1	3						
270–279					3	4	1					
280–289				1	5	7	1	4	1	1		
290–299					3	1	2	1	2			
300–309					1		1	5	1			
310–319							2	1	3	1		
320–329						2	2	3		2		
330–339						1	1	2	1	4	1	1
340–349							1		2	1	3	
350–359								1			1	1
360–369									2	1		1

TABLE 2 Age Groups

370–379								2				
380–389												
390–399												1
400–409												1
410–419												1
420–429												
430–439												
440–449												
450–459												
460–469												
470–479												
480–489												
490–499												
500–509												
Sums	7	4	1	5	13	18	11	19	12	11	5	6
Mean length	75.0	187.5	255.0	269.0	285.0	287.2	310.5	317.1	323.3	335.9	345.0	378.0

TABLE 2—Cont'd.

TABLE 2—Continued

Age Groups

	VII		VIII		IX		X		XI		XII		XIII	
10 mm.	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
330–339	1		1											
340–349			1											
350–359	1													
360–369	1													
370–379		1	1	1										
380–389		1		1		1								
390–399		1		1										
400–409		1				1				1				
410–419		1		1							1			
420–429				1	1			1						
430–439				1		2		2						
440–449		1		2		1				1				
450–459								2		1	1			
460–469						1								
470–479										1		1		
480–489												2		1
490–499														
500–509														2
Sums	3	6	3	8	1	6	0	5	0	4	2	3	0	3
Mean length	351.6	403.3	355.0	415.0	425.0	428.3	....	441.0	....	445.0	435.0	481.7	....	498.3

TABLE 2 Age Groups

These data, plotted in Figure 19, show a fairly rapid growth during the early years of life with the rate decreasing as age advances. The curves indicate that the growth of males is slower than that of the females and that the ultimate size attained is less.

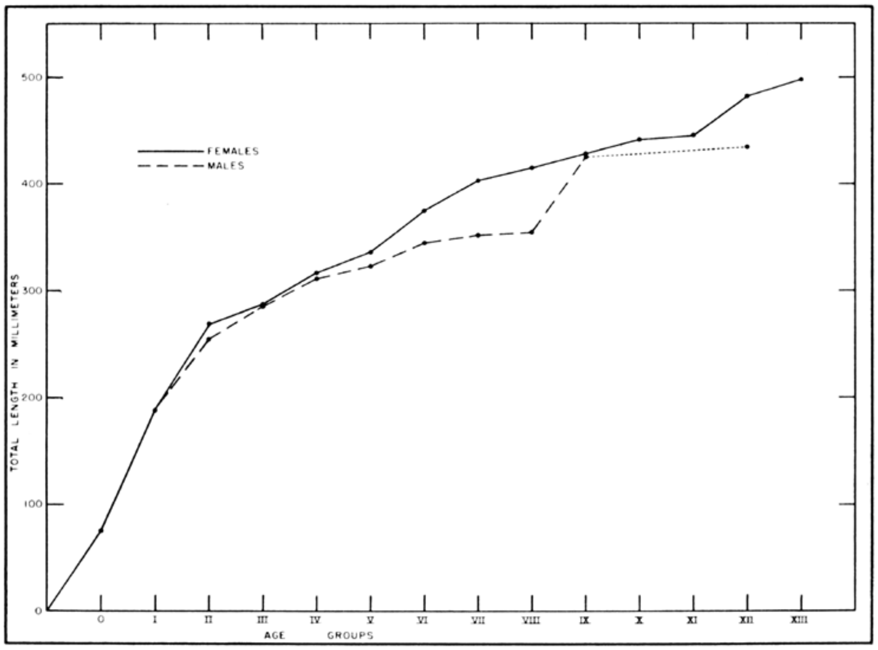

FIGURE 19. Preliminary growth curves of male and female Dover sole determined by 155 otoliths. In age groups 0 and 1 the sexes were not separated, and for all practical purposes the actual ages should be advanced one year as these fish were all taken in October and November before the complete winter check is formed.

FIGURE 19. Preliminary growth curves of male and female Dover sole determined by 155 otoliths. In age groups 0 and 1 the sexes were not separated, and for all practical purposes the actual ages should be advanced one year as these fish were all taken in October and November before the complete winter check is formed

The differential growth rates between males and females was first noticed by Villadolid (1927) and in his data the difference in growth rate seemed to appear in the second year, as the females at that age averaged about 8 mm. longer. The present study indicates that by six years the females average 30 mm. longer for the same age.

The fish enter the commercial catch at approximately 30 cm. in total length, and average about five years of age. Most of the catch is composed of fish 8 to 12 years of age, and ranging from 39 cm. to 46 cm. in total length. The larger fish in the catch are from 13 to 15 years old, and range from 48 cm. to over 55 cm. These larger fish are practically all females.

6. FECUNDITY

6.1. Size at Maturity

It is important to determine the size at which the Dover sole reaches maturity. Data used were mainly from market samples except for 150 small specimens obtained by the M. V. *N. B. Scofield*. As indicated in Figure 20, a few specimens of both sexes may remain immature until they achieve a total length of 43 cm. or even more. Most are ready to spawn at a much smaller size. In general the males mature earlier than do

TABLE 3

Total Length of Dover Sole at Maturity

Length in cm.	Males			Females		
	Mature	Immature	Percent mature	Mature	Immature	Percent mature
25				0	1	0.0
26	0	1	0.0	0	7	0.0
27	0	4	0.0	0	4	0.0
28	0	5	0.0	0	11	0.0
29	0	7	0.0	0	2	0.0
30	1	3	25.0	0	5	0.0
31	2	3	40.0	0	2	0.0
32	0	3	0.0	0	6	0.0
33	4	3	57.1	0	7	0.0
34	4	3	57.1	1	4	20.0
35	6	0	100.0	3	1	75.0
36	6	3	66.7	4	2	66.7
37	9	1	90.0	5	7	41.7
38	10	1	90.9	22	5	81.5
39	12	0	100.0	27	4	87.1
40	25	0	100.0	44	8	84.6
41	27	0	100.0	49	7	87.5
42	30	0	100.0	67	3	95.7
43	39	0	100.0	77	4	95.1
44	21	0	100.0	45	2	95.7
45	22	0	100.0	45	0	100.0
46	11	0	100.0	39	0	100.0
47	13	0	100.0	33	0	100.0
48	2	0	100.0	33	1	97.1
49	11	0	100.0	29	0	100.0
50	2	0	100.0	42	0	100.0
51	1	0	100.0	29	0	100.0
52				36	0	100.0
53				30	0	100.0
54				20	0	100.0
55				23	0	100.0
56				18	0	100.0
57				14	0	100.0
58				9	0	100.0
59				3	0	100.0
60				3	0	100.0
61				1	0	100.0
62				1	0	100.0
63				1	0	100.0
Totals	258	37		753	93	

TABLE 3 Total Length of Dover Sole at Maturity

the females. Some males are mature at 30 cm., whereas females begin to mature around 33 cm. At 32 cm. about 50 percent of the males sampled were mature, and at 39 cm. practically 100 percent were mature (Table 3). For the females, 50 percent of those sampled were not mature until they reached a total length of 35 cm. and at 45 cm. about 100 percent of the females are mature.

6.2. Number of Eggs

In the studies of fishes, it has been shown that there is a definite correlation between the number of eggs produced and the size of the fish. Large fish produce more eggs than do small ones. Since the ovary of the eyed side, the only one visible in Figure 21, is larger than that of the blind side, both ovaries of eight different mature females were disected out and preserved in a 10 percent solution of formaldehyde. These fish

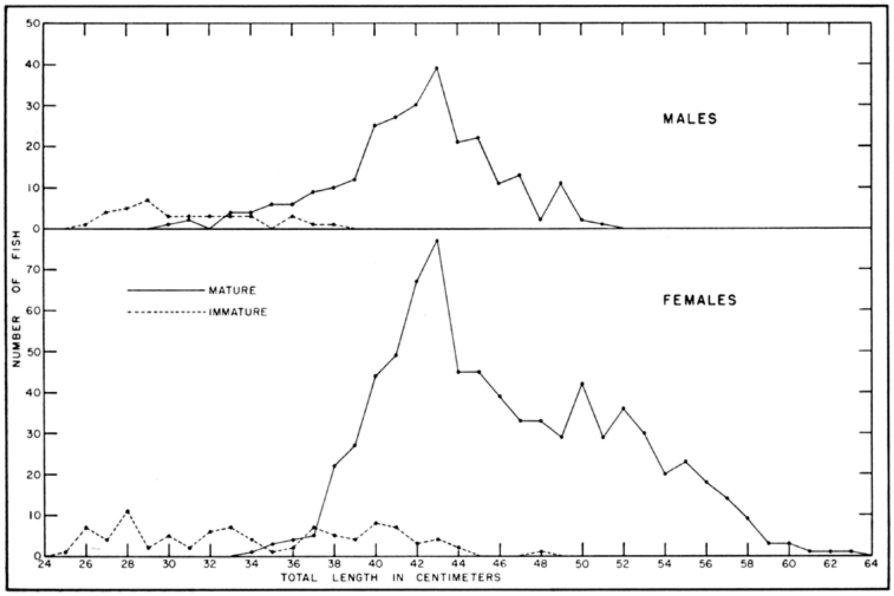

FIGURE 20. Total lengths at sexual maturity

FIGURE 20. Total lengths at sexual maturity

were in stage B (Developing). After six to seven hours the ovaries were hard, and the ovarian membrane could be teased away from the eggs, which remained intact. Both ovaries were weighed on an analytical balance scale to obtain the total weight. A one-gram sample through the central part of both ovaries was taken and all eggs seen by the naked eye were counted. An estimate of the total number of eggs was obtained by multiplying the total weight of both ovaries by the sample count. Figure 22 and Table 4 show egg production in thousands of eggs in relation to the length in centimeters of the 10 specimens. Fish from about 36 cm. to 38 cm. in total length produce from 37,000 to 50,000 eggs. Their ages would range from approximately six to seven years. A fish about 50 cm. long and from 12 to 15 years old would produce in the neighborhood of 230,000 eggs.

FIGURE 21. A mature female in stage B. The right ovary exposed to show its size and shape.

FIGURE 21. A mature female in stage B. The right ovary exposed to show its size and shape

TABLE 4

Egg Production

Total length in millimeters	Weight of ovaries in grams	Ova count in 1 gram sample	Estimated ova
362	10.625	3500	37,188
388	20.660	2500	51,650
406	45.450	2584	117,443
433	37.430	3100	116,033
447	50.920	2442	124,347
454	46.360	2700	125,172
471	63.390	2500	158,475
504	103.430	2220	229,615

TABLE 4 Egg Production

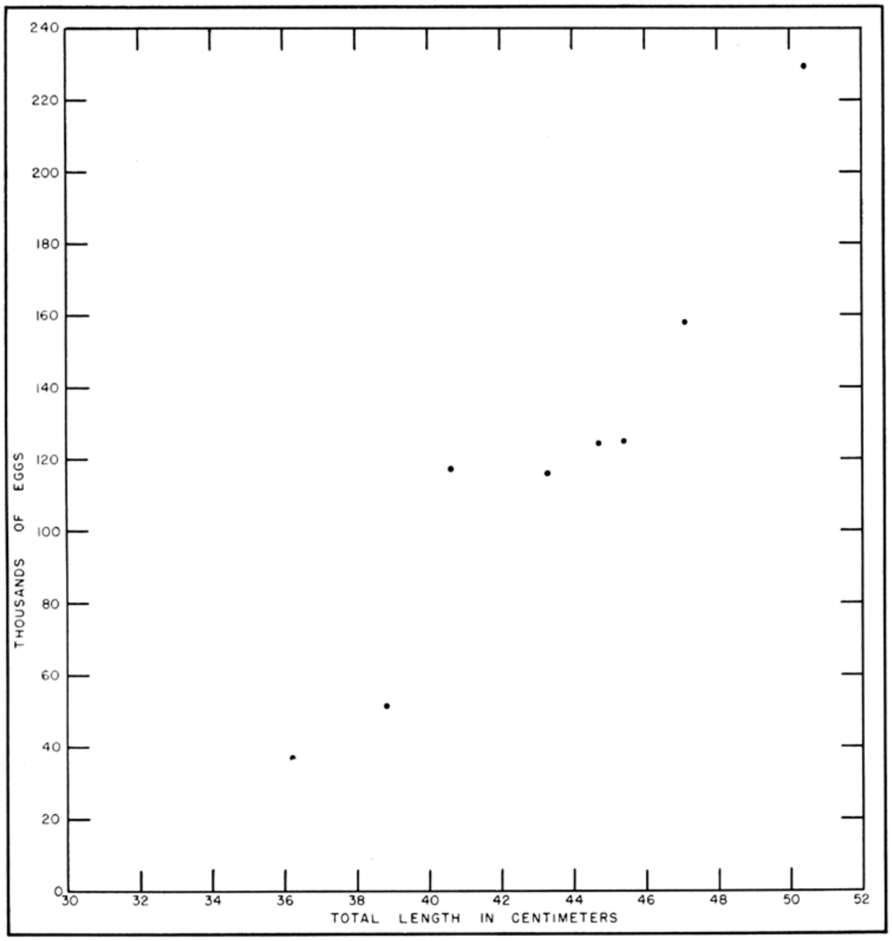

FIGURE 22. Estimates of egg production for both ovaries. Eight females sampled.

FIGURE 22. Estimates of egg production for both ovaries. Eight females sampled

Spawning Cycle

By sampling over a 12-month period six stages for the classification of ovaries were established as follows:

Immature:
A. Ovaries very small, pink in color and somewhat gelatinous. These were not hard to recognize especially at the peak of spawning.
Mature:
B. Developing. Ovaries enlarging, becoming yellowish in color and granular in consistency, full of developing eggs that can be distinguished by direct observation.
C. Gravid. Ovaries very full of yellowish granular eggs that are partly translucent. Ova can be extruded from the oviduct by exerting considerable pressure. Diameters range from 1.00 mm. to 1.20 mm.
D. Spawning. Ovaries very full of entirely translucent mature ova. Eggs will run under a very slight pressure. Diameters range from 2.05 mm. to 2.57 mm.
E. Spent. Ovaries flaccid, few translucent eggs left. Ovarian membrane very vascular (bloodshot) and sac-like. No ova of intermediate size are evident.
F. Resting. Ovaries becoming firm. No eggs discernible to the naked eye, color pinkish, texture gelatinous.

Testes were classified as "immature" if very small and yellowish, "latent" if the gonads were enlarged but retained the sperm, "ripe" if running sperm was evident, and "spent" if, after the spawning season, the testes were shrunken and yellow, brown or green in color.

Gross examination of gonads is quite adequate for distinguishing the above stages of the Dover sole, except during the summer months when there is some chance for error in differentiating immature from mature resting females. With the approach of the spawning period the difference between the two catagories is clearly marked. The other stages are fairly distinct.

Ovaries of early stage B (Developing) and early stage C (Gravid) were fixed, sectioned and stained. Carnoy's solution proved to be the best fixative, as there was no shrinkage. A modified paraffin method was used for this cytological study because difficulties due to brittleness of the yolk (which is very common in the case of this tissue) were encountered in the sectioning. A rubber-paraffin bath at 52° C. for one hour was used for embedding. Sections of the developing stage were cut at 10u and of the gravid stage at 20u. Nuclear stains used were Delafield's hematoxylin, iron hematoxylin, and hematein. Cytoplasmic counterstains tried were eosin, lights green and orange G. For photographic work, iron hematoxylin and orange G produced good results. Coelestine blue stained both nuclear and cytoplasmic material and differentiated yolk from the outer membrane of the ova.

The early developing ova of stage B are of several sizes within the stroma, however, by early stage C only one group of ova is evident (Figure 23). The dark stained bodies of the latter stage have been interpreted as nuclei of the ova for the next season. Both photomicrographs are of the same magnification. The diameters of the eggs have increased as much as 10 times in the interval between the early stage B taken in July and the early stage C in October.

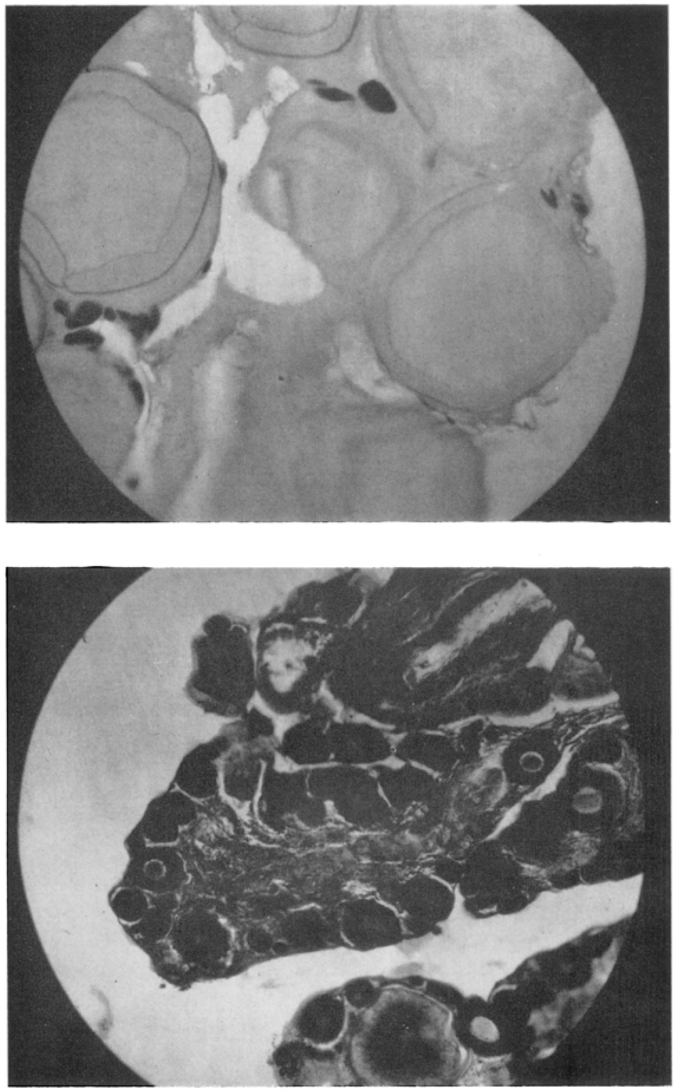

FIGURE 23. Left, early stage B (developing). Right, early stage C (gravid).

FIGURE 23. Left, early stage B (developing). Right, early stage C (gravid)

Gross examination gave no indication that intermediate size groups of eggs are partially developed between seasons. The fact that spent Dover sole are seen early in the spawning season and that the percentage of spent females increases rapidly as the spawning peak is reached, indicates that there is only one group of mature eggs spawned. A spent ovary is quite empty, sac-like, and bloodshot; all that remains is the ovarian membrane. The heavy spawning occurs over a three-month period—December, January, and February—and a few completely spent fish were noticed in November. By February, about 30 percent of the mature females had shed their eggs, and by April practically all of the mature females were spent (Figure 24 and Table 5).

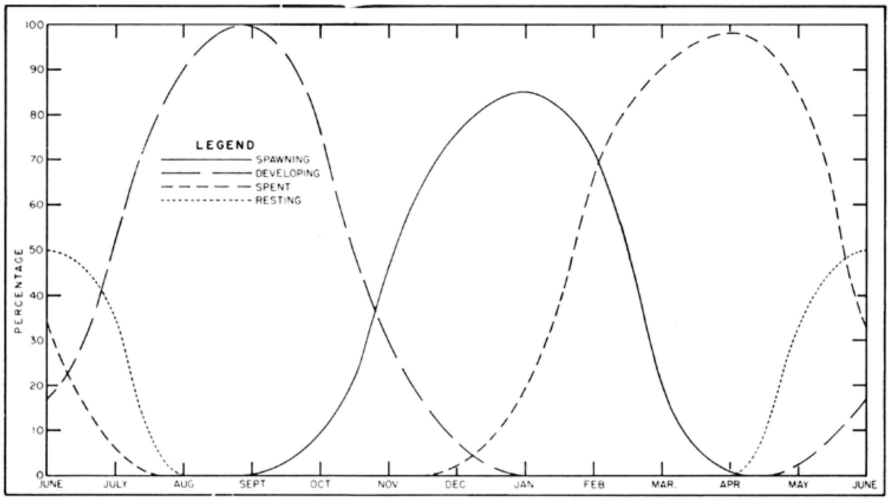

Figure 24. The reproductive cycle of the mature female Dover sole, the curves smoothed by eye. Stage C (gravid) was omitted for simplicity.

FIGURE 24. The reproductive cycle of the mature female Dover sole, the curves smoothed by eye. Stage C (gravid) was omitted for simplicity

TABLE 5

Stages of Ovary Development Expressed in Percentage of Total Sample
Immature Females Not Included

Month / Stage	January	February	March	April	May	June	July	August	September	October	November	December
Resting	0	0	0	0	19	50	49	0	0	0	0	0
Mature Developing and Gravid	5	0	10	1	9	17	41	100	99	94	43	28
Spawning	85	71	0	1	0	0	0	0	.5	5.5	50	67
Spent	10	29	90	98	72	33	10	0	.5	.5	7	5

TABLE 5 Stages of Ovary Development Expressed in Percentage of Total Sample Immature Females Not Included

7. DESCRIPTION OF EGGS AND YOUNG

7.1. Eggs

Dover sole eggs were collected by stripping very ripe females caught by commercial fishermen during the spawning season. The eggs were free-flowing and presumed to be completely mature. The eggs collected were preserved in a 4 percent formol-saline solution. There was no attempt to collect fertilized eggs at sea. In shape the eggs were generally spherical, although a small percentage were slightly elongated, or "egg-shaped." No fresh eggs were studied. The eggs are translucent and the shell or zona radiata is tough and thick with a raised vermiculate pattern over the surface, producing a wrinkled appearance when viewed under a microscope. They have an undivided yolk without an oil-globule. To measure the preserved eggs a micrometer eyepiece was used with a binocular microscope, and calibrated to 0.027 mm. per unit. With an enlargement of 30 diameters one hundred eggs were measured at random. Diameters ranged from 2.05 mm. to 2.57 mm., and average 2.33 mm.

7.2. Larval Development

The eggs and larvae of the Dover sole are buoyant and pelagic like those of the majority of pleuronectids (Norman, 1934). The pelagic life is prolonged for several months and metamorphosis is delayed. This characteristic may have an important bearing on the distribution of the species. With a prolonged pelagic life there would be an extended period before the assumption of a demersal habitat when the semitranslucent floating eggs and larvae would be influenced by the ocean currents. Although no attempt could be made to collect the pelagic stages of the Dover sole, specimens have been taken incidentally to other investigations over a period of several years. No identifiable prolarvae were available.

The Dover sole postlarvae (stage from yolk sac absorption to metamorphosis) can readily be identified and separated from other flatfishes by counts of vertebrae, and the rays of the dorsal, anal, and caudal fins. It is fortunate that these counts are not overlapped by the other species in the same family therefore permitting positive identification. A summary of the meristic characters taken from Townsend (1936) is as follows (Table 6).

TABLE 6

Number of Vertebra and Fin Rays

Vertebral range	Vertebral mean	Abdominal vertebral range	Abdominal vertebral mode	Dorsal range	Dorsal mean	Anal range	Anal mean	Caudal range	Caudal mode
51–54	51.8	11–12	12	94–116	105.7	80–96	87.6	20–22	21

TABLE 6 Number of Vertebra and Fin Rays

The early larvae of the flatfishes are very similar to those of ordinary symmetrical fishes, but as development takes place they assume the characteristic asymetry peculiar to their order. In the development of the postlarvae of the Dover sole marked changes take place as metamorphosis proceeds. These include the migration of the left eye to the right

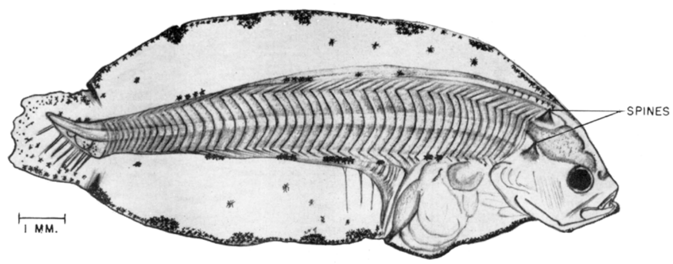

FIGURE 25. A young postlarval Dover sole. Total length 11.5 mm. Taken 160 miles southwest of San Francisco by the "Black Douglas," U. S. Fish and Wildlife Service, 1950.

FIGURE 25. A young postlarval Dover sole. Total length 11.5 mm. Taken 160 miles southwest of San Francisco by the "Black Douglas," U. S. Fish and Wildlife Service, 1950

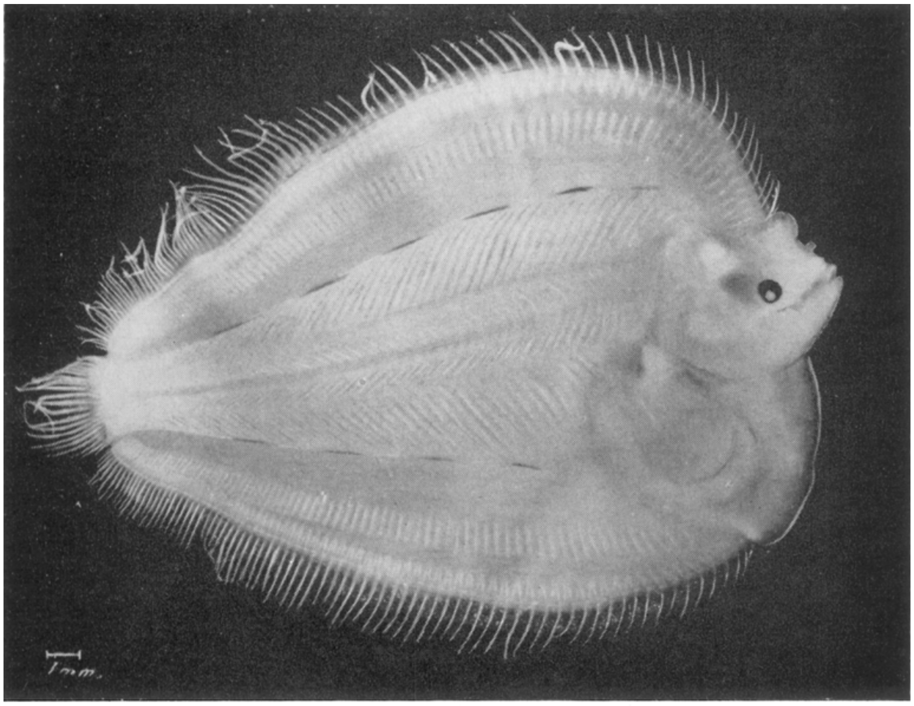

FIGURE 26. Postlarval Dover sole 26 mm. total length. Collected August 18, 1937, 35 miles west of Monterey, California.

FIGURE 26. Postlarval Dover sole 26 mm. total length. Collected August 18, 1937, 35 miles west of Monterey, California

side of the head, growth of the fins from primitive fin folds, increased depth of the body, and heavier pigmentation. All are permanent adult features. In the smallest specimen studied (11.5 mm., Figure 25), the lower jaw is well developed and projects forward at a lesser angle to the horizontal axis than it does in later stages (Figure 26). The posterior part of the notochord is turned upward approximately 20 degrees and a heterocercal caudal fin is developing. Three hypural cartilages are apparent as well as the ventral caudal radial and the distal portion of the dorsal caudal radial. Visible under magnification are 10 lepidotrichia along the ventral border of the caudal cartilages. The sigmoid-shaped myotomes are 51 in number and within the vertebral range of the Dover sole.

A very interesting feature of the Dover sole postlarvae is the appearance of two pairs of spinous protuberances near the occipital region on each side of the chondrochranium (Figure 25). These structures disappear before metamorphosis, and are not found on juveniles. In larger postlarvae approaching metamorphosis the spines are not as conspicuous as in the smaller sizes. Norman (1934) states that postlarvae of the turbot and brill of the Atlantic have similar spines on the head that disappear at metamorphosis, but there is no further mention of these characteristic spines in other pleuronectids (or flounder family). This feature may serve as a diagnostic characteristic to distinguish the Dover sole from other flatfish larvae of the Pacific.

In the young postlarvae the black pigmentation pattern in general is fairly distinct but there seems to be some variation in the location of pigment groups. The pattern is also confusing because some of the smaller specimens may have more extended spotting than the larger sizes.

There are usually five equally spaced groups of chromatophores along the outer edge of the anal fin anlage. These extend posteriorly from the anus to the caudal fin fold. Along the dorsal fin there is a similar pattern with usually six distinct spots. On both of these median fins there is a fine continuous border of pigmentation connecting the denser spots. The ventral abdominal ridge from the anus forward to the head is slightly pigmented and also the tip of the lower jaw. The head in general is lacking in pigmentation. The early postlarvae has pigmented bands along the border of the central muscular trunk that more or less fall in line with the dorsal and anal fin spots. This condition is more pronounced in older stages prior to metamorphosis. Pigmentation is retarded on the left side which is practically devoid of spots.

In advancing stages of metamorphosis from 30 mm. to 40 mm., when the left eye is on the dorsal ridge of the head, five or six spots become apparent intermediate between the central trunk and the base of the dorsal and anal fin rays. These persist and are found on the demersal young. The heavy adult pigmentation is found on the young ranging in length from 50 mm. to 55 mm. that have been caught on the bottom.

Body proportions change radically through the developmental stages, and the most noticeable is the ratio of depth of body into the length. The larva progresses in shape from elongate, to wide leaflike, and then back to the intermediate adult shape. Body depth in length ratios for postlarvae range as follows: 2.58 at 11.5 mm., 1.46 at 17.5 mm., 1.48 at 18.5 mm., 1.11 at 19.5 mm., 1.37 at 26.0 mm., and 1.56 at 43.0 mm. During part of their pelagic existence postlarvae have almost a 1.1 depth of body to length ratio.

Complete metamorphosis is delayed in the Dover sole, and available specimens indicate that the complete migration of the left eye does not take place until the total length reaches at least 35 mm. Even in a 48 mm. specimen the left eye was not quite in the adult position. The Atlantic relative of the Dover sole, the lemon sole, Microstomus kitt, attains a length of 30 mm. or more, before metamorphosis is complete. The pelagic life is probably prolonged over several months. Maximum spawning occurs from December to February and pelagic specimens as small as 26 mm. have been taken in August. Even if spawning occurred as late as April these larvae would be about four months old.

7.3. Distribution of Larvae

Dover sole larvae have been collected along the entire coast of California and south to 60 miles below the Mexican boundary. They have been taken as far offshore as 280 miles. Three one-inch long post-larvae were found in the stomach of an albacore caught by M. V. *N. B. Scofield* on September 11, 1948, about 240 miles west of San Pedro (Lat. 33° 20' N, Long. 123° 15' W).

Data supplied by the California Cooperative Sardine Research Program indicates that the general area southwest of Eureka and Cape Mendocino from 40 to 200 miles offshore has a greater abundance of young Dover sole than the more southern areas. However, an oceanographic station 50 miles west of Point Arena produced the greatest number per unit volume of water sampled. The pelagic young of this species are found 500 miles or more south of the commercial range, although still within the known range of the adults. Larvae were found at 32 stations, 19 north of San Francisco and 13 south. of the 13 southern stations five were north of Point Conception and eight were south. These southern specimens could be the progeny of small local populations, or their occurrence could result from the drift of pelagic eggs and larvae from the large spawning stocks to the north. In the area off Point San Luis which is over 200 miles south of the commercial fishery there are large quantities of young Dover sole close to shore. It is entirely possible that with the offshore spawning and the long pelagic stage of the young, there is a drift to the south and shoreward. The prevalent ocean currents along the Northern California coast over the spawning season flow south and curve inshore. Again the migration northward of the demersal young inshore could be aided by the northerly flowing California Coastal Subsurface Counter Current. This current is known to be effective at least as far as Cape Mendocino (Sverdrup 1943).

Specimens supplied by Dr. Rolf L. Bolin and Dr. Elbert H. Alstrom were taken in plankton tows from 0 to 75 meters. These were the youngest collected. The postlarvae caught in the San Diego trough by Dr. Gordon Tucker had a bathymetric range from 43 to 267 fathoms. The lengths ranged from 22 mm. to 48 mm. The smallest (22 mm.) was caught at a depth of 218 fathoms while the largest (48 mm.) was caught between 43 to 67 fathoms. These tows were at mid-depths and not on the bottom.

The young evidently become demersal between 50 mm. and 55 mm. in length and are found inshore along the bottom. Many of these sizes were taken from 70 to 110 fathoms off Point San Luis during the fall of 1950 in a small mesh beam trawl. Holt (1893) points out that Microstomus kitt, does not approach the shore until nearly two inches in length. Microstomus pacificus is thus similar to its Atlantic relative in that respect.

8. MIGRATIONS

It is well known to the commercial fisherman that marketable Dover sole do not remain on the same grounds throughout the year. Areas densely populated at one season will be barren at another and the fishermen seek different grounds in order to supply the dealers. The logs of the 15 most successful boats in the Northern California Dover sole fishery during 1948, show a striking increase in fishing depth during the winter indicating that these fish are found in deep waters. On the other hand during the summer months of June, July, and August the main population is taken in the comparatively shallow depths of 100 fathoms or less (Figure 27). It is probable that this area is richer in prey than is the deeper, colder, and darker region farther offshore, and that it constitutes a feeding ground. During the late summer and early fall months there is a noticeable but not particularly marked drift toward somewhat deeper water. However, in November the outward and downward migration, probably under the stimulus of a spawning urge, becomes a rush, and by December most of the fish have reached depths not usually fished. Here they remain during the peak of the spawning season and few fish are caught. By April most of the fish have returned to fishable grounds at about 140 fathoms and continue to move toward lesser depths for the

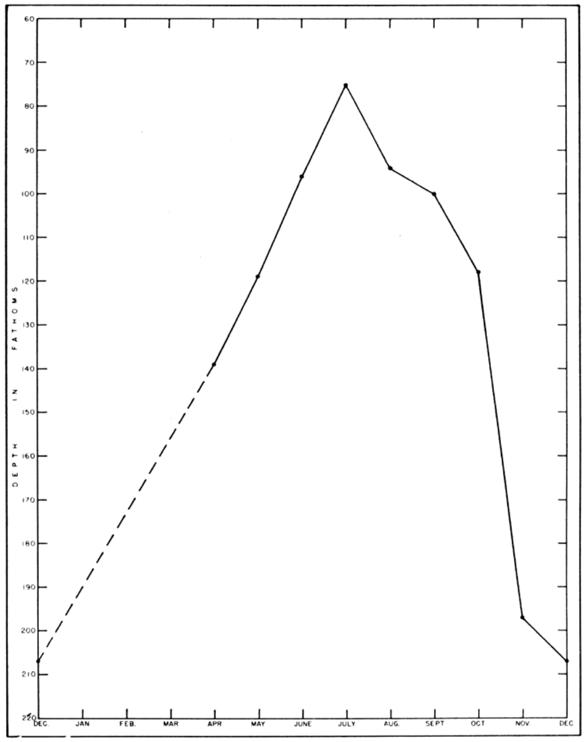

FIGURE 27. The average depths fished off Northern California in 1948 for Dover sole. Data taken from trawler logs and fish receipts. No significant amount of fish landed in January, February and March

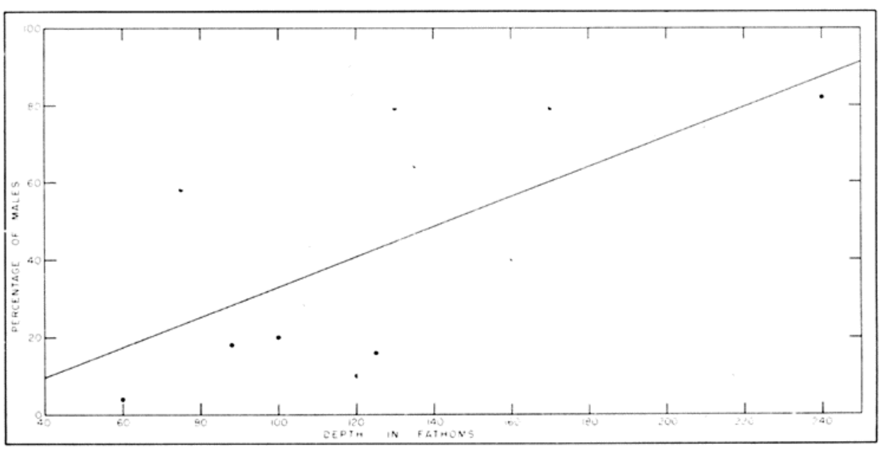

FIGURE 28. The percentage of males to females in relation to depths taken. Eleven samples (N = 546), July 1949. The regression line by least squares

next three months. This spring inshore migration is not as sharply defined as is the spawning migration; the schools appear to be smaller and less dense and their movements are more sporadic and unpredictable than in the fall.

At least during the summer, there seems to be a tendency for segregation of the sexes. Many catches were composed almost entirely of one sex or the other. Since those from deeper waters were particularly rich in males, it appears that the urge toward inshore migration may not be as strong in this sex as in females. Sex ratios and depths were recorded from eleven market samples that were taken in July, 1949. The percentage of males per sample was plotted against depth caught. A regression line computed by the method of least squares indicates a trend for the percentage of males to increase with depth for this particular period (Figure 28). This trend bears out the statements by the fishermen who claim their catches in deeper water contain more of the smaller and darker colored fish; these are definitely male characteristics.

Superimposed upon the annual migration is a bathymetric movement which extends over the entire life of the fish. Young and small specimens are restricted to comparatively shallow waters, while the largest specimens do not invade these nursery grounds.

9. FOOD HABITS

One of the most interesting facts about the food habits of the Dover sole is that up to the present time no vertebrate animals have been found in the stomach contents. In the stomach and intestine, mud was very prevalent throughout. Many small burrowing and mud inhabiting animals were found and it is believed that the Dover sole must scoop up mud directly in feeding. Sedentary forms such as small bivalves and scaphopods were common. Sipunculids, polychaetes (Nereis sp.), nematodes, echinoids (sea urchins), ophiuroids (brittle stars), and gastropods (Thais sp.) were found in varying quantities. At times the Dovers would be completely gorged with shrimp and other crustacean forms. Nematodes, although some were seen free inside of the digestive tract, probably are parasitic. Encysted nematodes were common throughout the mesenteries and on the liver. Stomach contents of year old fish indicate they have the same feeding habits as the adults. Demersel eggs also added to the young fishes diet.

10. CONSERVATION

The chances for continued survival in the face of heavy exploitation are probably greater in the case of the Dover sole than in any of the other commercially taken flatfishes. One of the main reasons for this optimistic prognosis is that the Dover sole has the greatest bathymetric range, and is found in depths of more than 500 fathoms. The spawning migration to deep water during the winter months almost completely eliminates the species from the fishery for a time. Furthermore, the winter storms tend to keep the trawlers from operating during this period. The resultant seasonal unavailability is of considerable survival value and characterizes the coast of California and Oregon and probably more northern areas as well (Figure 5).

TABLE 7

1949 Regulations Covering Otter Trawling for Flatfishes on the Pacific Coast

	California	Oregon	Washington
Mesh	5″ min., inside knots	None	4¼″ min.
Closed ocean areas	Inside 3 mi., Northern Calif. Inside 25 f., Central Calif. All closed, Southern Calif.	Inside 3 miles All bays	Bays and certain areas of Puget Sound.
Size limits	None	None	11½″ soles 14½″ flounders
Log books	Required	Optional	Optional

TABLE 7

1949 Regulations Covering offer Trawling for Flatfishes on the Pacific Coast

Furthermore, the immature Dover sole are generally found close to shore, and these nursery grounds are not fished. Present regulations of California and Oregon prohibit trawling inside of the three-mile limit (Table 7).

Even if young Dover sole do enter a trawl, the lack of a pronounced first interhaemal spine permits a large percentage of escapement through the meshes of the net. In the petrale sole (Eopsetta jordani), English sole (Parophrys vetulus), and rex sole (Glyptocephalus zachirus), this spine tends to snag the small fish in the net, even though they are normally small enough to escape through the mesh.

Finally, it has been shown that the Dover sole escapement is the greatest of any flatfish. In savings-gear experiments conducted off the California coast by Clark in 1935, the minimum total length retained in the experimental five-inch mesh cod end was 300 mm., compared to 210 mm. for English sole, 230 mm. for petrale sole, and 230 mm. for rex sole. This can probably be explained by three facts: first, the Dover sole is very slippery because of the excessive amounts of mucus produced; second, the body is very flexible and can be bent to conform to the openings in the mesh of the nets; and third, there is no interhaemal spine. Fishermen remark that when the cod end of a drag net is being held alongside of the fishing vessel prior to lifting it on deck, the roll of the boat toward the side where the net is being held tends to lessen the stress on the mesh, and large Dover sole up to 24 inches have been seen to escape.

11. SUMMARY

Facts on the biology of the Dover sole (Microstomus pacificus) are presented, as well as data on the trawl fishery it partially supports.

Dover sole range from Southern California to Alaska, but are mainly important from San Francisco northward along the Oregon coast.

The bulk of the material was gathered from the fish markets at Eureka and Fort Bragg. Three thousand two hundred specimens were examined.

Dover sole were taken as early as 1878, but seldom reached the markets until 1943. The filleting and quick freeze method revolutionized the marketing procedures, and in 1950 the catch skyrocketed to 9,600,000 pounds and represented 38 percent of the total sole catch.

Dover sole are found in deeper waters than the other flatfishes, and frequent muddy bottoms. There is a seasonal migration into deep water over the winter months, and in the summer large catches are taken in shallow depths of 100 fathoms or less.

The length frequency method of estimating growth rates is not satisfactory in the Dover sole. About 10 age classes are being taken.

Length-weight curves were fitted by the method of least squares with the resulting formulas for males and females. Y is the weight in pounds and X is length in centimeters.

Males: $Y = .000244X^{2.95}$

Females: $Y = .0002389X^{2.97}$

Age and rate of growth were determined both by scales and otoliths. The fish enter the catch at approximately 30 cm. in total length, and average about five years of age. Most of the catch is composed of fish 8 to 10 years of age, and range from 39 cm. to 46 cm. in length. The larger fish are all females.

Males mature earlier than females, beginning at 30 cm.; by 32 cm. 50 percent are mature, and at 39 cm. practically all are mature. Females begin to mature at 33 cm., and by 35 cm. 50 percent have reached maturity. Almost all are mature at 45 cm.

The spawning season occurs over December, January, and February. A few spawn in November and March. Egg production was determined by a sample count, and large females are estimated to produce about 230,000 eggs.

The larvae have a prolonged pelagic life, and metamorphosis is delayed. The distribution is along the entire California coast south to 60 miles below the Mexican boundary, and offshore as far as 280 miles. There is indication that there is a drift to the south and shoreward of the eggs and young due to the prevailing ocean currents during the spawning season. The young become demersal between 50 mm. and 55 mm. in length and are found inshore along the bottom.

Stomach contents reveal that the Dover sole feeds only on invertebrates, mainly mud inhabiting sedentary forms.

Chances of survival seem better for the Dover sole than the other flatfishes because of its migrations, larger escapement size, and separate nursery areas.

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