NATURAL HISTORY AND METHOD OF CONTROLLING THE STARFISH (*Asterias forbesi*, Desor)[1]

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INTRODUCTION

The studies of the natural history and methods of controlling the starfish, *Asterias forbesi*, were carried out under the provisions of a special appropriation by Congress in 1935 for the purpose of providing aid to the oyster growers in protecting their crops against natural enemies. Under the direction of Dr. Paul S. Galtsoff, In Charge of Shellfisheries Investigations of the United States Bureau of Fisheries, the work was conducted in Buzzards and Narragansett Bays, Long Island Sound, and lower Chesapeake Bay. Principal attention, however, was focused on Long Island Sound, where depredations by starfish inflict great losses to the oystermen. The work in this section was carried out by Dr. V. L. Loosanoff.

The authors are greatly indebted to the Connecticut Shellfisheries Commission for providing the State boat *Shellfish* to conduct field observations over the entire area of

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Long Island Sound, and in setting aside State land at Milford, Conn., for the construction of experimental tanks and the erection of a temporary laboratory building. To Capt. E. Hoyt, of the Connecticut Shellfish Commission, belongs the credit for assistance in performing three extensive surveys of starfish distribution in Long Island Sound. The following persons, temporarily employed by the Bureau of Fisheries, also participated in various phases of this investigation: Dr. Kenneth S. Rice, J. J. Hellewell, H. A. Kumin, O. K. Fletcher, Jr., and G. Mishtowt were engaged in surveying starfish distribution in Buzzards and Narragansett Bays; J. Lucash, R. B. Burrows, J. Lipsett, E. Larson, J. Piatt, A. Kammeraad, R. Naumann, and J. B. Engle carried out various observations on distribution and biology of starfish in Long Island Sound and the lower Chesapeake Bay. In presenting the results of the present investigations it appeared desirable to utilize some of the unpublished material obtained in 1929–32 by Louise Palmer, at that time employed by the Bureau. Her observations and experiments are indicated in the text.

GENERAL APPEARANCE, DISTRIBUTION, AND DESTRUCTIVENESS OF STARFISH

Asterias forbesi (Desor), (fig. 1), the common starfish of the Atlantic coast, is characterized by five stout, almost cylindrical, blunt rays or arms beset with coarse spines. Occasionally, abnormal individuals are found with 4, 6, or 7 rays. Between the bases of two of the rays on the aboral surface is situated a bright-orange madreporite, a peculiar skeletal plate pierced by numerous openings through which the sea water may enter the water-vascular system. The pedicellariae, or minute forceps-like appendages scattered over the surface of the body, are broad and rounded. The color of the animal is extremely variable; the most common shades are orange and purple, but greenish-black and brown individuals are occasionally found. The purple starfish, *Asterias vulgaris* Verrill (fig. 2), another common species inhabiting the inshore waters, is characterized by its flattened and pointed rays; long and pointed pedicellariae; numerous spines forming a noticeable longitudinal row on the aboral surface of each arm; and pale-yellow madreporite. Because of the great variability in color of the body, shape of the arms, and arrangement of spines, it is not always easy to distinguish the two species. Coe (1912) considers that the most reliable characteristic which permits a correct identification is found only in the shape of the major pedicellariae; very broad and rounded in *A. forbesi* and long and pointed in *A. vulgaris*.

According to the personal communication of Austin Clark, Curator of Echinoderms, United States National Museum, the range of distribution of *A. forbesi* extends from Penobscott Bay, Maine, south to Lower Matecumbe Key, Fla., and to Pensacola, Fla., in the Gulf of Mexico. This form is most abundant from Cape Cod to Virginia, becoming local north of Cape Cod and is usually not common south of Virginia. It is found in shallow water from the shore line to 30 fathoms, being most numerous in the littoral zone.

A. vulgaris occurs from Labrador to Cape Hatteras, N. C., from the shoreline down to 167 fathoms. This species is common in water of moderate depth, but south of Long Island Sound is not found along the shore. In Casco and Penobscot Bays, Maine, and in waters of Massachusetts, Rhode Island, Connecticut, and New York, both species are found along the shoreline, but *A. vulgaris* chooses deeper and cooler water and therefore is rarely found in the shallow places at the heads of the bays preferred by *A. forbesi*. The difference is clearly shown on charts 48 and 49 of the distribution of these species in Vineyard Sound and Buzzards Bay (Sumner, F. B.; Osburn, R. C.; and Cole, L. J.; 1913).

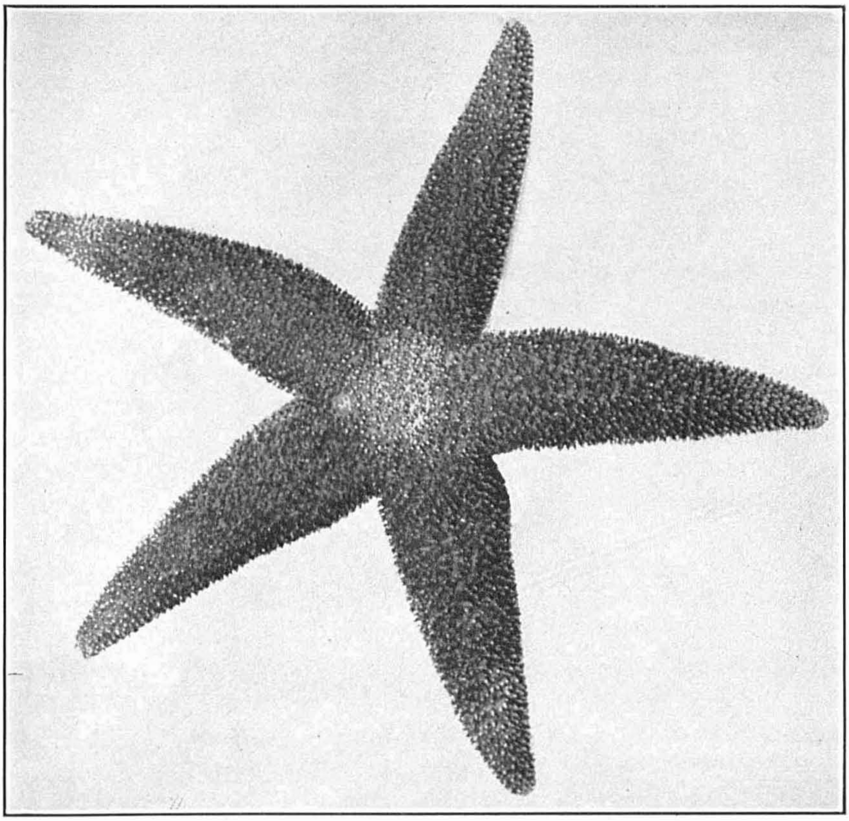

FIGURE 1.—*Asterias forbesi*, Desor. Dried specimen from Menemsha Bight. Diameter 8 inches. Collection of the U. S. National Museum.

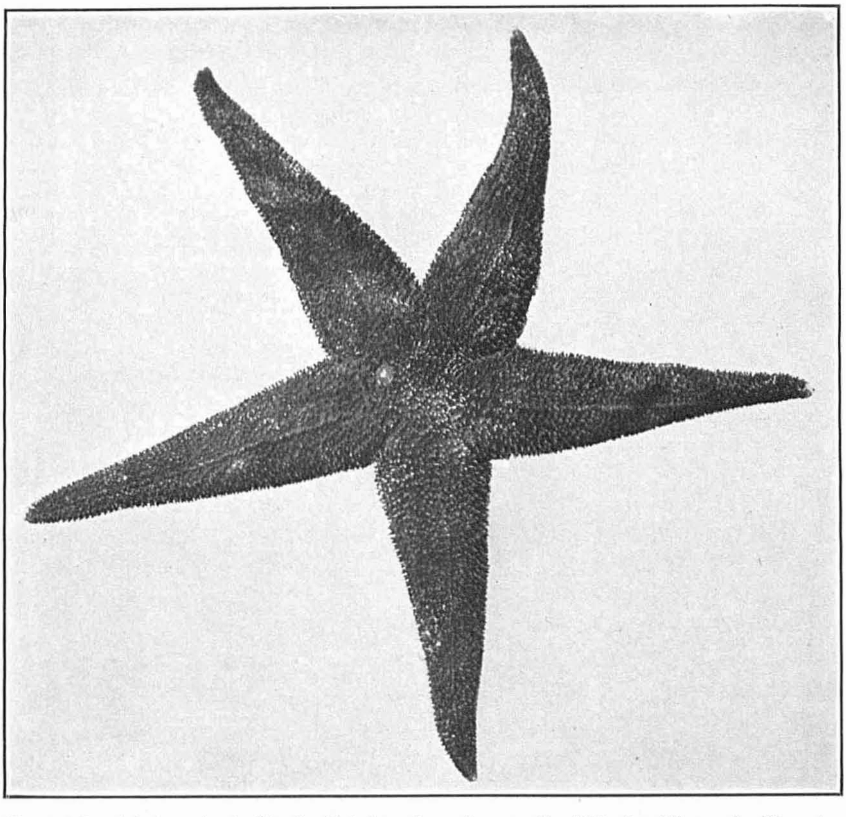

FIGURE 2.—*Asterias vulgaris*, Verril. Dried specimen from south of Marthas Vineyard. Diameter 8¼ inches. Collection of the U. S. National Museum.

Since the beginning of oyster culture in the United States, in 1845, the starfish has been regarded as one of the most destructive enemies of shellfish on the Atlantic coast. By far the greater part of the loss caused by this animal is borne by the oyster growers, who often find their transplanted stock annihilated and their seed oysters destroyed by starfish. Only through most watchful and persistent vigilance can this pest be kept in check. The gravity of the injury to the oyster industry was recognized by the Connecticut General Assembly which, in 1901, passed a law forbidding, under penalty of fine and imprisonment, the deposition of starfish in the navigable waters of the State. A correct estimate of damages inflicted by this enemy is difficult to make for it should include the potential value of the lost young oysters as well as the loss of marketable mollusks and the cost of protecting the bottoms. Unfortunately such an estimation is at present impossible, but a good idea of the destructiveness of the pest can be gained from the statements found in the reports of the Connecticut Shellfisheries Commission and from the records of individual oyster companies operating in Long Island Sound and Narragansett Bay. Collins (1891) states that the direct damage done by starfish in Connecticut waters amounted to $463,000 in 1887, $631,500 in 1888, and $412,250 in 1889. At present, according to the opinion of the leaders of the oyster industry, the destruction of starfish in Long Island Sound probably runs into several hundred thousand bushels of oysters annually. Thus, for example, Mr. Howard W. Beach, manager of the F. Mansfield & Sons Oyster Co. and president of the Oyster Growers and Dealers Association of North America, in his letter to Dr. Loosanoff, states:

> My estimate is, that since 1921 not less than 500,000 bushels annually have been destroyed. If these oysters had grown to market size, they would have had a value of $500,000.

In addition to the direct monetary loss caused by the destruction of marketable oysters, the industry is compelled to spend a large sum of money for starfish-boat operation, handpicking of starfish on dredge boats, and their destruction by all other methods. According to Mr. Gordon Sweet, general manager of the H. C. Rowe Oyster Co.:

> The average overhead and direct cost of operating a boat to fight starfish is not less than $35 a day on Long Island Sound. If we should assume that 20 such boats operated 200 days a year, you would have a total annual charge of $140,000. I do not consider that this estimate is excessive. I am including the interest on capital invested, depreciation, and other indirect charges.

Mr. Howard W. Beach supports this statement by stating in his letter:

> Since 1931 our firm has spent for boat and labor to catch starfish a minimum of $10,000 per year. Supplies, repairs, and depreciation of equipment would bring the cost up 50 percent, i. e., to $15,000 per year. In view of our costs, I estimate that the industry of Connecticut expends directly for fighting starfish an average of $100,000 to $150,000 per year.

Statements received from nine large oyster companies in Narragansett Bay show that each of them, during 1929–32, spent from $2,000 to $10,000 per year to catch starfish. These figures do not include repairs and depreciation of equipment and no attempt was made by the Rhode Island oystermen to estimate the loss due to destruction of marketable oysters. According to observations of the senior author in 1931–32, the starfish were so abundant on oyster bottoms in Narragansett Bay that the dredge dragged over the infested bottoms would often bring more starfish than oysters. The intensity of infestation can be judged by the data obtained from one company which kept complete records of dredging operations on 1,500 acres of oyster bottoms leased in Narragansett Bay. In 1931 as many as 6,987,650 starfish were removed from this small area. In other years starfish have been even more numerous, since the same company caught and destroyed almost twice as many in 1929.

The scallop, another valuable mollusk of the Atlantic coast, suffers greatly from the attacks of starfish. It is interesting to note that in spite of its free living habits and ability to swim, it becomes an easy prey of the sluggish starfish. Thus, in 1931, the natural scallop grounds of Buzzards Bay were seriously depleted through starfish depredations. The Massachusetts Division of Fisheries and Game reported that the value of the scallop industry in this bay shrank from $795,000 in 1929 to $142,000 in 1931, and that the number of persons employed by the industry decreased during this same period from 1,212 to 839. The greater part of this depreciation was attributed by the State authorities to the gradual increase in starfish population, which reached its maximum in 1930 and 1931. In 1932 the Massachusetts State Legislature, recognizing the gravity of the situation caused by the presence of the tremendous number of starfish in Buzzards Bay, appropriated $15,000 for their extermination. During the 3-year period, with the aid of State and C. W. A. funds, 203,590 bushels, or more than 60 million starfish, were removed from the waters of Buzzards Bay and eastern Vineyard Sound, at an average cost of about 22 cents per bushel. This activity resulted in a noticeable decrease in starfish population in Cape Cod waters.

Experience of the oyster growers in Long Island Sound, Narragansett and Buzzards Bays indicates that the density of starfish population undergoes considerable fluctuation from year to year. A good example of these changes over a period of 17 years is shown by the data prepared by the Narragansett Bay Oyster Co., which operates a steamer continuously for the sole purpose of destroying starfish (table 1). During this period there was no significant change either in the practice of combating starfish or in the extent of oyster bottoms held by the company.

TABLE 1.—*Starfish destroyed by the Narragansett Bay Oyster Co., 1921–38*

[Ten average starfish equal 1 pound]

Year	Pounds	Year	Pounds	Year	Pounds
1921	29,270	1927	172,636	1933	149,445
1922	(1)	1928	232,201	1934	10,000
1923	11,125	1929	1,300,195	1935	10,475
1924	209,900	1930	807,074	1936	13,684
1925	101,280	1931	698,665	1937	13,175
1926	108,740	1932	479,515	1938	[2] 14,530

[1] Too few to weigh. [2] For January 1938 only.

Oystermen usually refer to a sudden increase in starfish over the oyster bottoms as an "invasion." It was one of the purposes of this investigation to determine whether the invasions are due to actual migrations of starfish or should be attributed to the increased rate of propagation and survival of the local stock. An answer to the question can be obtained by comparing the results of several surveys of starfish populations in Long Island Sound and Buzzards and Narragansett Bays undertaken in the course of the present studies.

Since information received from the oystermen regarding the centers of starfish infestations referred only to their own oyster bottoms, and was therefore incomplete and often contradictory, it was necessary to undertake a survey of the inshore areas using uniform quantitative methods of collecting and covering the entire region regardless of the character of the bottom. It was expected that comprehensive surveying repeated during various seasons of the year would provide reliable data on the distribution of *Asterias forbesi* and other species of starfish in relation to environmental conditions and would permit, with a certain degree of accuracy, the determination of the extent of seasonal or other types of migrations.

The procedure used throughout this investigation was invariably as follows: Stations were arranged at frequent intervals from 1 to 3 miles apart, depending on local conditions. Upon reaching a station the boat was brought to a stop and a sounding taken. The bottom temperature was recorded with a reversing thermometer and a sample of water for salinity determination was obtained by means of a Greene-Bigelow bottle lowered to within 3 feet of the bottom. The samples were later titrated with a silver-nitrate solution according to Knudsen's method. A regular scallop dredge or scraper, 28 inches wide, was lowered overboard and towed at uniform low speed until an eighth of a mile, determined by log reading, had been traversed. The dredge was then raised, the type of bottom recorded, and all the starfish caught in the dredge counted and classified according to species and size. From 6 to 12 animals were opened and their sex glands examined and preserved for further studies.

Additional pH observations of the water were frequently made and in many instances plankton samples were collected. All laboratory work was carried out at the United States Fisheries stations at Milford, Conn., and Woods Hole, Mass.

DISTRIBUTION OF STARFISH IN BUZZARDS BAY

The distribution of the starfish population in Buzzards Bay was studied from June 17, 1935, to April 29, 1936. During this period four surveys of the bay were made on the following dates: June 24–July 9; September 10–18; December 2, 1935–January 8, 1936; and April 1–29, 1936. During the last survey, 11 stations, Nos. 42–48, 50, and 52–54, were visited twice, at the beginning and at the end of the month. During the first survey 66 sampling stations, approximately 2 miles apart, were established over the entire area of the bay from the entrance of the Cape Cod Canal to Cuttyhunk Light (fig. 3). In the December and April surveys 12 stations were added, covering the area between Cuttyhunk Island and Sakonet Light, thus connecting the westerly limits of the area under observation with the easterly limits of the Narragansett Bay survey. Due to adverse weather conditions only 7 stations in this new area were visited in December and observations at 5 other stations were successfully completed in April. Beginning with the third survey, in December, a modification was made in the technique of collecting by adding a tangle attached behind the bag of the dredge. The horizontal bar of the tangle was the same length as the blade of the dredge. Therefore, in dredging, the tangle and dredge covered the same bottom area. This method served to give more accurate information as to the presence of starfish which might have been missed when the dredge was bumping over a rocky bottom or had turned over in deeper water. All the records of starfish taken with tangles were kept separate from those caught in the dredge. The results of all the observations, showing the number of starfish caught at each station, arranged in numerical order, are listed in table 2. The total number of starfish caught in the dredge at all the stations was rather small. The first survey yielded only 215 starfish and the following three surveys resulted in the capture of 328, 378, and 229 starfish, respectively.

Although there was a noticeable increase in the number of adult starfish caught in December 1935, they were much less abundant than one would have expected to find in these usually infested waters. The scarcity of starfish in 1935–36 was undoubtedly the result of the eradication activities carried out by State authorities during the preceding years. (See Report of the Bureau of Marine Fisheries, Commonwealth of Massachusetts, 1934.)

A comparison of the results obtained with the dredge and tangle (table 2) shows that the latter was about twice as efficient as the former, although, in a few instances, as for example stations 15, 40, 42, and 52, made in December, the dredge yielded more than the tangle. It has been noticed that in heavy weather, and when working over rocky bottoms, the tangle was always more efficient than the dredge.

Throughout the year over 90 percent of the starfish population was found to be confined to shallow water not exceeding 40 feet in depth. Occasionally a few single specimens were found in deep water, occurring even at depths of over 100 feet, but the number of starfish caught below 40 feet constituted only 8.8 percent of the total annual catch. Within the upper 40-foot zone, 55.4 percent of starfish were collected at depths not exceeding 20 feet. The negative correlation between the depth and

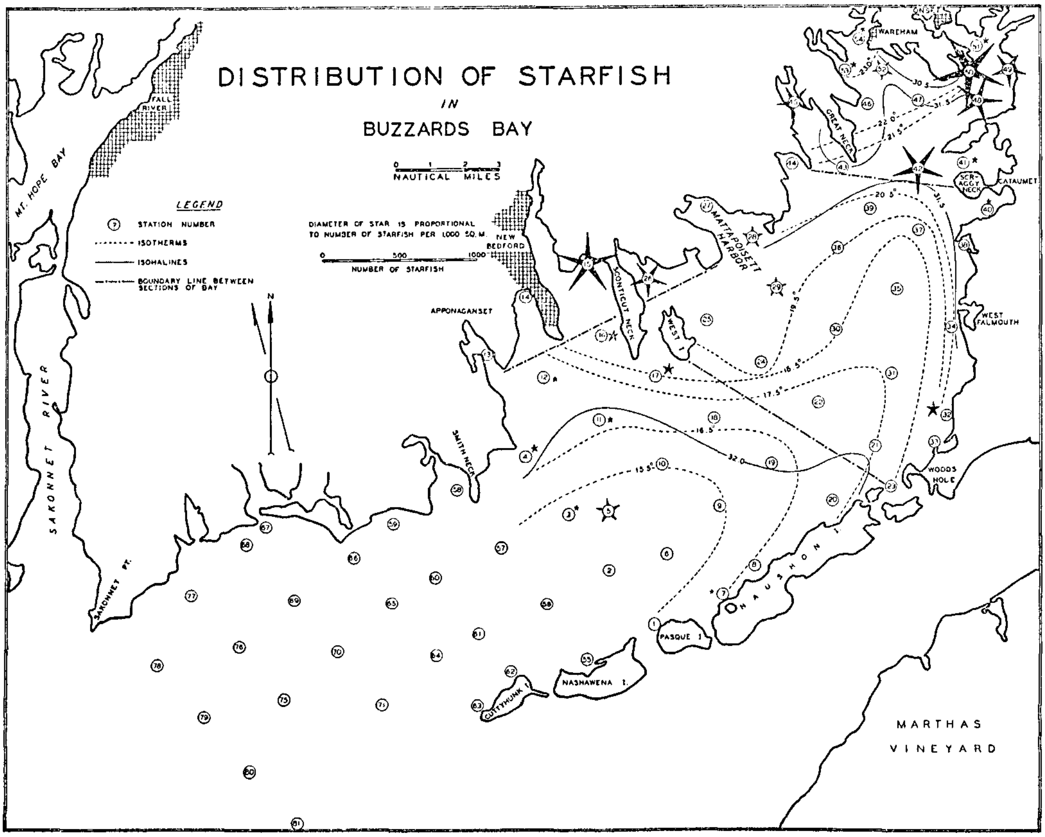

FIGURE 3.—Distribution of starfish in Buzzards Bay, June 24–July 9, 1935. The abundance of starfish is shown by black stars, the diameters of which are proportional to the number of animals per 1,000 sq. meters. Figures in circles indicate station numbers. Dotted lines are bottom isotherms and solid lines are bottom isohalines.

abundance of starfish (table 3) is shown by the decrease of their total number with the increase of depth, as well as by the decrease in the average number of starfish per station.

The starfish were almost equally abundant on hard, rocky, sandy, and soft bottoms containing shells and living mollusks (table 4). The fact that they were scarce on muddy bottoms, lacking a population of mollusks, but were abundant on the same type of bottom where mollusks were present, indicates that the presence of food rather than the character of the bottom is the controlling factor of their distribution. This undoubtedly explains the concentration of starfish in the inshore areas, for both cultivated oyster bottoms and natural oyster beds are located in Buzzards Bay close to the shoreline.

TABLE 2.—*Number of starfish caught by dredge (D) or tangle (T) at each station in Buzzards Bay, 1935–36*

Station No.	Depth in feet	Bottom	June D	Sept. D	Dec. D	Dec. T	Apr. D	Apr. T
1	20	Hard	0	0	0	21	0	0
2	56	Soft	0	0	0	2	0	0
3	36	Sand	1	0	2	89	3	1
4	26	Rocky	3	1	0	17	2	79
5	51	Soft	10	0	0	2	0	11
6	40	do	0	0	0	4	0	1
7	27	Rocky	1	0	3	5	1	13
8	23	do	0	0	0	0	0	0
9	48	Sand	0	0	0	0	0	1
10	45	Rocky	0	4	0	4	1	3
11	30	do	2	5	6	8	3	24
12	26	Hard	2	3	23	34	6	26
13	10	Soft	2	125	2	6	9	5
14	14	Rocky	0	12	5	16	17	5
15	10	Soft	25	10	63	36	31	36
16	21	do	4	2	0	16	1	13
17	16	Rocky	5	14	0	1	0	6
18	43	Mud	0	0	0	7	0	0
19	48	Soft	0	0	0	0	0	2
20	16	Hard	0	0	0	0	0	0
21	42	Mud	1	0	0	0	0	1
22	45	Soft	0	0	0	0	0	2
23	22	Hard	0	0	2	11	9	4
24	45	Sand	0	1	1	6	2	4
25	26	Rocky	0	1	1	7	0	0
26	16	do	14	0	1	4	0	2
27	12	Mud	0	0	3	1	0	5
28	18	Hard	9	0	9	12	8	9
29	30	Mud	7	1	1	1	0	1
30	42	Soft	0	3	1	0	0	0
31	48	do	0	0	0	0	0	1
32	23	Hard	8	10	0	5	3	23
33	18	Rocky	0	0	0	4	0	2
34	22	do	2	1	1	29	1	10
35	38	Soft	0	1	3	15	0	1
36	30	Rocky	0	4	3	1	0	3
37	36	Hard	0	16	1	16	0	0
38	9	Rocky	----	0	1	0	0	2
39	11	Sand	0	10	----	----	0	8
40	15	Rocky	1	2	28	14	11	10
41	12	do	3	15	10	6	16	13
42	36	do	20	17	44	18	9	14
43	20	Soft	0	1	2	4	9	5
44	20	do	0	1	4	5	7	32
45	13	do	13	1	15	12	20	6
46	14	do	2	0	1	3	15	5
47	14	do	0	0	9	6	2	0
48	13	do	22	3	5	4	3	3
49	11	Rocky	15	1	6	10	0	6
50	12	Soft	27	3	15	9	3	4
51	13	Hard	2	14	2	1	----	----
52	13	do	9	1	94	27	27	5
53	12	Mud	3	1	1	0	6	5
54	10	Soft	2	2	0	0	0	2
55	26	Rocky	----	0	0	0	0	2
56	60	Hard	----	0	0	0	4	5
57	38	Soft	----	2	0	0	0	0
58	19	Mud	----	1	1	0	0	2
59	26	Rocky	----	4	7	75	0	45
60	48	Soft	----	2	0	11	0	0
61	108	Rocky	----	0	0	4	0	1
62	34	Soft	----	33	2	12	0	1
63	18	Sand	----	----	----	----	0	0
64	59	Rocky	----	0	----	----	0	0
65	56	Hard	----	0	----	----	0	0
66	15	do	----	0	----	----	0	0
67	31	Rocky	----	----	----	----	0	1
68	48	do	----	----	----	----	0	0
69	48	Hard	----	----	----	----	0	0
70	54	Rocky	----	----	----	----	0	0
71	54	Hard	----	----	----	----	0	0
72	----	----	----	----	----	----	----	----
73	----	----	----	----	----	----	----	----
74	----	----	----	----	----	----	----	----
75	68	Soft	----	----	----	----	0	0
76	59	do	----	----	----	----	0	0
77	54	do	----	----	----	----	0	0
78	70	do	----	----	----	----	0	1
79	70	do	----	----	----	----	0	3
80	80	do	----	----	----	----	0	0
81	45	Rocky	----	----	----	----	0	0
Total			215	328	378	601	229	475

TABLE 3.—*Starfish caught at various depths in Buzzards Bay, all surveys*

Depth in feet	Number of stations	Number of starfish	Percent of total catch	Number of starfish per station
1–20	29	1,233	55.4	42.5
21–40	22	796	35.8	36.2
41–60	22	188	8.4	8.5
61–80	4	4	0.2	1.0
81–100	0	0	0	0
101–120	1	5	.2	----

TABLE 4.—*Distribution of starfish in Buzzards Bay in relation to the character of the bottom*

Type of bottom	Number of stations	Number caught	Percent	Number per station
Mud with shells	28	799	35.9	28.5
Rocky	25	788	35.4	31.5
Hard	14	461	20.7	32.9
Sand	5	129	5.8	25.8
Mud (no shells)	6	49	2.2	8.2
Total	78	2,226	100.0	----

DISTRIBUTION AND SIZE OF STARFISH

Specimens collected at each station were measured by orienting the animal on the measuring board in such a way that readings could always be made between the tip of the arm on the left side of the madrepore and the tip of the fourth arm from it, counting in clockwise direction. In order to determine the reliability of a single measurement, the distance between all opposite arms was measured in 353 specimens in all possible ways. It was found that 30.3 percent measure the same all five ways and 61.4 percent measure the same three ways. In the remaining 8.3 percent there was a difference in each of the combinations which did not exceed one-half centimeter.

In order to make a comparison between the different sections of the bay the stations are combined into four areas as indicated in figures 3, 4, 5, and 6 by heavy dotted lines. The Woods Hole section comprises all the stations southeast of the line between the entrance to the Hole and West Island; the Bay proper area extends

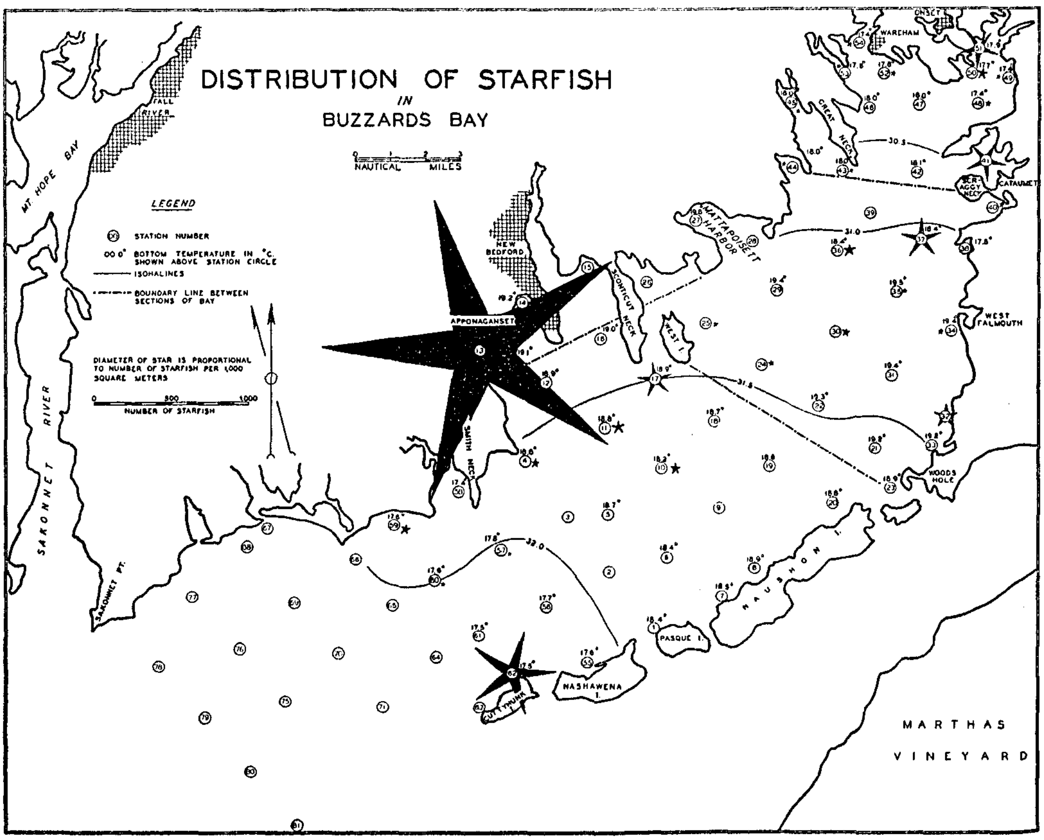

FIGURE 4.—Distribution of starfish in Buzzards Bay, Sept. 10–18, 1935. Figures above circles indicate bottom temperatures. Other legends same as those in Fig. 3.

northwest of the northern boundary of the preceding section as far as the Cataumet-Blake Point line; the Head of the Bay area comprises the uppermost section of the bay, including important oyster bottoms near Onset and Wareham; the New Bedford section covers a small inshore territory north of the line between Ricketson Point and the end of Mattapoisett Neck.

Despite the general scarcity of starfish in 1935 and 1936, which made impossible a detaled study of their growth in different sections of the bay, the results of four surveys consistently show that throughout the year the population in the inshore areas at the head of the bay consisted of the largest starfish. This fact becomes noticeable by observing the mean and median sizes of starfish (see table 5) in four different sections. Because of the unsymmetrical frequency curves (see fig. 7) the changes in the median are particularly significant. Although there may be some doubt regarding the reliability of the data obtained in June because of the use of traps,[2] in which great numbers of starfish were collected at Woods Hole, the fact that the larger starfish are more abundant in the inshore areas is well substantiated by the results obtained during three other surveys. In September the starfish were collected only by dredging and in December and April both dredge and tangle were used. The latter was necessary for catching small starfish, of less than 3 cm. in diameter, which would escape the dredge.

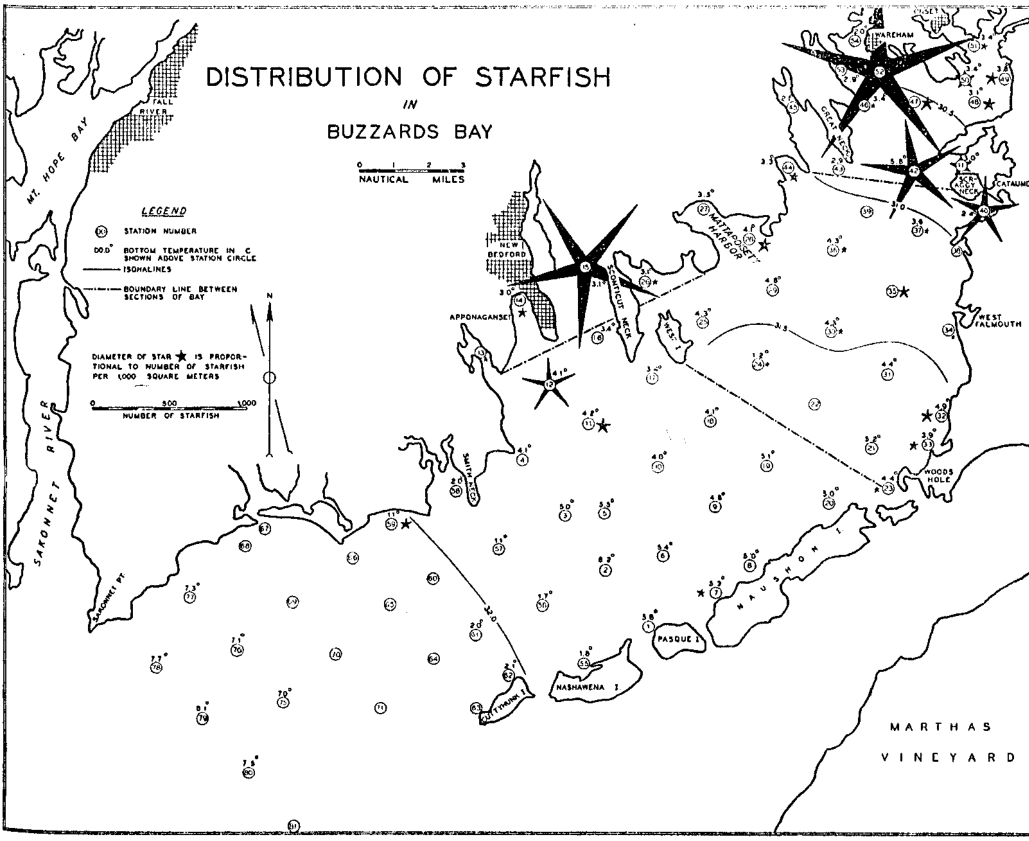

FIGURE 5.—Distribution of starfish in Buzzards Bay, Dec. 2, 1935–Jan. 8, 1936. Figures above circles indicate bottom temperatures. Other legends same as those in Fig. 3.

TABLE 5.—*Mean and median sizes of starfish collected in Buzzards Bay*

	June	September	December	April
WOODS HOLE				
Mean	4.93	6.20	3.50	3.91
Standard deviation	1.62	2.86	2.66	2.41
Probable error	1.11	1.92	1.80	1.62
Median	5.05	7.00	2.60	3.23
BAY PROPER				
Mean	7.35	6.72	6.38	6.17
Standard deviation	2.19	1.64	2.96	2.24
Probable error	1.47	1.10	1.99	1.51
Median	7.15	7.05	6.25	5.90

	June	September	December	April
NEW BEDFORD				
Mean		11.23	7.12	7.79
Standard deviation		2.06	3.05	4.48
Probable error		1.39	2.06	3.02
Median		11.33	6.16	7.10
HEAD OF BAY				
Mean	11.26	9.25	10.81	10.48
Standard deviation	2.50	3.77	3.13	3.49
Probable error	1.69	2.54	2.11	2.35
Median	10.31	8.72	10.11	10.00

[2] These wire bag traps filled with shells and small oysters were set for catching drills and apparently attracted starfish. For description of method of trapping see: Galtsoff, P. S., H. F. Prytherch and J. B. Engle. Natural history and methods of controlling the common oyster drills (Urosalpinx cinerea Say and Eupleura caudata Say). Bureau of Fisheries Circular No. 25, 1937: 1-24.

A study of the frequency distribution of starfish in four sections of the bay (fig. 7) presents some interesting biological points. The predominance of large animals at the head of the bay, clearly shown by their median size (table 5), may be attributed either to their migration from the offshore areas or to the higher rate of growth in the shallow waters. Unfortunately, the size of a starfish is not an accurate indication of its age, for its growth varies considerably depending on the amount of food consumed. Observations of Mead (1901) in Narragansett Bay and at Woods Hole show that under favorable conditions young starfish, 4 months from the time of

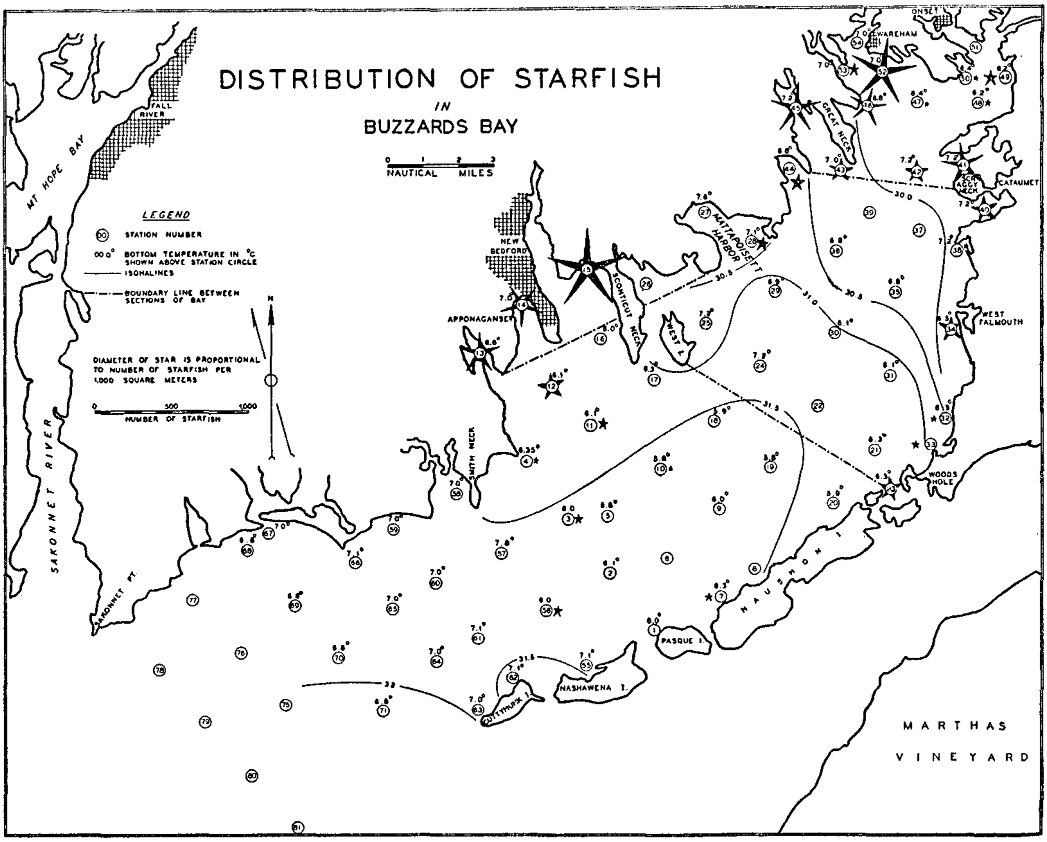

Figure 6.—Distribution of starfish in Buzzards Bay, Apr. 1-29, 1936. Figures above circles indicate bottom temperatures. Other legends same as those in Fig. 3.

setting, may attain a length of 5.4 cm. measured from mouth to tip of arm; more than 10 cm. in diameter if measured according to the method used in this work. This is more than twice the length of many of the animals which were found by Mead just before the beginning of the breeding season. According to his estimate the larger year-old starfish in the early summer would be about 13 cm. in diameter. In view of these observations it appears more reasonable to attribute the difference in size of starfish in various sections of Buzzards Bay to differential growth rate rather than to their migrations.

Small starfish comprising the greatest part of the population in the Woods Hole region in December and April and not found in such an abundance in the summer and fall are probably the young animals less than 1 year old (fig. 7). One can notice that their growth during the winter is very slow. The frequency curves of starfish population at the head of the bay in December and April (fig. 7) show bimodal distribution. It is very probable that the 8–9 cm. class, which makes the first peak of the

April curve, is formed by starfish less than 1 year old and that the 13-cm. class, responsible for the second maximum, comprises older animals.

There was a noticeable decrease in the number of larger animals in the New Bedford section from September to December and at the head of the bay from December to April, which apparently was the result of eradication efforts.

Throughout the year the majority of starfish were confined to the areas where food was most abundant. During the year there was no sign of any extensive migra-

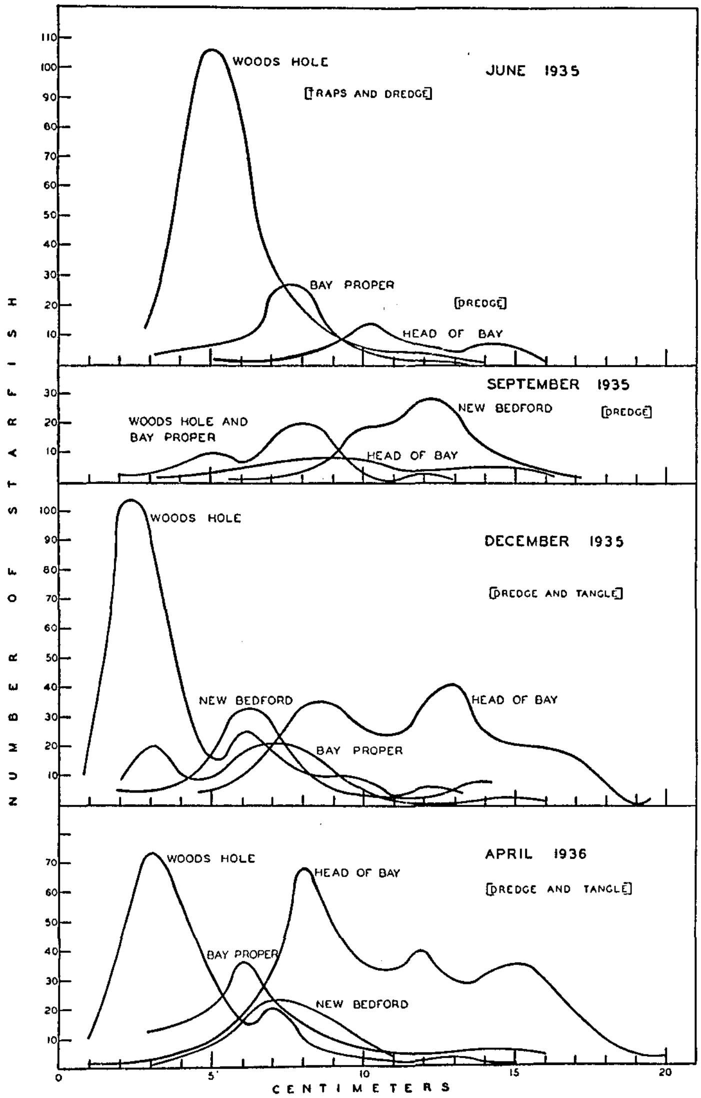

FIGURE 7.—Frequency distribution of size of starfish in four sections of Buzzards Bay.

tion from shallow water to deeper levels or vice versa, the inshore areas of the bay always being more densely populated than its deeper parts. There were, however, some seasonal changes in the abundance of starfish at various inshore stations (figs. 3, 4, 5 and 6). In order to obtain comparable data, only the starfish caught by dredging were considered in preparing these charts and the number of animals collected by tangle in the last two surveys was disregarded. No doubt some of the changes observed in the distribution of starfish during the four consecutive surveys were due to their limited local wanderings. One must also bear in mind that throughout the period of observations, especially during the summer months, extermination of starfish by dredging and mopping was intensively carried out under the supervision of the State Conservation Department, and oystermen were paid bounty for every bushel of starfish delivered to the State officer. This unusual activity probably accounted for a decrease in the number of starfish in the vicinity of Onset at Wareham, at the head of the bay, in September (fig. 4). Their increase in December (fig. 5) coincided with the temporary respite in dredging operations during the fall. In April this section was visited twice, between the 10th and 16th when the temperature ranged from 6.2° to 7.8° C., and again between the 18th and 29th. During the latter part of the month the water temperature varied from 8.2° to 11.4° C. The noticeable increase (table 6) in the number of starfish found at stations 42, 46, and 52, suggests local migration of animals from nearby areas. No significant change occurred, however, at other stations. This indicates that there was no general redistribution of starfish in the bay.

TABLE 6.—*Number of starfish per station caught in dredge and tangle at the head of Buzzards Bay, April 1936*

Station No.	April 10-15			April 18-29		
	Dredge	Tangle	Total	Dredge	Tangle	Total
42	9	14	23	55	39	94
43	9	5	14	10	3	13
44	7	32	39	2	18	20
45	20	6	26	15	2	17
46	15	5	20	10	20	30
47	2	0	2	1	1	2
48	2	3	5	1	0	1
50	3	4	7	4	3	7
51	2	1	3			
52	27	5	32	49	46	95
53	6	5	11	3	5	8
54	2	1	3	5	1	6

From an analysis of the distribution of starfish, disclosed by the results of four consecutive surveys, it is evident that there was no mass migration in Buzzards Bay and that the changes in abundance observed at various stations were due to the redistribution of the local stock. There was no evidence of the existence of a large starfish population in the open sea outside the bay. From these observations a conclusion is drawn that natural annual fluctuations in abundance of starfish are not "invasions," as the oystermen are accustomed to call them, but are due to the increase or decrease in the rate of propagation and survival of local population.

DISTRIBUTION IN RELATION TO TEMPERATURE AND SALINITY

During each of the surveys a record was taken of the bottom temperature and salinity of the water. The data show that neither of the two factors affects the distribution of starfish in the bay. In June (fig. 3) there existed a marked temperature gradient from the mouth of the bay (16.5° C.) toward its head (23° C.). In December (fig. 5) the situation was reversed, for the temperature at the entrance of the bay remained around 7–8° C., whereas in the shallow water of the bay it ranged between 6.2° C. and 1.1° C. In September (fig. 4) the temperature was more or less uniform throughout the bay, varying between 17.6° C. and 20.2° C. and showing no distinct horizontal gradient. Almost homothermic conditions were found again in April (fig. 6), when the temperature ranged between 5.8° C. and 7.8° C. The difference in temperature at various stations observed during the fall and spring should be attributed to daily temperature fluctuations rather than to a definite temperature gradient in the bay.

The salinity of Buzzards Bay water remains nearly constant throughout the year. There is a definite salinity gradient from 23.0 parts per mille at the lower part of the bay to 30.5 parts per mille at its head (figs. 3–6). The salinity of the Wareham River on Onset Bay, at the head of Buzzards Bay, ranged between 27 and 30 parts per mille.

DISTRIBUTION OF ASTERIAS VULGARIS

Only a few specimens of *Asterias vulgaris* were collected during the investigations, as one can notice from table 7, and they were found at depths between 20 and 51 feet. Not a single specimen of this species was found on oyster beds.

TABLE 7.—*Occurrence of* Asterias vulgaris *in Buzzards Bay, 1935–36*

Station No.	Depth in feet	Date	Number of starfish caught	Station No.	Depth in feet	Date	Number of starfish caught
1	20	Dec. 13	2	7	27	Dec. 13	1
3	36	do	6	12	26	Apr. 14	1
4	26	Apr. 14	5	50	26	Jan. 8	6
5	51	do	1	59	26	Apr. 23	6
6	40	do	1	62	34	do	1

DISTRIBUTION OF STARFISH IN NARRAGANSETT BAY

A limited number of observations on the distribution of starfish in Narragansett Bay was made by J. J. Hellewell. Using the method employed in Buzzards Bay two cruises were made, one between September 10 and October 23 and the second between November 20 and December 10, 1935. During the first survey 103 stations in Narragansett Bay and 47 in Block Island Sound were visited. The distribution of salinity indicated in fig. 8 by isohalines shows a decrease from 33 parts per mille just outside the bay to 29 parts per mille at the head of the bay. The temperature of the water near bottom ranged from 15.3° in deeper parts to 23.8° C. in shallow places. Two distinct concentrations of starfish were found—one in the vicinity of Dyer Island, southeast of Prudence Island, and another around Hog Island and Mount Hope Bridge, as indicated by the largest stars on the map. Weekly observations made since completion of the first cruise until the end of January 1936 detected but very little change in the distribution of these two groups, although there was a distinct difference in the size of the animals. The group near Dyer Island comprised small starfish (mode 4.5 cm.), while those near Hog Island consisted of much larger specimens (mode 7.4 cm.).

During the second cruise, in November–December, 80 stations were visited. There were no significant changes in the salinity distribution and no essential changes in the concentration of starfish were observed (fig. 9). The temperature varied between 6.8° and 11.5° C. The comparative size of starfish noticeably increased from mode 4.5 to 7 cm. near Dyer Island and from 7.4 to 9 cm. around Hog Island and Mount Hope Bridge. It is of interest to note that few starfish were found on oyster beds. No starfish were found in Block Island Sound with the exception of the stations off Watch Hill Point, where few specimens were caught. The results of the two cruises clearly indicate that starfish are entirely confined within the boundaries of the bay.

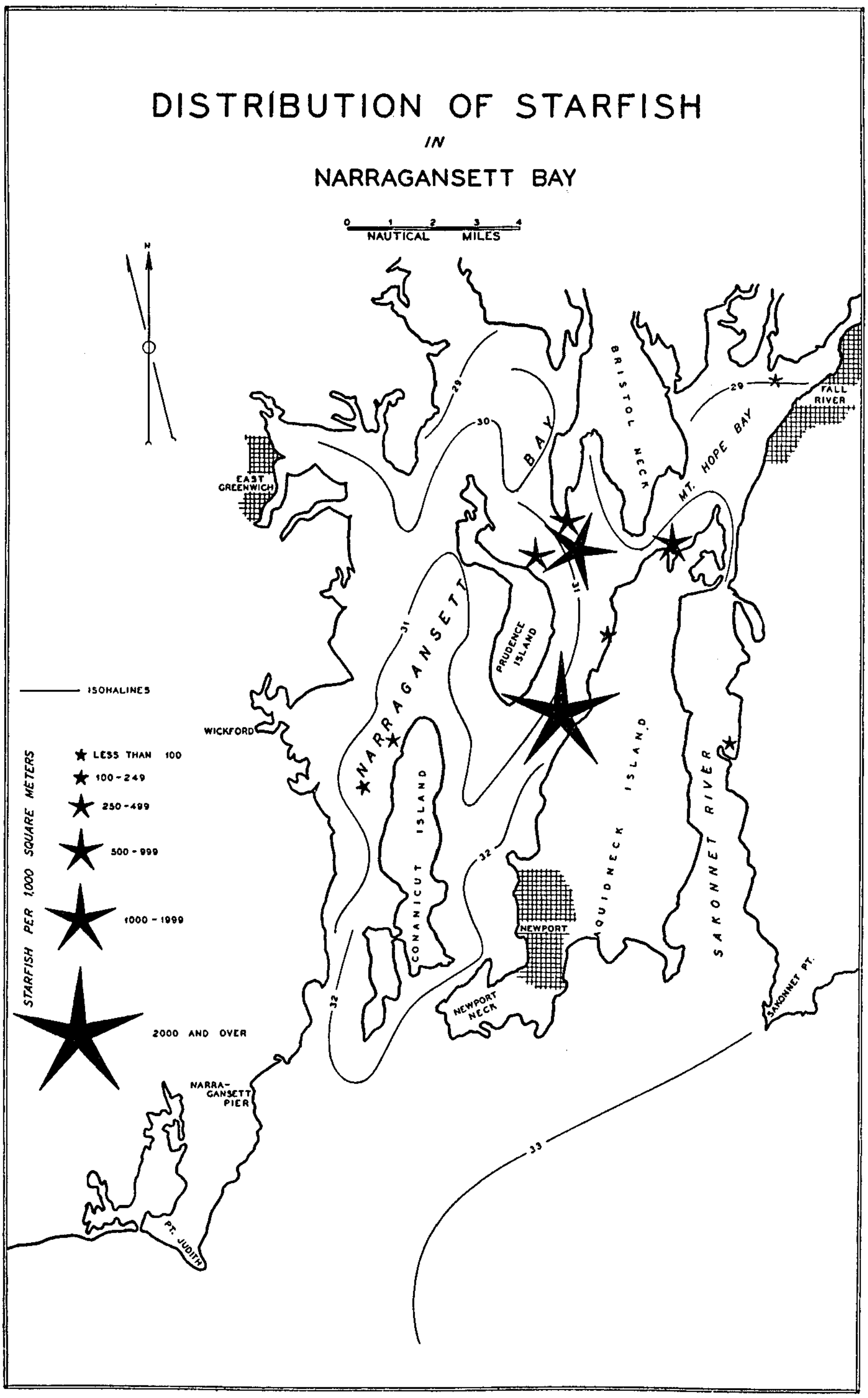

FIGURE 8.—Distribution of starfish in Narragansett Bay, Sept. 10-Oct. 25, 1935. The number of starfish per 1,000 sq. meters is indicated by black stars of various sizes. Distribution of salinity is shown by isohalines (solid lines).

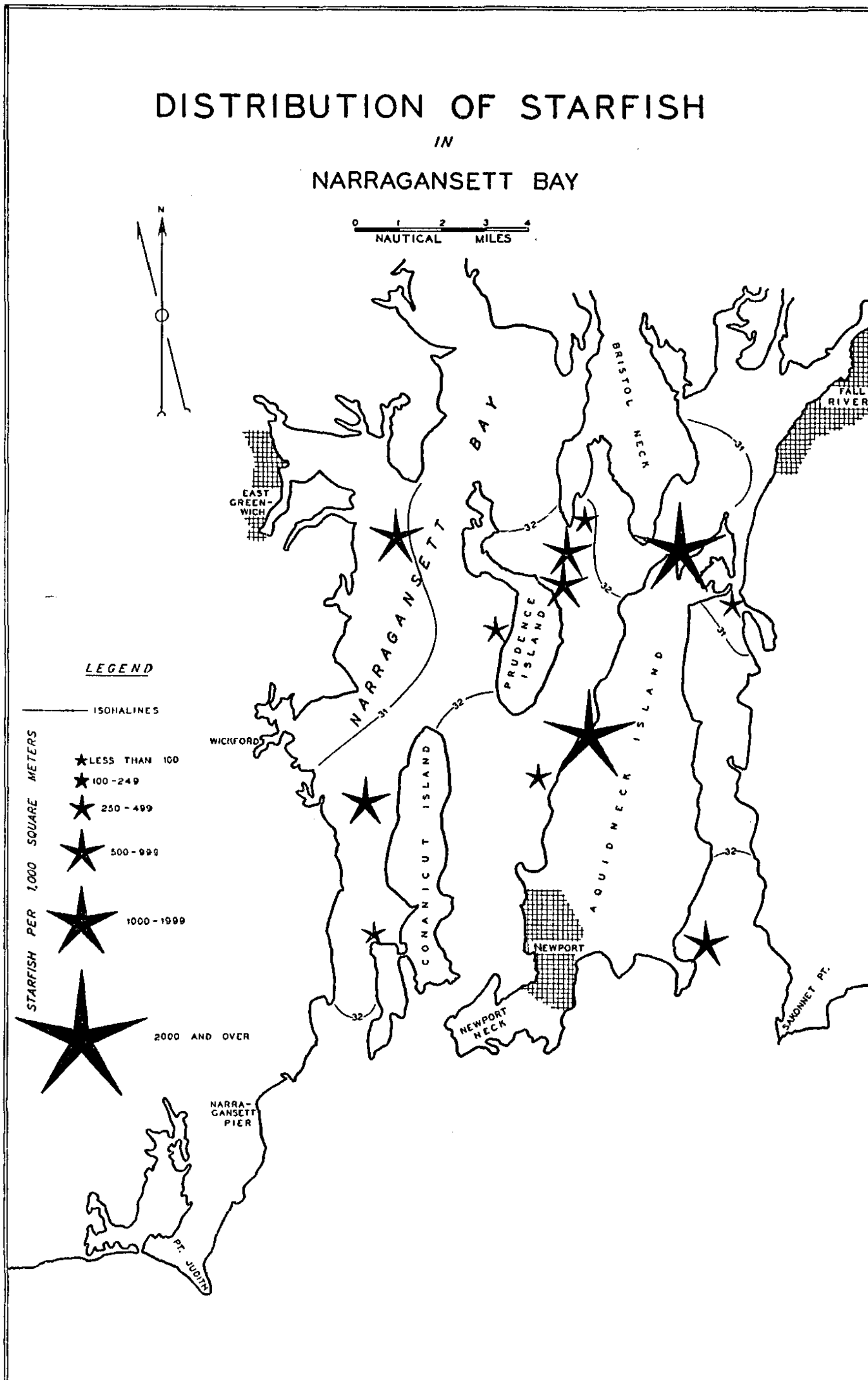

FIGURE 9.—Distribution of starfish in Narragansett Bay, Nov.-Dec. 1935. Legends same as those in Fig. 8.

DISTRIBUTION OF STARFISH IN LONG ISLAND SOUND

Three surveys were made in Long Island Sound in 1935. The first extended from May 20 to June 21, a period when the water temperature is rapidly increasing and starfish are approaching the spawning condition; the second lasted from August 27 to September 18, when spawning activities of the animals were already completed; and the third, begun on November 19 and ending December 19, recorded the winter conditions. Altogether, 143 stations were visited during the surveys (fig. 10).

The distribution of starfish and their relative abundance in different areas of the Sound, as determined on each survey, are shown in figures 11, 12, and 13 and are summarized in table 8. The location of sampling stations is indicated in figure 10. While a few discrepancies may be noticed, in general the distribution of starfish in the summer and fall is very similar. The third survey, although an abbreviated one, does not indicate any significant changes during the winter. All surveys show that starfish are concentrated in comparatively shallow water near the shore of the western part of the Sound, especially along the Long Island Sound side. The eastern part of the Sound is only sparsely populated.

There were 2,735 starfish caught on the first survey, as compared with 2,051 on the second (table 8). The greater number of starfish obtained during the first survey was due to a single large catch at station 40. There is no other evidence that the starfish of Long Island Sound in May–June were more abundant than in August–September. During the third survey the number of starfish per station showed a considerable decrease. No explanation for this can be advanced unless it is assumed that a heavy mortality occurred during the time elapsing between the second and third surveys. There is, however, no evidence to substantiate this assumption.

TABLE 8.—*Stations at which starfish were found on the first, second, and third surveys. Stations not visited are marked (—). Depth as determined on second survey*

Station No.	Depth in feet	Number of survey			Station No.	Depth in feet	Number of survey			Station No.	Depth in feet	Number of survey		
		1	2	3			1	2	3			1	2	3
1	8	146	118	2	36	11	14	16	3	69	44	14	33	(—)
1*a*	48	(—)	19	(—)	37	17	121	382	40	70	62	1	0	(—)
1*b*	52	(—)	30	(—)	38	24	159	308	(—)	77	54	7	1	0
2	10	66	0	1	39	28	147	95	(—)	78	56	1	0	15
3	24	17	39	7	40	18	1,015	196	(—)	80	40	39	4	0
4	22	0	14	6	41	18	136	3	11	81	30	15	2	(—)
5	10	72	128	(—)	42	31	0	14	(—)	82	51	10	0	(—)
6	42	28	1	(—)	43	30	82	89	72	83	47	6	5	(—)
7	17	17	1	9	45	24	11	13	(—)	84	46	17	0	(—)
8	24	11	84	(—)	46	20	0	27	5	87	102	0	1	(—)
9	20	13	3	(—)	48	20	5	44	1	91	134	2	0	(—)
10	22	14	38	(—)	49	19	6	66	(—)	92	96	2	4	1
11	8	1	6	0	50	19	48	10	0	93	72	7	5	(—)
12	10	1	1	(—)	51	27	0	1	(—)	94	235	8	0	(—)
13	17	69	0	(—)	52	28	0	11	(—)	96	149	0	1	2
14	11	11	25	27	53	18	1	0	(—)	98	104	1	8	(—)
15	21	14	0	18	54	20	2	19	(—)	99	53	0	0	2
16	21	3	0	(—)	56	27	5	3	(—)	106	88	2	0	(—)
17	15	5	0	(—)	57	27	4	1	(—)	110	66	0	0	1
18	24	61	1	0	59	23	1	0	4	112	66	5	6	(—)
20	17	50	11	(—)	60	29	7	11	(—)	113	100	0	0	2
21	12	2	0	(—)	61	32	6	5	(—)	128	72	1	0	(—)
23	23	10	0	(—)	62	38	0	0	21	129	75	6	0	(—)
31	18	0	0	2	63	46	13	28	(—)	131	68	6	0	3
32	19	1	1	(—)	65	73	0	2	0	135	89	1	0	(—)
33	54	19	4	(—)	66	35	60	3	4	37*a*	14	1	0	(—)
34	29	0	1	0	67	54	6	91	2	38*a*	14	95	9	(—)
35	22	1	9	7	68	78	5	0	9	41*b*	16	2	0	(—)
Grand total												2,735	2,051	277

Only one species of starfish, *Asterias forbesi,* is numerous enough in the Sound to be a menace to the oyster industry (table 9). Two other species, *A. vulgaris* and *Henricia sanguinolenta*, constitute less than 1 percent of the total starfish population.

They are found largely in the eastern part of the Sound, far from the cultivated oyster beds. At present the last two species cannot be regarded as endangering oyster beds of Long Island Sound. The fourth species, *A. tenera*, reported from Long Island Sound by Coe (1912), was not encountered in our survey.

The northern starfish (*Asterias vulgaris*) is said to occur as far west as the Falkner and Thimble Islands, 27 miles farther west than our station 94 (fig. 10), where 7 specimens of this species were collected at a depth of 235 feet. Two more specimens were found near Fishers Island (station 66) at a depth of 27 feet. All these findings were made during the summer and not a single one was found in September or in November–December.

TABLE 9.—*Number of starfish of different species as recorded on each of 3 surveys, 1935*

Species	First survey	Second survey	Third survey	Total
Asterias forbesi	2,711	2,050	276	5,037
Asterias vulgaris	9			9
Henricia sanguinolenta	15	1	1	17
Total	2,735	2,051	277	5,063

DISTRIBUTION IN RELATION TO DEPTH

In analyzing the distribution of starfish in relation to depth, all stations were grouped into eight depth classes. The first five classes were arranged at 20-foot intervals, and the last three, because of the scarcity of starfish at depths exceeding 100 feet, at 50-foot intervals. Since it was not always possible to return to the exact spot visited on the previous survey, the same station may be included in different depth classes shown in table 10. Often, if the bottom was steep, the soundings on two consecutive surveys may have been taken within a very short distance of each other and yet show quite a difference in depth. Nevertheless, the same number of stations in each depth class were visited during the first and second surveys.

On the first survey starfish were caught at all depths from low-water mark to 250 feet, but on the last two none were recorded at a depth greater than 149 feet. In all surveys, by far the majority of starfish were found in water less than 40 feet deep (table 10). In a depth of 40–59 feet the number of starfish decreased, and in still deeper water dropped to negligible quantities. In May and June the greatest density of starfish was found at a depth of 20–39 feet, whereas in September the majority of starfish was confined between mean low-water mark and 19 feet. On the third survey the largest number of starfish was also recorded in water less than 40 feet deep.

TABLE 10.—*Distribution of starfish in Long Island Sound according to depth, 1935*

Depth range (feet)	Number of stations			Number of starfish			Average number of starfish per station			Average number per 100 square meters of bottom			Percent of total number of starfish in each depth class		
	Survey			Survey			Survey			Survey			Survey		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
0–19	31	31	10	728	973	107	23.5	31.4	10.7	14.3	19.1	6.5	26.6	47.5	38.7
20–39	31	37	13	1,633	835	112	52.7	22.6	8.6	32.1	13.8	5.2	59.8	40.7	40.4
40–59	17	16	5	206	216	36	17.4	13.5	7.2	10.6	8.2	4.4	10.8	10.5	13.0
60–79	23	20	7	55	13	17	2.4	.7	2.4	1.5	.4	1.5	2.0	.6	6.1
80–99	16	18	1	3	4	0	.2	.2	0	.1	.1	0	.1	.2	0
100–149	17	16	7	12	10	5	.7	.6	.7	.4	.4	.4	.4	.5	1.8
150–199	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0
200–249	1	1	0	8	0	0	8.0	0	0	4.9	0	0	.3	0	0
Total	139	141	43	2,735	2,051	277	19.7	14.5	6.4	12.0	8.8	3.9	100.0	100.0	100.0

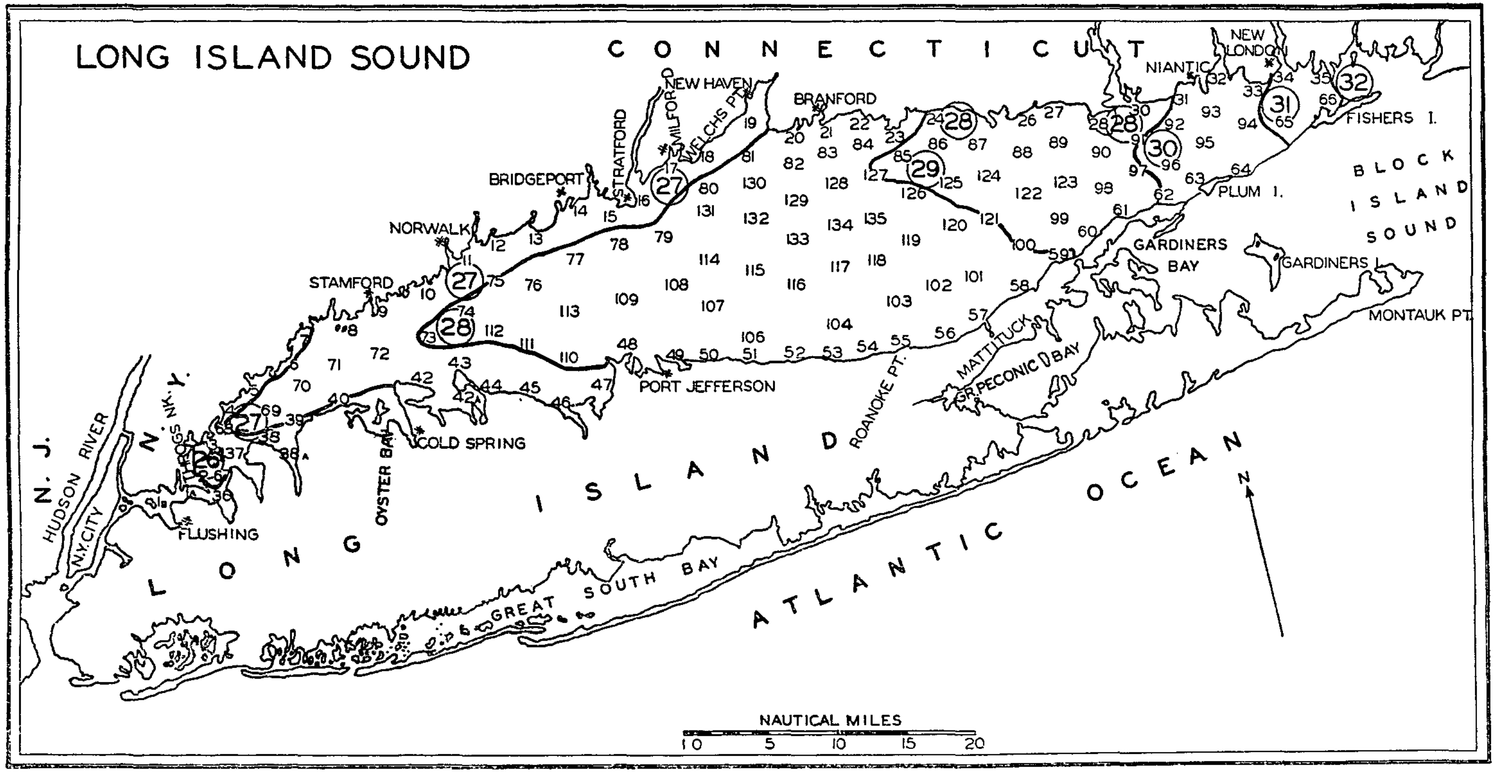

FIGURE 10.—Locations of stations visited on three surveys of Long Island Sound, and distribution of bottom salinity in the Sound in August and September, 1935. Location of stations is shown by plain figures. Isohalines are shown by solid lines and their values are indicated by encircled figures.

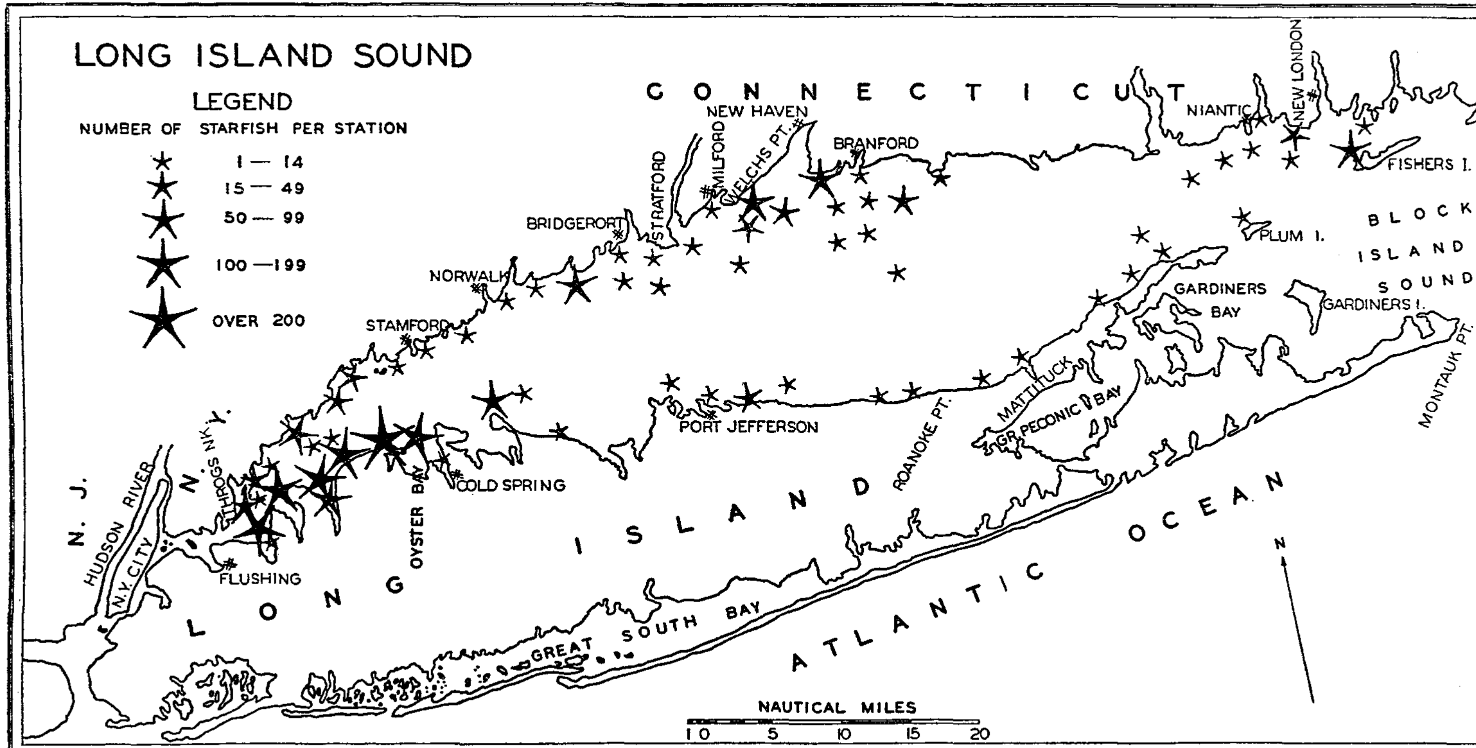

FIGURE 11.—Distribution of starfish in Long Island Sound as determined by the first survey, May 20–June 21, 1935.

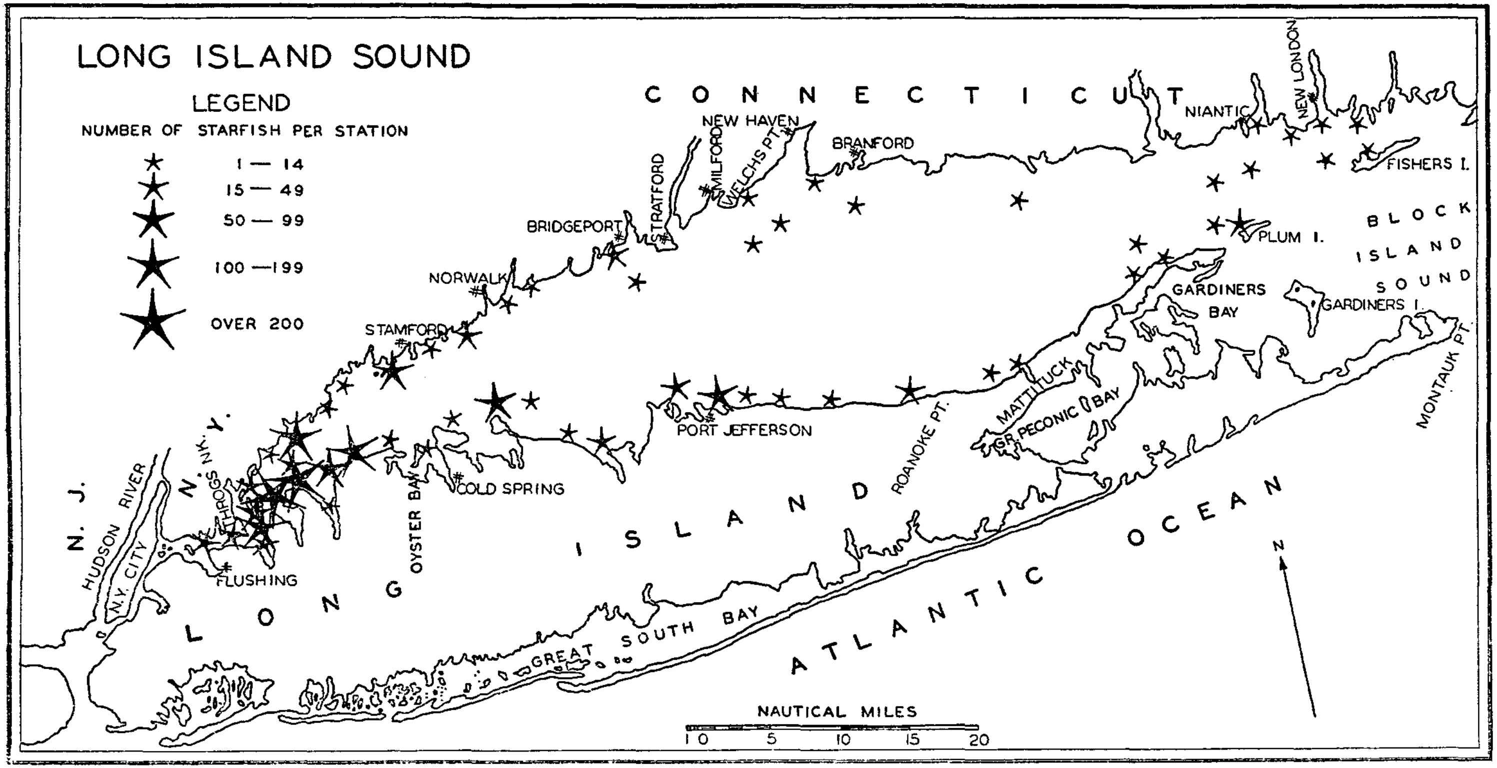

FIGURE 12.—Distribution of starfish in Long Island Sound as determined by the second survey, Aug. 27–Sept. 18, 1935.

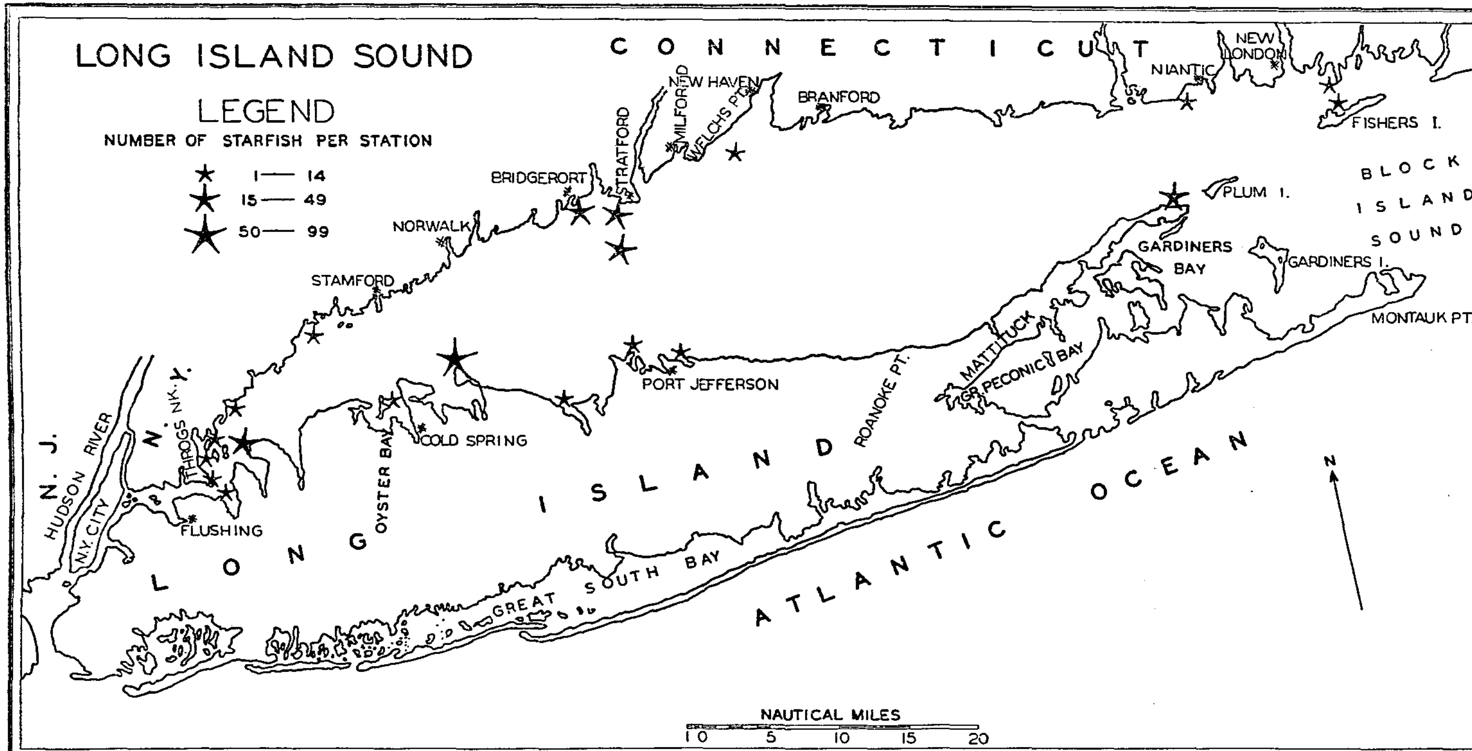

FIGURE 13.—Distribution of starfish in Long Island Sound as determined by the third survey, Nov. 19–Dec. 18, 1935.

The density of the starfish population sharply decreases with the increase in depths over 40 feet (fig. 14). The apparent discrepancy noticeable in the last depth-class is due to the finding of several specimens of *Asterias vulgaris* counted together with *A. forbesi.* The latter species was never found at depths below 149 feet. The first two surveys agree in the respect that more than 85 percent of all starfish were collected at depths of less than 40 feet (table 10) and less than 3 percent were found below 60 feet. The data obtained by the third survey, although giving slightly different numerical values, do not indicate any material changes in the distribution of starfish.

As can be seen by records of dredging, the scarcity of starfish collected from deep water is not due to the small number of observations at the greater depths. Seventy-nine stations of the first survey were located at depths between 0 and 59 feet, and the depths of the other 60 stations ranged from 60 to 249 feet. Starfish were

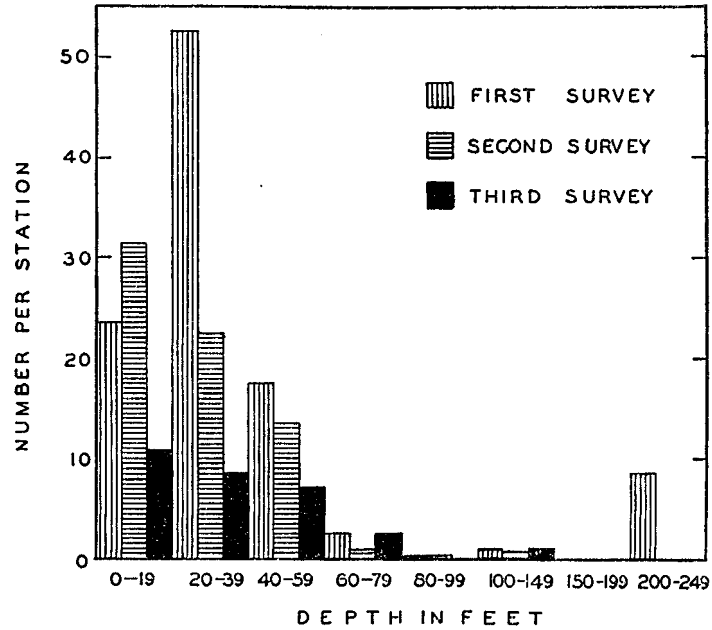

FIGURE 14.—Distribution of starfish according to depth. Average number of starfish per station in each depth-class, as determined on each of three surveys.

found at only 68 of the 139 stations on the first survey and at 58 of the 141 visited on the second. Areas free of starfish were usually confined to the middle (deeper) part of the Sound. Of the 43 stations visited on the third survey, starfish were found at 27 stations (fig. 13).

Regardless of slight changes in the distribution recorded by the three surveys, the majority of the starfish remained throughout the period of investigation in approximately the same areas of the Sound (fig. 15). There was no marked change in the starfish distribution and apparently no seasonal migration from shallow to deep water, or vice versa, took place during this time (figs. 11, 12, and 13).

Starfish tend to gather where large numbers of mollusks or shells are found and are rarely found on bottoms devoid of them. This becomes evident by comparing the distribution of shellfish, or their shells (fig. 16), with the general distribution of starfish in Long Island Sound (fig. 15). As one can notice, both areas almost coincide. During the three surveys, 4,998, or approximately 99 percent of starfish, were collected at stations where shells were present, as compared with only 65 starfish found at stations located on other types of bottom.

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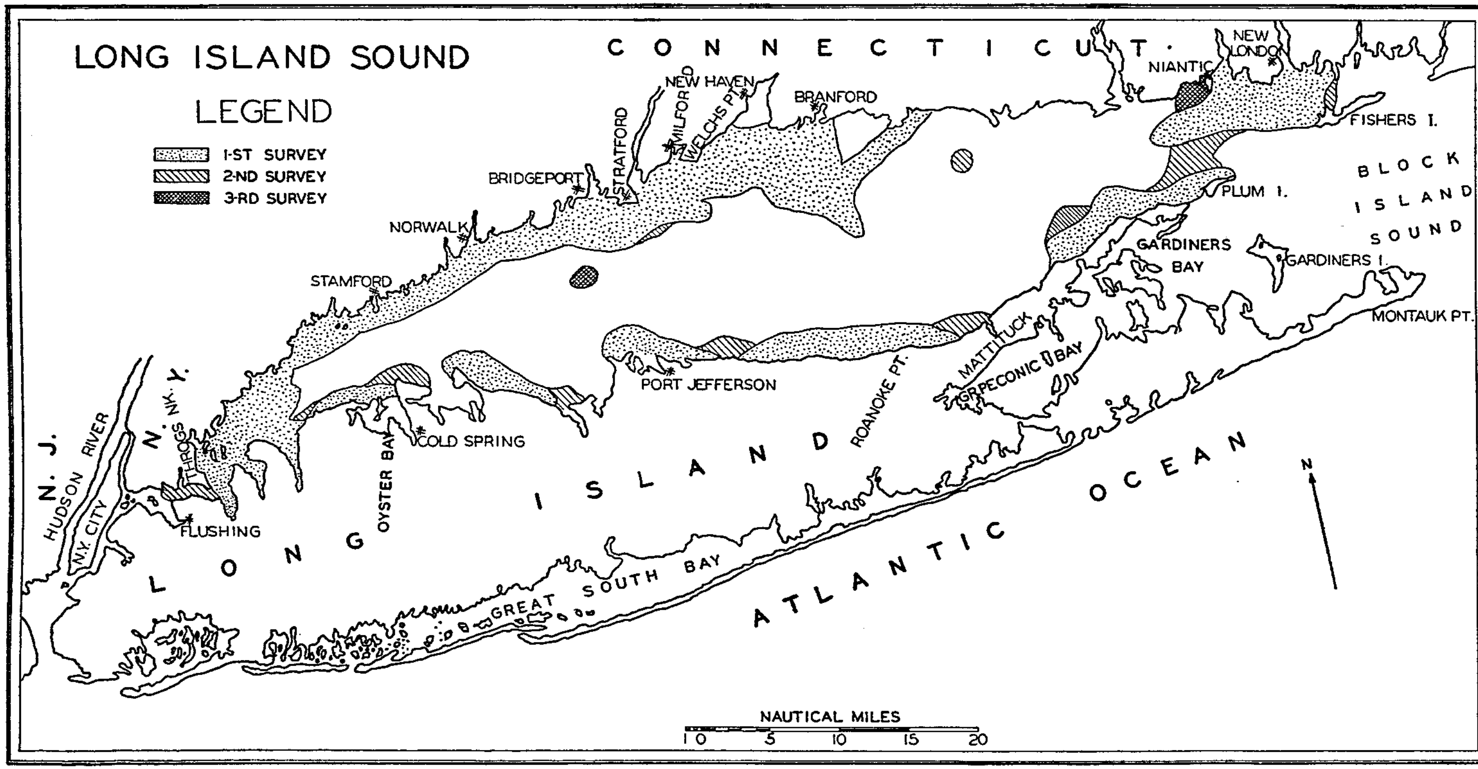

Figure 15.—Areas of Long Island Sound found on the first survey to be inhabited by starfish, with additional areas discovered on the second and third surveys.

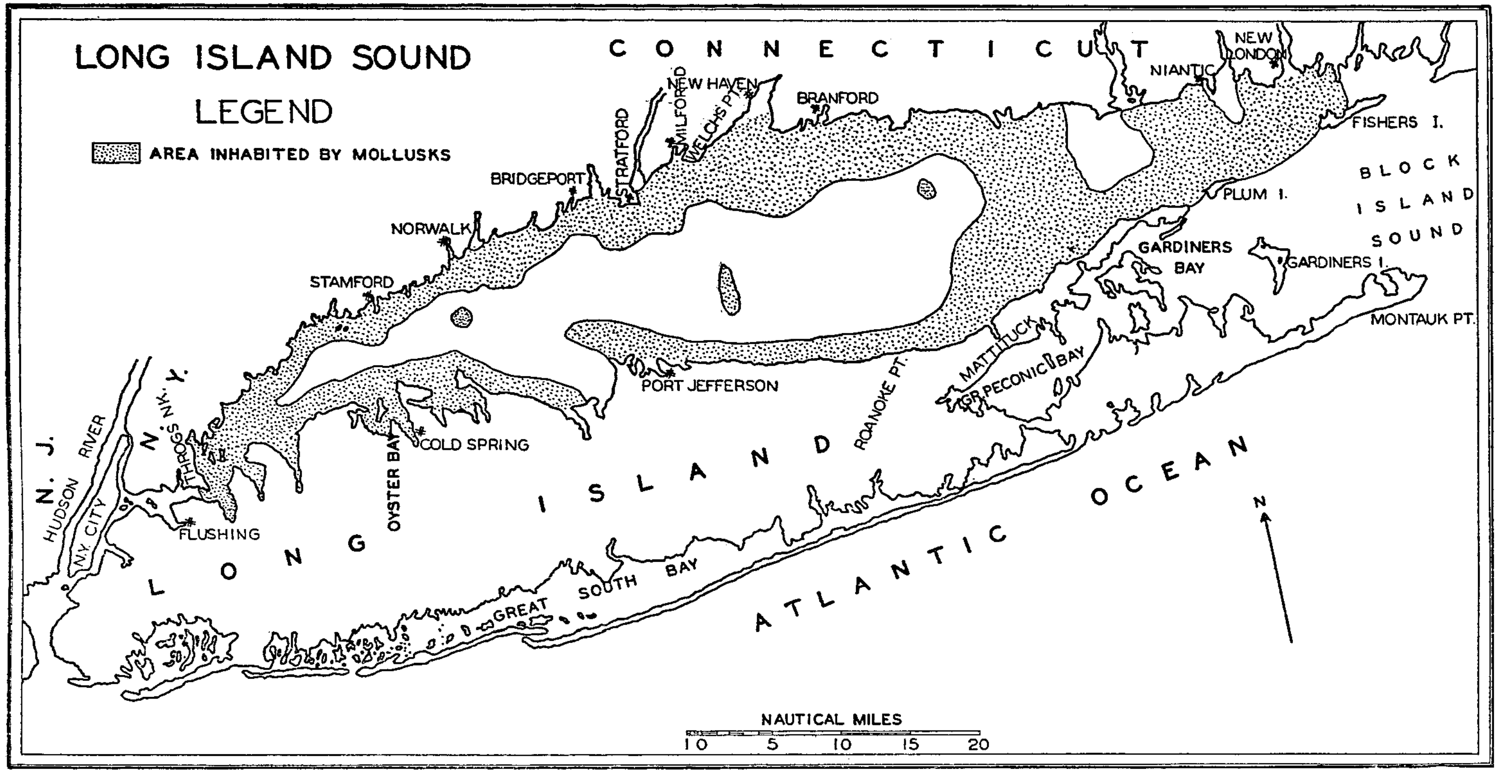

FIGURE 16.—Distribution of mollusks, or their shells, on the bottom of Long Island Sound, as determined by three surveys.

Although a quantitative estimate could not be made, it was readily noticed that shells and mollusks were scarce or less abundant in the eastern part as compared with the western part of the Sound. The scarcity of mollusks and shells was also evident in the middle of the Sound, which was virtually devoid of starfish. Thus the correlation between the distribution of starfish and the character of the bottom appears to be well established (Loosanoff, 1936).

DISTRIBUTION IN RELATION TO TEMPERATURE

Because the completion of a survey required about 1 month, the temperature of the water in the Sound underwent quite a change between the beginning and end of each survey. Thus, for example, the lowest temperature recorded during the last few days of the first survey, May–June, was higher than the highest temperature at the beginning of the survey. If an average temperature for all stations visited on the same day is calculated and compared with the temperature obtained on other days, the gradual but nevertheless rapid change in water temperature during each survey is quite evident. Table 11 gives such average temperatures for all stations visited on the same day. It shows that the water temperature at the beginning and end of each survey varied by several degrees. Therefore, it is difficult to make a comparison of temperature conditions existing at the same time at all stations. It may be stated, however, that the difference in bottom temperatures of shallow and deep stations visited on the same day seldom exceeded 2.0° C. At certain seasons this difference was even smaller. This is shown in table 12 which gives the bottom water temperatures recorded on the same day at stations 25, 87, 124, 121, 101, and 57 which extended across the Sound in an almost direct line from one shore to the other (fig. 10).

TABLE 11.—*Average temperature for all the stations visited*

Survey	Date	Temperature ° C.	Date	Temperature ° C.	Date	Temperature ° C.
First	May 20	8.3	June 5	11.5	June 13	12.2
Do	May 21	9.9	June 6	13.5	June 17	14.2
Do	May 22	9.1	June 7	13.0	June 18	14.4
Do	May 23	9.5	June 10	14.5	June 19	13.9
Do	May 24	9.6	June 11	14.0	June 20	13.6
Do	May 29	9.8	June 12	14.8	June 21	13.7
Second	Aug. 27	21.2	Sept. 3	20.9	Sept. 11	19.3
Do	Aug. 28	22.1	Sept. 5	20.8	Sept. 12	20.4
Do	Aug. 29	21.4	Sept. 9	18.8	Sept. 13	19.4
Do	Aug. 30	20.0	Sept. 10	18.8	Sept. 17	19.8
					Sept. 18	19.7
Third	Nov. 19	10.8	Dec. 4	9.3	Dec. 16	6.7
Do	Nov. 21	10.7	Dec. 6	8.2	Dec. 18	5.8
			Dec. 7	7.2		

TABLE 12.—*Bottom water temperature and salinity recorded at the stations extending across Long Island Sound*

[Date of first survey, June 18; second survey, Sept. 11; third survey, Dec. 18, 1935]

Station No.	Depth in feet	Temperature, °C		Salinity		Third survey			
		Survey		Survey					
		1	2	1	2	Station No.	Depth in feet	Temperature, ° C.	Salinity
				Parts per mille	*Parts per mille*				*Parts per mille*
25	22	14.4	19.6	28.42	28.43	15	16	5.4	28.35
87	75	14.1	19.3	---------	29.34	77	47	6.0	28.64
124	75	14.4	19.5	---------	28.93	113	107	6.8	28.84
121	70	14.3	19.7	29.07	28.93	110	71	6.2	28.53
101	66	14.2	20.1	28.80	28.96	46	23	5.4	28.42
57	45	14.6	21.5	27.65	28.10				

Since the general distribution of starfish throughout the period of observation remained virtually the same, one may conclude that the seasonal warming or cooling of the water of shallow areas fails to influence the migration. Therefore, Verrill's assumption (1914) that each fall starfish migrate and remain in the regions of the Sound where the water is warmer is not sustained by present observations.

DISTRIBUTION IN RELATION TO SALINITY

A general idea of the distribution of salinity at the bottom of Long Island Sound may be obtained from fig. 10, which represents the results of observations made in August–September 1935.

The concentration of salt in the water gradually increases from 26 parts per mille at the western end to 32 parts per mille at the eastern extremity of the Sound. It is somewhat lower at the mouths of the rivers. In May–June 1935, the salinity ranged

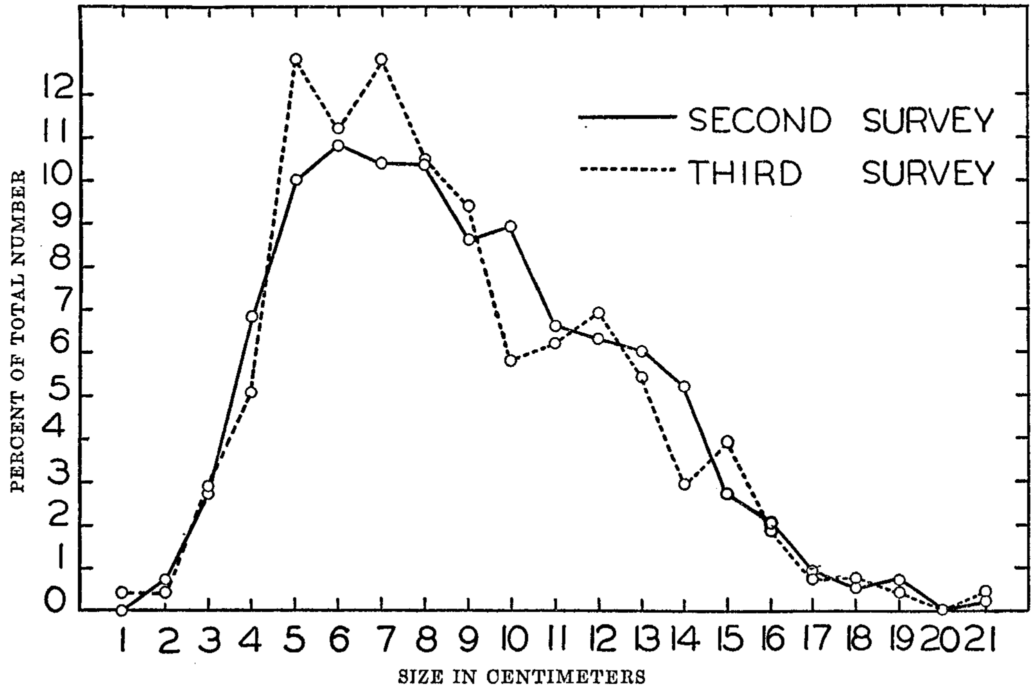

FIGURE 17.—Percent of starfish of different sizes among the animals caught on thes econd and third surveys on Long Island Sound.

from 25 to 30 parts per mille, with at least two-thirds of the Sound having a salinity between 26 and 27. In general, the salinity of the water of Long Island Sound was lowest in the spring, increased in the summer, and reached its maximum in late fall. Seasonal variations at each given point in the Sound were rather small, ranging from about 1 to 2 parts per mille during the year's cycle.

The salinity of the water in the middle of the Sound was usually slightly greater than inshore. This is illustrated in table 12, which shows the difference of bottom salinity as recorded at stations located approximately 3 miles apart extending across Long Island Sound. The difference along the hydrographic profile seldom exceeded 1 part per mille. Present observations show that within the range observed in Long Island Sound starfish distribution is not controlled by salinity.

SIZE OF STARFISH

All starfish caught during the first survey were roughly classified into three size groups: Large animals, over 12.5 cm. in diameter; medium-sized, ranging from 5.0 to 12.4 cm.; and small, less than 5.0 cm. in diameter. All animals collected during the second and third surveys were measured between the tips of the two longest rays. Small starfish, less than 1.5 cm., were not included in the table, for only very few of them were collected by dredging. The results shown in fig. 17 indicate that starfish of 5.0 to 8.0 cm. in diameter were predominant. The percentage of the three size groups of starfish caught during each survey is given in table 13.

TABLE 13.—*Percent of starfish in each of the 3 size groups*

Size group	Survey		
	1	2	3
	Percent	*Percent*	*Percent*
Large, 12.5 cm. and over	12.3	11.4	10.9
Medium, 5.0 to 12.4 cm.	70.9	68.9	68.1
Small, less than 5.0 cm.	16.8	19.7	21.0

DISTRIBUTION OF STARFISH IN CHESAPEAKE BAY

A survey of the distribution of starfish in the lower Chesapeake Bay was conducted by Loosanoff and Engle in March 1937. Observations were made at 46 stations, the locations of which are shown in figure 18. Starfish were found to be confined south of a line extending across the bay from a point 4 miles below New Point Comfort (Hampton Roads) on the Western Shore, to the city of Cape Charles on the Eastern Shore. Their distribution was not uniform (fig. 19). A very dense population was encountered near York Spit Light (stations 17A and 18) and northeast of Back River (station 22). Other areas of heavy infestation were at and near stations 25, 26, 30, and 40. Scattered specimens were found in many other places in the southern part of the bay. Stations 1 to 10, at the mouth of York River and Mobjack Bay, as well as stations 11 to 17, located along the Western Shore of the bay north of New Point Comfort, were free of starfish.

TABLE 14.—*Depth, bottom temperature, salinity, and number of starfish found at each station in lower Chesapeake Bay, March 19–26, 1937*

Station No.	Depth in feet	Bottom temperature °C.	Salinity, parts per mille	Number of starfish	Station No.	Depth in feet	Bottom temperature °C.	Salinity, parts per mille	Number of starfish
1	38	5.4	17.65	0	22	26	6.1	26.42	121
2	13	5.5	17.56	0	23	18	7.2	18.68	0
3	15	5.6	18.55	0	24	21	7.4	18.50	0
4	20	5.6	18.35	0	25	16	7.4	18.95	66
5	17	5.5	16.89	0	26	17	7.3	18.69	81
6	26	5.6	16.85	0	27	17	7.8	19.22	1
7	15	5.7	16.92	0	28	36	7.2	19.79	0
8	19	5.6	16.92	0	29	25	7.4	19.76	0
9	33	5.4	19.38	0	30	22	6.6	25.14	81
10	25	5.2	--------	0	31	19	6.4	27.16	5
11	30	5.9	16.46	0	32	32	6.7	28.03	10
12	28	6.3	16.22	0	33	37	6.6	27.83	13
13	25	6.1	18.66	0	34	32	6.6	25.01	11
14	27	6.1	18.44	0	35	18	7.0	23.96	6
15	29	6.1	17.86	0	36	21	7.2	26.49	17
16	17	6.7	17.12	0	37	16	7.9	27.83	7
17	30	6.3	19.61	0	38	17	8.0	29.22	0
17A	32	6.3	19.05	86	30	27	8.1	28.31	5
18	25	6.2	19.11	136	40	14	7.9	22.65	58
18A	30	6.1	20.53	16	41	73	7.9	26.40	24
19	15	6.4	19.13	0	42	37	7.0	24.04	1
20	35	6.1	18.37	8	43	35	6.7	23.82	0
21	20	6.8	18.86	0	44	30	6.9	24.51	18

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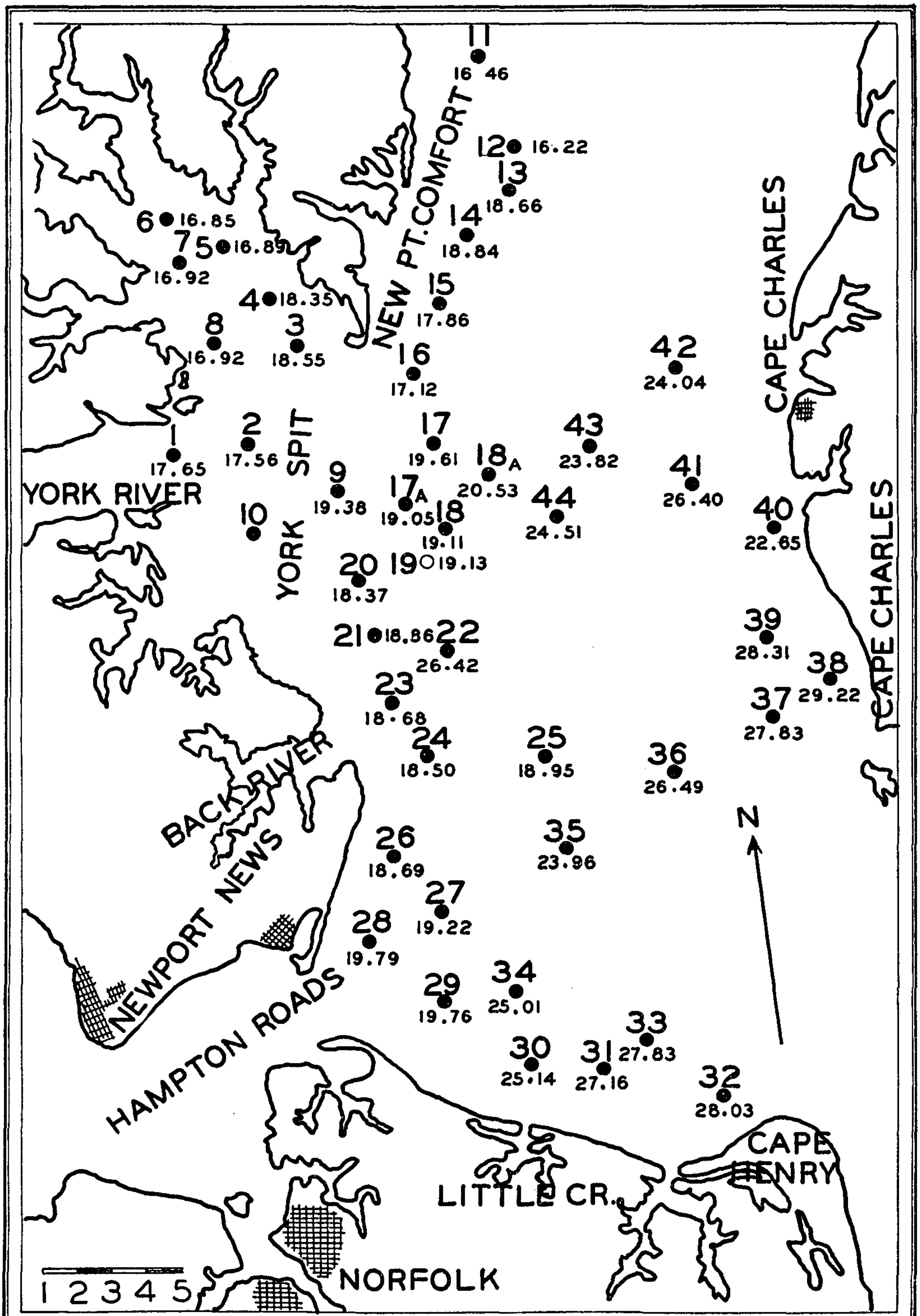

FIGURE 18.—Location of stations visited during the survey of Chesapeake Bay, and bottom-water salinity at each station. Large figures indicate station number and small figures indicate salinity. March 1937.

During the time of the survey, starfish at stations 17A, 18, and 22 were so abundant that the dredges were filled to their capacity after several feet of dredging. The taking of a quantitative sample was therefore impossible. An idea of the great abundance in this locality was obtained by examining the dredge contents of crabbing boats working in that area. According to captains of the boats, each vessel caught as many as 750 to 1,000 bushels of starfish daily (fig. 21). Each time the dredges were lowered to the bottom they came up, after 2 or 3 minutes of dredging, filled with starfish.

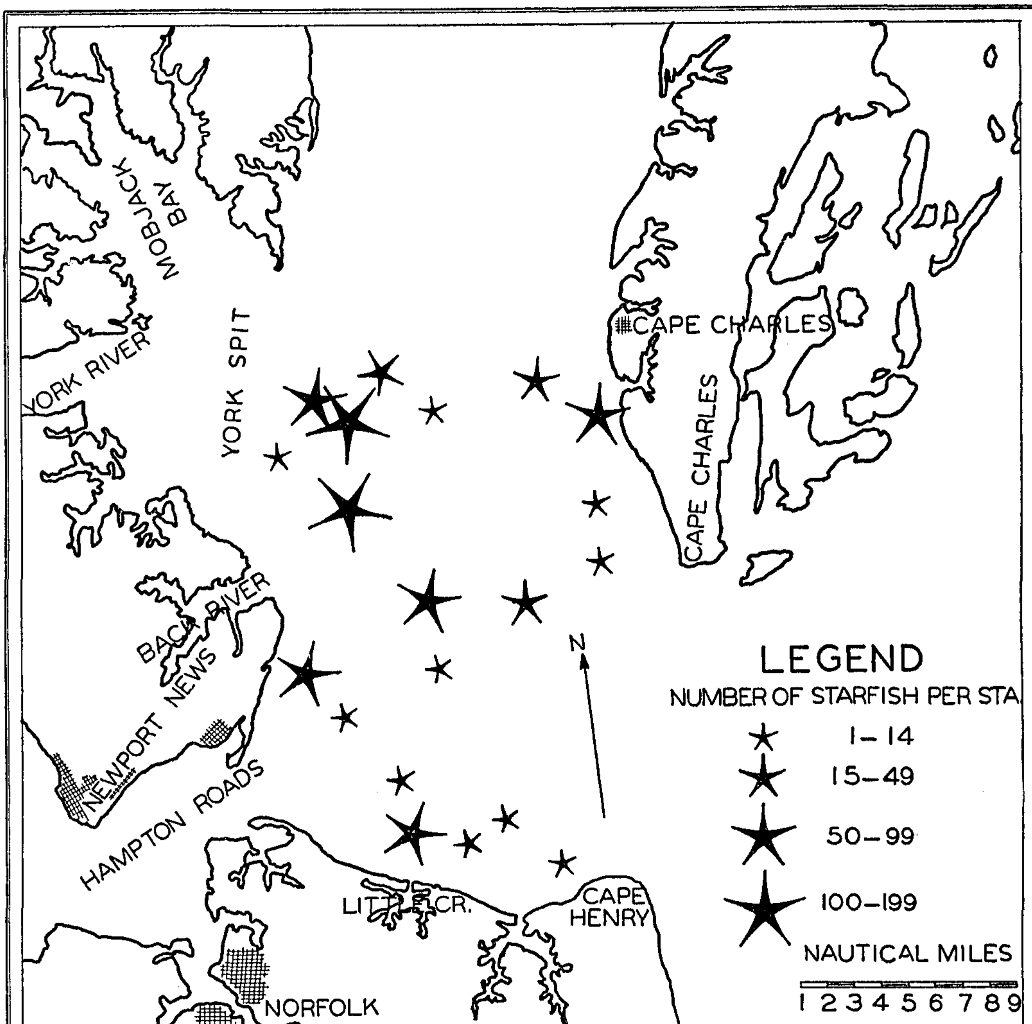

FIGURE 19.—Distribution of starfish in Chesapeake Bay in March 1937.

Studies of the bottom samples showed that the distribution of starfish in the lower Chesapeake Bay was somewhat dependent upon the presence of food. As a rule, starfish were numerous in the areas where there was an abundance of small clams, *Mulinia lateralis*, and few were encountered on bottoms devoid of mollusks.

Starfish of the lower Chesapeake Bay were found living in water having a salinity ranging from 18.37 to 28.31 parts per mille (table 14). No definite correlation between salinity and distribution of starfish could be observed, although very large concentrations of starfish occurred in the area where the salinity was only about 19 parts per mille (stations 17A and 18). Equally large groups were noted at stations 22 and 30, where the salinity was 26.42 and 25.14 parts per mille, respectively.

During the spring of 1938 a large number of starfish were again noticed in the area from the York Spit Light to Wolf Trap and in the deeper waters below York Spit. Two starfish boats, working for a commercial concern manufacturing fertilizer, were handling from 400 to 500 bushels of starfish per boat per day during February. The salinity of the water tested at the last of ebb tide on February 2, 1938, at York Spit Light was 20.70 parts per mille, and the water temperature was 3.7° C. The next month no starfish were found by the Bureau's research boat in the vicinity of York Spit. Commercial fishing was still continued near Wolf Trap Light, but the catches were small and the fishermen planned to suspend operations within the next few days. On March 19, the salinity of the water in the area of York Spit Light, determined at the last of flood tide, was 18.73 parts per mille and the water temperature rose to 10° C.

The greatest catch in 1938 was 500 bushels of starfish per boat per day, as compared with 750 bushels in 1937. The average catch during the spring of 1938 was about 300 bushels per boat per day. As in the previous year, only a few starfish were found on oyster bottoms in the bay and its tributaries.

Laboratory experiments carried out at Milford show that starfish become sluggish, refuse to eat, and eventually die in a salinity between 16 and 18 parts per mille. Evidently their absence from the areas at the mouth of the York River, in Mobjack Bay, and north of New Point Comfort is due to unfavorable salinity which constitutes an effective natural protection of the valuable oyster bottoms in these waters.

As far as can be ascertained, oyster bottoms in the Chesapeake Bay are not attacked by starfish and no attempts are made, therefore, to control them in this body of water.

REPRODUCTION

The sexes of starfish are separate. Since externally all the animals look alike, their sex can be ascertained only by microscopic examination of the gonads.

According to observations on starfish kept in experimental tanks at the Milford Laboratory, young animals are able to breed when only 1 year old, provided the first year of life was spent under favorable environmental conditions. This conclusion is based upon the observation of growth and sexual development of several hundred starfish spat kept over a period of 1 year in aquaria and in outdoor tanks.

Food supply is a very important factor in the growth and sexual development, since, as will be shown later (p. 112), young individuals given small quantities of food failed to mature at the end of their first year.

The starfish are very prolific breeders, a mature female having in each of its rays paired sexual glands containing thousands of eggs. The number of eggs depends, of course, upon the size of the animal (Coe, 1912).

SPAWNING

In the process of spawning the starfish assumes a characteristic arched position with the center of its body elevated, only the tips of the rays touching the bottom. The sexual products are discharged from the paired genital openings at the base of each ray. If the water around the animal is quiet the eggs usually sink to the bottom. Since both sexes spawn simultaneously, fertilization takes place at once.

The number of gonads engaged in the spawning of a single individual may vary. Sometimes ovulation or ejaculation was noticed in only two of them while the other

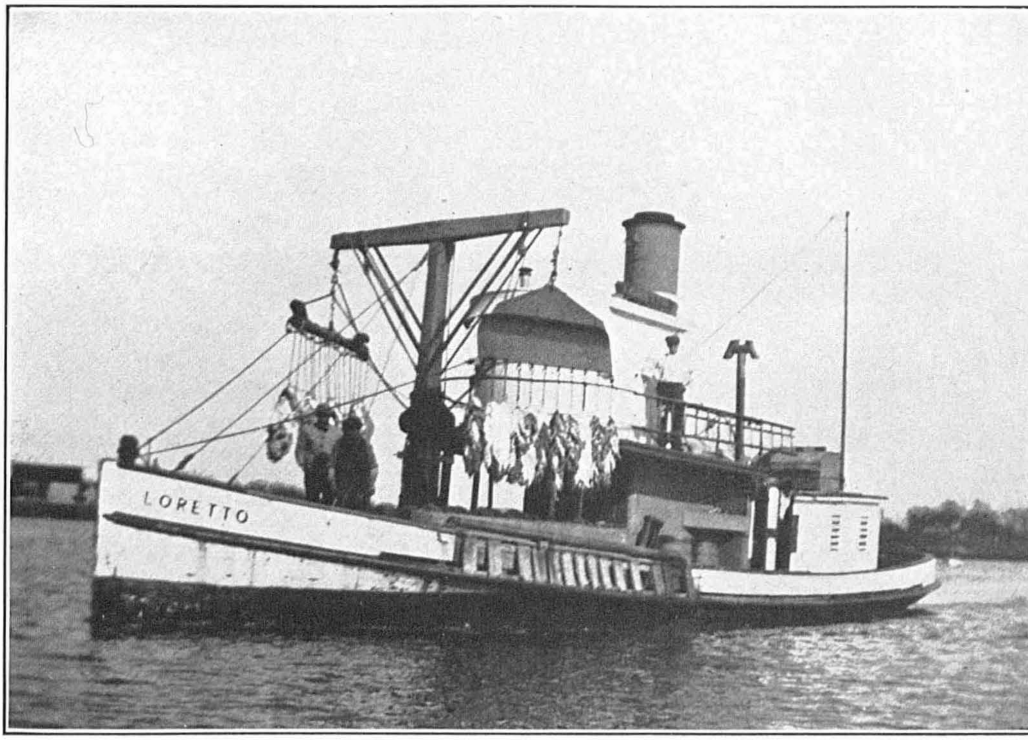

FIGURE 20—Typical starfish boat, operating in Long Island Sound, equipped with mops.

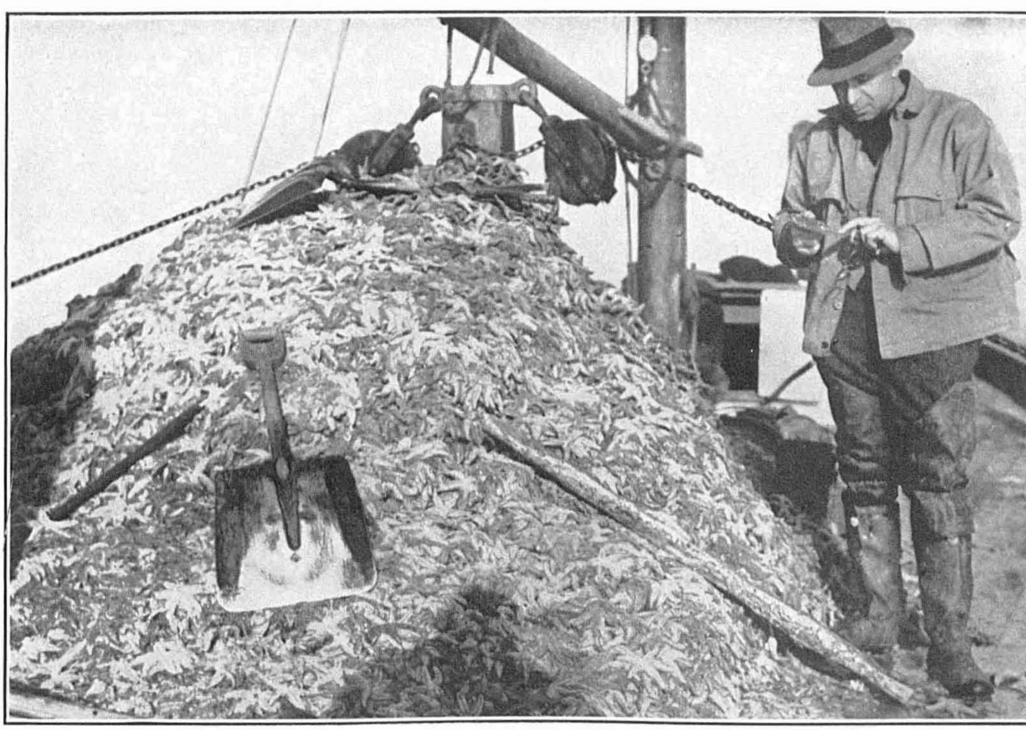

FIGURE 21.—Starfish caught in 4 hours by a boat crabbing in the vicinity of station 17-A.

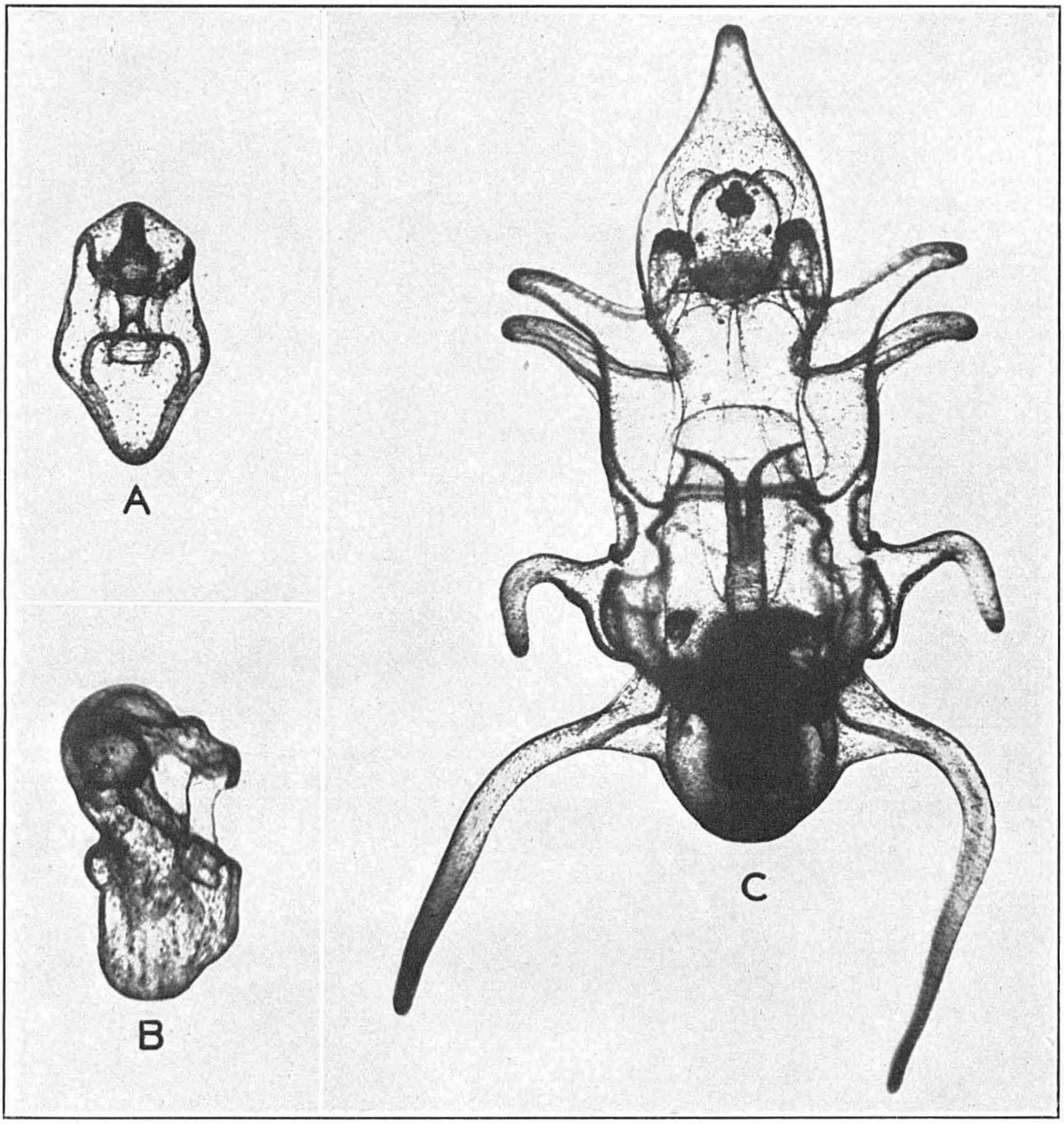

FIGURE 22.—Larvae of *Asterias forbesi* photographed alive, magnification × 120. *A*, Larva 24 hours after fertilization; *B*, bipinnaria, 3 days old; *C*, brachiolaria, 3 weeks old.

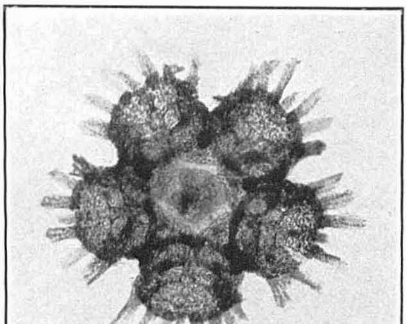

FIGURE 23.—Starfish, 1 day old, × 25.

three remained passive. Such partial spawning could be correlated with the unequal state of ripeness of gonads in different rays. That the same individual may spawn several times during the summer has been observed in two animals, male and female, which discharged spawn four times between June 2 and July 3, 1938.

Ripe animals can be induced to spawn by raising the temperature of the water to about 20° C. This has been established by laboratory experiments carried out early in the season and during the summer. On May 25, 1935, six starfish were brought from Long Island Sound, where the water temperature was 9.5° C., and placed in aquaria. After the temperature was gradually raised to 20.0° C., four animals spawned. As the season progressed, starfish were found to be even more responsive to this stimulus and easily spawned in the laboratory when placed in water 2 or 3 degrees warmer than that of the Sound. However, in almost every case, there were specimens which failed to respond even to a temperature of 25.0° C. That temperature is probably not the only factor influencing spawning is indicated by the results of the experiments performed at Milford during the summers of 1936 and 1937 when spawning was observed to take place at 15°–16° C.

Ripe starfish will spawn independently of the presence or absence of individuals of the same or opposite sexes. If the animal did not respond to temperature stimulation in a reasonable length of time, spawning could not be induced by other means. Attempts to induce spawning of such individuals by addition of sperm or eggs always failed.

Field observations conducted in Long Island Sound in 1936 and 1937 showed that starfish commenced to spawn in June, within a few days after the water temperature reached 15.0° C. The time of spawning was estimated by examining the state of the gonads, by determining the age of a few starfish larvae found in plankton samples, and by ascertaining the beginning of the setting period. Mead (1901), working on *Asterias forbesi* at Kickemuit River, R. I., observed that the height of the spawning period of starfish in that locality occurred between June 4 and 16 and was completed by the end of the month. Agassiz (1877), on the other hand, states that *A. forbesi* of northern waters spawns during the last part of July. In Long Island Sound, however, the spawning of starfish in 1936 and in 1937 continued from June until the end of August.

Soon after the completion of spawning gonads of starfish undergo the process of resorption, which is especially pronounced during late August and September. In October resorption is completed in most cases and development of new sex cells commences. The newly formed young gonads are at that time very small in size. During November and December the growth of gonads is very rapid, and by January to March many starfish possess gonads of full or nearly full size. However, the fullness of gonads does not indicate that sex cells are morphologically and physiologically mature, and winter and spring eggs are, as a rule, not capable of fertilization. The fully ripe condition develops during the early spring and summer.

SETTING OF LARVAE

Fertilized starfish eggs develop into free-swimming transparent larvae which float in the water. Three consecutive stages in their complex development are shown in fig. 22, representing photomicrographs taken with equal magnification from the live specimens reared in the Woods Hole laboratory. The larvae deprived of shell or any tough coverings are very delicate. Their food consists of minute algae and other microscopic forms found in plankton.

At the end of the free-swimming period, which lasts from 3 to 4 weeks, depending upon the temperature of the water and the abundance of food (Coe, 1912), the starfish larva undergoes metamorphosis and sets on some object at the bottom. The newly formed young starfish, orange-red in color, is about 1 mm. in diameter (fig. 22). Soon after setting it begins to feed upon various minute animals, such as very young snails, small clams, recently set oysters, and larvae of marine worms.

In the summer of 1937 systematic observations on the setting of larvae were carried out by Loosanoff in Long Island Sound. The method employed consisted in placing at different depths wire bag collectors filled with oystershells and examining them every third or fourth day. All bags were of the same dimensions and contained an equal number of shells of approximately equal size. They were placed off Stratford Point at depths of 0, 5, 10, 20, 30, 40, 50, and 70 feet at mean low water. Each time a bag was removed for examination another was set in its place. Recovered bags were brought to the laboratory in a moist condition, the shells were examined for newly set starfish, and the number of starfish on 20 shells taken at random from each bag was counted. Complete records of these observations calculated on the basis of 100 shells are given in table 15.

TABLE 15.—*Starfish set per 100 shells, semiweekly examinations at Stratford Point stations, July 2 to October 4, 1937*

	Station No. 1 (0 feet)	Station No. 2 (5 feet)	Station No. 3 (10 feet)	Station No. 4 (20 feet)	Station No. 5 (30 feet)	Station No. 6 (40 feet)	Station No. 7 (50 feet)	Station No. 8 (60 feet)	Station No. 9 (70 feet)	Total for all stations	Average per station
July 2	0	0	0	0	0	0	0	0	0	0	0
8	15	45	45	25	15	10	0	--------	--------	155	22.14
12	50	45	35	215	65	20	--------	0	0	430	53.75
15	15	35	45	90	45	40	30	20	0	320	35.55
19	10	5	65	35	0	5	15	0	10	145	16.11
22	120	75	80	45	15	35	5	0	0	375	41.66
26	200	295	465	125	60	--------	10	0	0	1,155	144.25
29	10	65	105	30	10	0	5	10	15	250	27.77
Aug. 2	10	55	95	40	10	5	10	5	20	250	27.77
5	255	275	355	375	50	140	20	10	20	1,500	166.66
9	80	190	145	--------	50	20	5	0	0	490	61.25
12	70	60	50	--------	70	65	10	0	0	325	40.63
16	10	30	45	20	0	0	0	0	0	105	11.66
19	10	30	45	25	15	15	5	0	0	145	16.11
23	20	25	80	115	65	100	135	20	0	570	63.33
26	0	10	30	85	55	215	45	75	45	560	6.22
30	5	--------	5	20	0	50	10	20	0	110	13.75
Sept. 2	5	5	5	10	5	70	0	0	0	100	11.11
7	0	0	15	30	5	--------	0	0	--------	50	7.15
9	0	0	0	0	--------	0	0	0	5	5	.63
14	0	0	0	0	--------	5	5	10	5	25	3.13
16	0	0	0	0	--------	0	5	5	0	10	1.25
20	0	0	0	0	0	0	5	5	5	15	1.66
23	0	0	0	0	0	0	10	0	5	15	1.66
27	0	0	0	0	0	0	0	--------	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0
Oct. 4	0	0	0	0	0	0	0	0	0	0	0
Total	885	1,245	1,710	1,285	545	795	330	180	130	7,105	--------

Setting of starfish occurred at all depths ranging from mean low water to 70 feet (fig. 24) continuing from about July 2 until September 23 (fig. 25). In shallow water, at a depth not exceeding 50 feet, the setting began and ended from 10 to 21 days earlier than at deeper stations. At three stations (0–10 feet) the heaviest setting occurred in the middle of the season. There were two distinct peaks, one around July 22 and the other around August 3. At stations 20 and 30 feet deep the intensity of setting was rather irregular, showing several peaks during the season. At deeper stations the peak of setting occurred toward the end of August. The starfish set at all depths from 0 to 70 feet, with the maximum at 10 feet (fig. 24).

At the beginning of the setting season the bottom-water temperatures ranged from 15.1° to 16.4° C. (table 10). The first set at 50 feet and below was recorded at the temperature of 15.6° C. Two heavy periods of setting recorded at shallow stations on and around July 22 and August 3 coincided with a sharp increase in water temperature. The heaviest setting at the three deepest stations also occurred when the water rose rapidly. However, a raise in temperature is not always followed by a

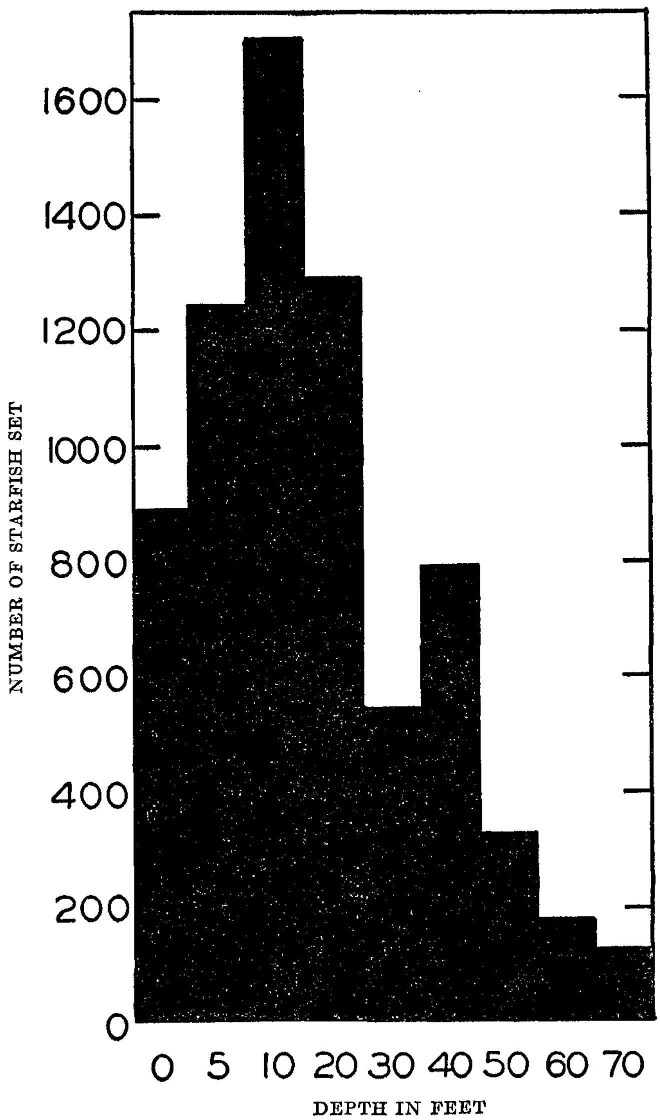

FIGURE 24.—Total number of starfish set per 100 shells at each of 9 stations established at different depths of Stratford Point area in 1937.

wave of heavy setting. Thus, for example, between July 12 and 15 the water temperature at deep-water station No. 8 rose from 15.9° to 19.9° C., but no setting occurred near that date.

The changes in water salinity in the areas of setting showed a slow increase throughout the summer (table 17). With the exception of two short periods on July 15 and August 12, when the sea water at shallow stations was diluted with large quantities of rain water brought down by the Housatonic River, the salinity at shallow and deep stations seldom differed from each other by more than 2 parts per mille. Evidently the small difference in the salinity cannot be regarded as an important factor responsible for the much heavier setting in shallow areas. No correlation between changes in salinity and intensity of setting could be found at either shallow- or deep-water stations.

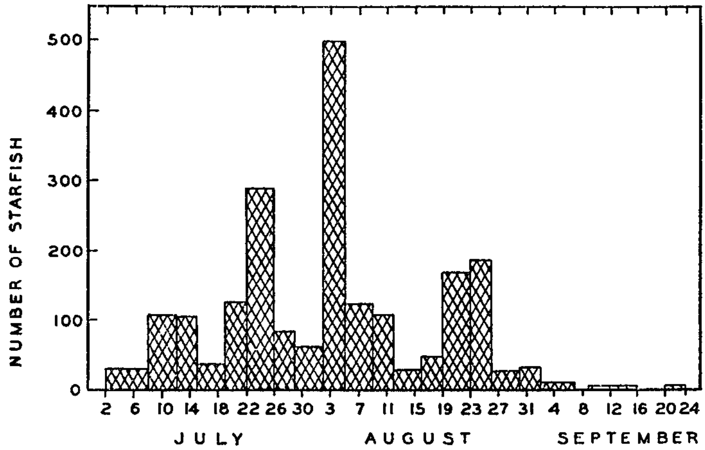

FIGURE 25.—Daily number of starfish set per 100 shells for all stations of Stratford Point area. July 2–Sept. 24, 1937.

TABLE 16.—*Semiweekly bottom-water temperature recorded at 3 stations of Stratford Point series during the period from July 2–Oct. 4, 1937*

Date 1937	Station No. 3 (10 ft.)	Station No. 5 (30 ft.)	Station No. 8 (60 ft.)
	°C.	°C.	°C.
July 2	16.4	15.1	14.6
July 8	17.5	15.7	15.6
July 12	21.4	18.1	15.9
July 15	21.4	19.9	19.9
July 19	20.1	16.9	16.6
July 22	21.9	18.9	16.8
July 26	19.6	17.3	17.5
July 29	18.6	18.4	18.6
Aug. 2	22.8	21.5	18.8
Aug. 5	20.8	18.9	18.9
Aug. 9	22.7	20.9	19.5
Aug. 12	22.8	20.0	22.0
Aug. 16	21.3	20.6	20.6
Aug. 19	22.1	21.5	21.3
Aug. 23	21.5	22.0	22.0
Aug. 26	21.9	22.0	21.6
Aug. 30	22.9	22.6	21.5
Sept. 2	23.8	23.0	21.5
Sept. 7	22.0	21.5	21.6
Sept. 9	21.4	21.4	21.6
Sept. 14	18.7	19.9	20.9
Sept. 16	20.9	20.7	21.0
Sept. 20	19.4	20.0	20.3
Sept. 23	19.7	19.5	19.7
Sept. 27	18.8	19.2	19.5
Sept. 30	18.3	18.1	18.7
Oct. 4	17.7	17.9	18.3

It appeared from field observations that heavy sets of young starfish occur on or near the areas inhabited by large numbers of adult animals. To verify this conclusion the density of the adult starfish population at each of the eight setting stations was determined in August 1937. At station No. 1, located at mean low-water mark, no sample was taken because the rocky bottom did not permit dredging. At other stations the usual methods of collection were employed. The data presented in figure

TABLE 17.—*Bottom-water salinity recorded at 3 stations of Stratford Point series during the period from July 2–Sept. 30, 1937*

Date 1937	Station No. 3 (10 ft.)	Station No. 5 (30 ft.)	Station No. 8 (60 ft.)
	Parts per mille.	*Parts per mille.*	*Parts per mille.*
July 2	26.29	26.67	27.12
July 8	26.64	25.79	27.07
July 15	22.41	26.18	25.79
July 22	25.90	26.49	27.09
July 29	26.60	26.74	27.56
Aug. 5	27.12	27.47	27.70
Aug. 12	25.95	27.61	27.90
Aug. 19	27.09	27.63	27.97
Aug. 26	27.54	27.61	27.81
Sept. 2	27.43	27.09	28.13
Sept. 9	27.77	27.57	28.28
Sept. 16	27.54	27.81	28.46
Sept 23	27.56	27.57	28.40
Sept. 30	27.77	27.54	28.04

26 show a striking correlation between the density of the adult population and the intensity of setting. Hence a conclusion can be drawn that the majority of larvae develop and reach the setting stage near the place where the eggs were discharged. This accounts for an uneven distribution of young starfish in the Sound.

OBSERVATIONS OF STARFISH LARVAE IN BUZZARDS BAY

Two sets of observations were carried out during the summer of 1935 to determine the time of starfish spawning in Buzzards Bay. Adult starfish were examined for the condition of their gonads, and the presence of larvae in the water was ascertained by collecting plankton samples on alternate days. For the latter purpose a No. 20 plankton net, 1 foot in diameter, was towed at various levels for periods lasting from 10 to 30 minutes. Plankton samples were collected at stations Nos. 50 and 48 and in the areas off Scraggy Neck, Marion Harbor, Nasketucket Bay, New Bedford section, Cleveland Ledge, North Falmouth, Woods Hole, and Kettle Cove. As early as the second week in June it was noticed that the majority of starfish caught by the Bureau of Fisheries boats, and those collected by the Marine Biological Laboratory at Woods Hole, had gonads completely spent. Some of the starfish, however, still had full gonads. On July 30 and August 1, large starfish kept in the live car at the Fisheries Laboratory had partly full gonads and two females were quite ripe. The results of plankton sampling were rather disappointing, for only a few starfish larvae (brachiolariae) were found at stations 50 and 48 during the week of July 10 and none were observed after July 17. Inquiry was also made at the Woods Hole Oceanographic Institution regarding the presence of starfish larvae in the waters of Vineyard Sound. Although plankton was collected by this institution twice every week throughout the summer, using a No. 20, ¾-meter net, only one brachiolaria was found, and that in the sample taken early in August off Tarpaulin Cove.

The almost complete absence of starfish larvae in plankton samples does not permit any conclusions to be drawn regarding the time of spawning in 1935. However, examination of the gonads of the adult starfish indicated that general spawning must have occurred early in June and continued until the end of the month. This conclusion is in accord with previous observations made by L. Palmer and P. S. Galtsoff in 1932. In this year starfish larvae, in the various stages of their development, were abundant in plankton samples taken from May 14 to July 1, indicating that spawning continued during this period of time. Judging by the presence of large numbers of bipinnariae, there were two periods of general spawning in 1932—first, between May 14 and 20, and second, from June 4 to 11. Light spawning continued in July and possibly in August. About the first week of July 1932 certain sections of the bay were heavily infested, with very small starfish covering shells and rocks along the shoreline. As many as 40 small starfish could be found at that time on every medium-sized oystershell.

It was observed that this abundant starfish set in Buzzards Bay greatly decreased within 1 month after setting. In places where as many as 40 starfish were found on

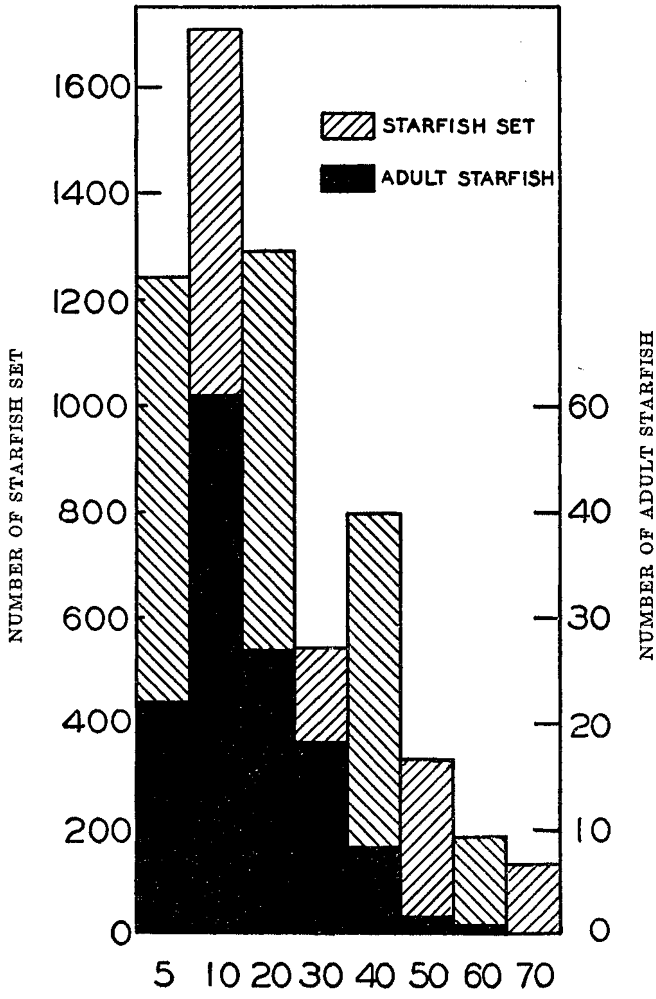

FIGURE 26.—Number of adult starfish per unit of area recorded in August 1937, at each of 8 stations established at different depths of Stratford Point area, and the total season's set of starfish per 100 oyster shells at corresponding stations, 1937.

each oyster shell, only 2 or 3 remained. Observations in the laboratory indicated great cannibalism among the young starfish which may account for the sudden disappearance of large numbers of the small animals.

In the summer of 1935 no small starfish were found in the bay in spite of a careful search on rocks, shells, and among seaweed. Furthermore, no newly set starfish were found in the chickenwire bags filled with clean shells and set in shallow water at stations Nos. 50 and 48 near Woods Hole. These collectors were examined at regular intervals and each time replaced by fresh ones. Small starfish from 2.0 to 3.9 cm. in diameter were caught, however, between August 6 and 29 in the oyster-drill traps. Fairly abundant set was found in Waquoit Bay, on the Marthas Vineyard side of the cape.

GROWTH OF STARFISH

For a study of growth, young starfish ranging from 0.5 to 1.0 cm. in diameter were collected in Long Island Sound in August 1936 and placed in large concrete tanks. In one of the tanks a large quantity of food was always available, whereas, in the second tank, the supply was very limited. By the middle of October many

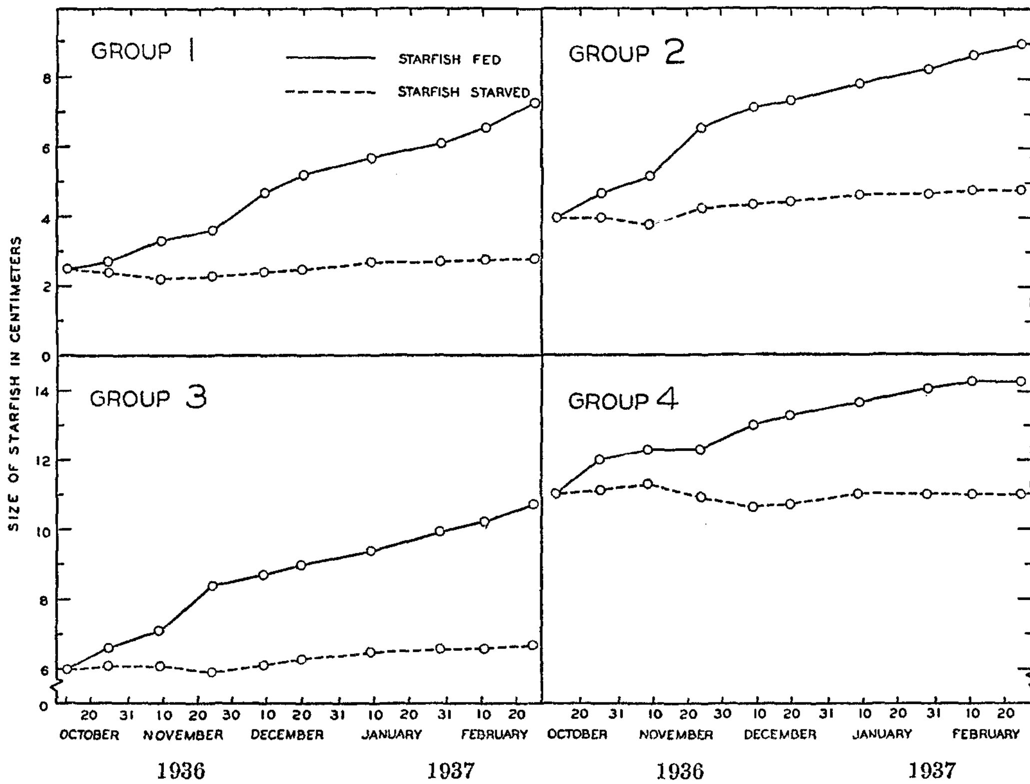

FIGURE 27.—Growth of starfish of 4 different size-groups subjected to maximum feeding (solid lines), and to semistarvation diet (dotted lines). Oct. 13, 1936–Feb. 25, 1937.

starfish of the first tank attained the size of 8.0 cm., while the largest animals of the second tank were only 3.0 cm. in diameter.

A more detailed study of the growth of starfish of different sizes subjected to maximum feeding or to semistarvation diet was performed by Loosanoff under laboratory conditions. On October 13, 1936, 48 starfish of 4 different sizes were brought from the outdoor tanks and placed in laboratory aquaria. The size of all animals of group 1 was 2.5 cm.; group 2, 4.0 cm.; group 3, 6.0 cm.; and group 4, 11.0 cm. All the animals, except those of group 4, were known to be of 1936 set. Starfish of every size group were divided into two subgroups, each consisting of 6 animals. The animals of one subgroup of each size were given all the food they could consume, while the second subgroup was allowed to feed 1 day per week only. Except for the difference in the quantity of food available, all experimental animals were kept under identical conditions. The temperature of the water during the experiments, which extended from October 13, 1936, until February 25, 1937, fluctuated between 17.0° and 20.0° C.

All starfish used in the experiment were measured and the average size for each subgroup determined at frequent intervals. Well-fed starfish outgrew those kept on semistarvation diet (fig. 27). Experiments showed that well-fed young animals, set in July, may reach the size of adult individuals before the onset of winter. Poorly fed starfish, on the other hand, grew but little, or even decreased in size.

The growth of well-fed starfish of different sizes proceeded at different rates. Animals of the 2.5-cm. group, at the end of 4½ months, grew to 7.8 cm., thus showing an increase of 4.8 cm., or 172 percent, over the original size. Groups 2, 3, and 4 at the end of the same period showed an increase of 125, 78.3, and 30 percent, respectively. In the case of the semistarved animals the increase in size at the end of the experiment was hardly noticeable.

The rate of growth of young starfish is of interest because, to a certain extent, it determines their sexual maturity. Young starfish which grew rapidly and reached 6–7 cm. in diameter, were found to be sexually mature by the end of the first year, whereas small, slowly growing animals did not become sexually mature until they were 2 years old.

It is of interest to note that starfish subjected to semistarvation actually decreased in size during the first part of the experiment (fig. 27). Such shrinkages were observed in each size group.

Results of the Milford experiments are in agreement with those of Mead (1901), who also found that by varying the amount of the food supply amazing differences in the size of two starfish of the same age could be produced.

LOCOMOTION AND MIGRATION

All starfish crawl on the bottom by means of so-called tube-feet, special organs of locomotion situated in deep grooves on the oral surface of each ray. In *Asterias forbesi* the tube-feet are arranged in four rows extending from the mouth of the animal to the tip of each ray. Movement of the animal's body results from the coordination of the tube-feet of one or several rays. All the tube-feet may be extended in the same direction, backwards or forwards, right or left. When ascending the perpendicular side of a tank or stone, the discs of the tube-feet adhere to these objects and the tube-feet themselves contract, thus moving the body of the starfish to the point of adhesion. The adhesion of a tube-foot is partly due to suction and partly to the secretion of mucus (Smith, 1937). Their great number enables the starfish to crawl with equal ease over the soft muddy bottom or smooth hard surfaces. Jennings (1901) has shown that in locomotion on horizontal surfaces the tube-feet act as levers for swinging or shoving the body of the starfish forward. They do not pull, but, on the contrary, they slightly push backward. The walking of the starfish is therefore mechanically similar to that of higher animals, the suckers merely serving as a means of attachment.

The movements of starfish are quite slow. In a tank the average rate of progress was from 3 to 6 inches per minute. In some cases, however, much more rapid movement was observed. For example, on one occasion a starfish traveling on a straight line covered a distance of exactly 1 foot in 52 seconds. Another traveled a distance of 10 feet in 14 minutes. Such a rapid rate of movement is seldom maintained for any length of time. Ordinarily the starfish moves a few inches at a time and then remains still. Usually the movement is not in one direction but along an irregular path.

Starfish locomotion is either considerably retarded or entirely stopped in the winter. A series of experiments on the effect of low temperature upon their movements was performed at Milford during the winter of 1936–37. Each experiment consisted in keeping six individually marked starfish in a large outdoor tank and recording their positions at regular intervals. The temperature of the water was taken at each observation. Food, consisting of small oysters and soft-shell clams or mussels, was always present. In one experiment, continued from December 29, 1936, until January 9, 1937, a period of 11 days, none of the six experimental animals moved away from the point where they had been placed at the beginning of the experiment. The

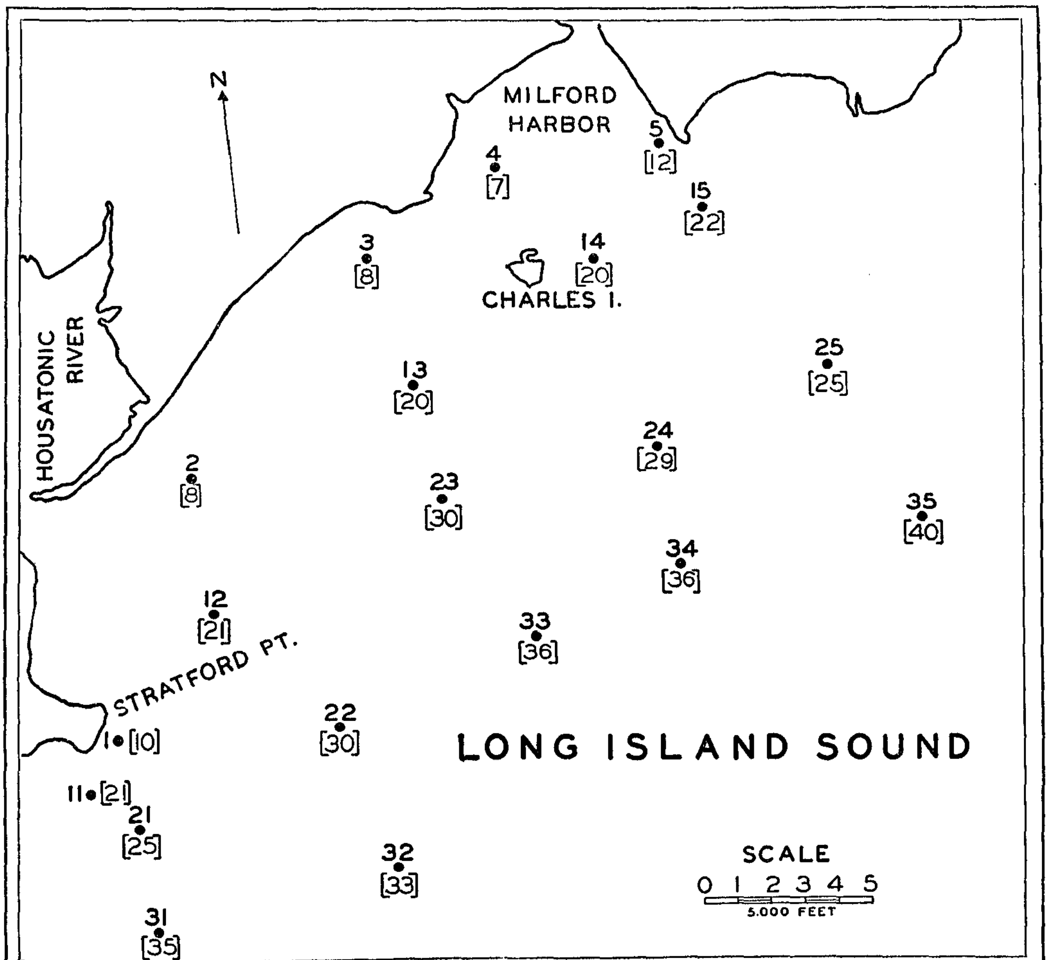

FIGURE 28.—Location and depth of 20 stations established for observations of movements of starfish population in Milford Harbor-Stratford Point area. Upper figures indicate station numbers, figures in brackets indicate depth in feet.

temperature during this time ranged from 2.8° to 4.5° C. In another experiment, extending from February 1 until February 19, 1937, the temperature of the water varied from 0.0° to 2.2° C. During this time only one animal moved a few feet. Five other animals remained inactive. At the close of this experiment all the animals were taken to the laboratory and placed in an aquarium filled with water from the experimental tank in which they were previously kept. After several hours the water in the aquarium warmed up and the starfish began to move about. Evidently the animals were healthy and normal. Their inactivity in the outside experimental tank can only be attributed to the cold water.

Many similar experiments with freshly caught starfish were conducted in the outside tanks at temperatures ranging from −0.5° to 6.0° C. In the majority of cases the animals neither moved nor fed. In a few instances, however, several of the experimental animals did move or were found upon the food even when the temperature was near the zero mark. Apparently, in the case of starfish as in many other marine invertebrates, physiological differences in individuals may be of considerable magnitude.

There is a prevailing opinion among oystermen that in Long Island Sound masses of starfish migrate early in the summer to shallow waters to spawn and return to deeper waters in the fall. Verrill (1914) was of the same opinion but Mead (1901) and Coe (1912) opposed it. The data obtained by present field observations covering the entire Long Island Sound and Buzzards Bay indicate that the relative density of the starfish population at different depths remains virtually the same throughout the year. It was therefore apparent that in these waters no general migration of starfish

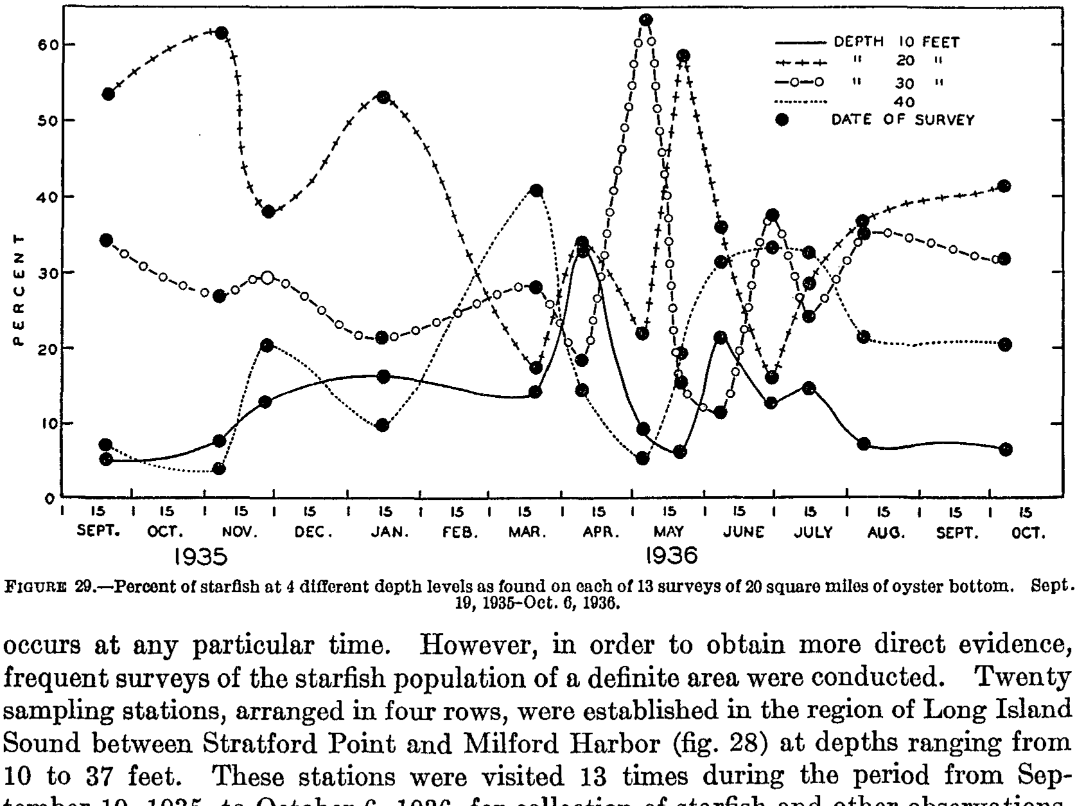

FIGURE 29.—Percent of starfish at 4 different depth levels as found on each of 13 surveys of 20 square miles of oyster bottom. Sept. 19, 1935–Oct. 6, 1936.

occurs at any particular time. However, in order to obtain more direct evidence, frequent surveys of the starfish population of a definite area were conducted. Twenty sampling stations, arranged in four rows, were established in the region of Long Island Sound between Stratford Point and Milford Harbor (fig. 28) at depths ranging from 10 to 37 feet. These stations were visited 13 times during the period from September 19, 1935, to October 6, 1936, for collection of starfish and other observations.

Of the 13 dates at which samples were taken 9 showed the largest number of animals at the 20-foot, 2 at the 30-foot, and 2 at the 37-foot level (table 18). Predominance of starfish at certain depths could not be correlated with any seasonal changes. On two occasions, but at different seasons of the year, they were found to be more abundant at the 37-foot level than at other depths, once in March and once in the middle of July. It is of interest that starfish were never found in predominating numbers within the upper 10-foot level. This observation is significant in disproving the idea that a regular inshore migration occurs during the prespawning time. The percentage of starfish at this level was consistently and generally much lower than at a 20-foot depth (fig. 29). In only two instances were starfish more numerous at a 10-foot level than at a 30-foot depth. In all other cases the percentage of starfish confined to a 30-foot depth greatly exceeded that of shallow water. In general, the study of starfish distribution in a chosen area of 20 square miles, over a period of 13 months, corroborates the conclusions reached during the three extensive surveys of the entire Long Island Sound, namely, that starfish do not migrate inshore or offshore during the different seasons of the year.

TABLE 18.—*Number of starfish at each of 20 stations, recorded on various dates in 1935–36 over an area of 20 square miles of oyster bottom, between Welchs Point and Stratford Point*

Station No.	Depth in feet	Number of starfish recorded													Total for each station for all surveys
		Sept. 19, 1935	Nov. 6, 1935	Nov. 26, 1935	Jan. 15, 1936	Mar. 20, 1936	Apr. 9, 1936	May 5, 1936	May 21, 1936	June 9, 1936	June 29, 1936	July 15, 1936	Aug. 7, 1936	Oct. 6, 1936	
1	10	5	12	12	16	2	25	6	13	30	4	29	24	46	224
2	8	17	15	18	8	28	1	13	9	21	33	15	3	4	185
3	8	0	1	0	3	0	1	1	0	1	0	0	0	2	9
4	7	0	5	19	5	2	12	0	5	0	4	1	1	0	54
5	12	1	4	5	6	1	6	2	5	1	2	0	1	3	37
11	21	135	203	30	57	3	19	30	212	28	19	50	42	253	1,081
12	21	72	72	65	36	3	8	10	41	13	2	19	77	71	489
13	20	6	1	0	0	0	0	0	0	0	1	0	0	10	18
14	20	17	28	43	11	2	13	8	37	38	25	10	10	6	248
15	22	3	0	23	23	32	6	4	6	10	6	8	15	5	141
21	25	29	65	73	25	7	6	131	51	22	95	37	93	184	818
22	30	13	1	46	4	1	2	1	11	0	1	0	3	14	97
23	30	21	1	0	0	5	0	0	0	0	0	1	0	19	47
24	29	64	41	5	0	16	2	2	3	1	1	7	6	37	185
25	25	21	25	1	21	36	15	16	12	5	29	30	36	12	259
31	35	3	6	5	4	4	4	0	15	7	22	3	4	3	80
32	38	4	0	14	0	27	0	0	22	11	25	20	8	19	150
33	36	1	4	33	0	28	1	6	32	35	4	27	48	60	279
34	36	1	3	29	2	3	0	0	24	25	33	31	2	75	228
35	40	21	6	5	17	32	15	7	4	0	27	19	21	15	189
Total	-------	434	493	426	238	232	136	237	502	248	333	307	394	838	4,818

During the summer of 1935 attempts were made to trace the movements of starfish by releasing specimens marked in such a way that they could be easily recognized when caught. Tagging and other mechanical means of marking failed, but it was found that a vital stain could be used satisfactorily (Loosanoff, 1937). Starfish dipped for 1 minute in a 1-percent solution of Nile-blue sulfate acquired a distinct blue color which was retained by the animals for more than 9 months. In November 1935, about 12,000 starfish stained with this blue dye were liberated on an oyster bed in approximately 15 feet of water. Arrangements were made with all local oystermen operating within a radius of 10 miles from this location to report the finding of every blue starfish with the date and exact location of recovery. By the end of August 1936, the Bureau and oystermen, chiefly the Connecticut Oyster Farms Co., had recovered 287 blue starfish. The farthest distance from the point of release traveled by any of the recovered animals was approximately 5,000 feet, or less than 1 nautical mile. There was a tendency to stay in more or less the same depth of water, preferably from 15 to 25 feet. Instead of migrating into deeper water with the approach of winter and returning to shallower places in the spring, as is generally assumed by the oystermen, the movements of starfish took place in all directions and appeared to be very irregular (Loosanoff, 1936).

It has been reported by several oystermen that on more than one occasion great numbers of starfish suddenly appeared on their oyster beds. The appearance of these animals in such cases was attributed to migration from deep parts of the Sound. It is more probable, however, that such sudden appearance of masses of starfish on certain oyster beds is due to the very rapid growth of small individuals which set in that area, or to the irregular invasion from adjoining grounds.

FOOD AND FEEDING

METHOD OF ATTACKING MOLLUSKS

The small size of the starfish's mouth, which in the adult animal is about one-fourth of an inch in diameter, prevents the taking of large pieces of food directly into the stomach. The most common food of the starfish consists of comparatively large animals and mollusks well protected by heavy shells. To open an oyster or other mollusk the starfish wraps itself around its prey in such a manner that its rays are attached to the shells by a series of tube-feet. This being done, it begins to pull the valves of the animal apart. According to Paine (1926) the average adhesive force of an ambulacral foot of a starfish (*Asterias vulgaris*) is 29.4 g. An oyster or hard-shell clam can resist a strong pull for a short time, but a continuous steady pulling eventually fatigues the adductor muscle, which holds the valves together, and the mollusk finally gives up and opens wide (Schiemenz, 1896). After the shells are opened, the attacking starfish protrudes its stomach and digests the soft meat. As soon as the oyster is eaten the stomach of the starfish is withdrawn

It has been suggested that starfish open the shells of oysters by secreting some substance capable of paralyzing the adductor muscle. The suggestion is, to a certain extent, confirmed by the observation of Van der Heyde (1922), who demonstrated the toxic effect of the extract of starfish stomach on the heart of the scallop and the gastrocnemius of the frog. Sawano and Mitzugi (1932) also have shown that the stomach extract of various Japanese starfishes produce tetanic contraction of the isolated heart of *Ostrea circumpicta* immersed in this preparation. The few experiments carried out at the Milford Laboratory show that the stomach extract of *Asterias forbesi* produces abnormal shell movements in oysters. The question of the exact manner in which starfish open oysters, and whether the secretion of a paralyzing substance is the principal method used by them, requires further investigation.

Besides the mollusks such as oysters, clams, and mussels, the food of the starfish also consists of sea-snails, small crustaceans, worms, and dead fish. Often, if food is scarce, cannibalism may be observed.

VORACITY

The voracity of starfish can easily be observed under laboratory conditions if the animals are kept in a favorable environment. Mead (1901) noticed that a single small starfish devoured over 50 clams (*Mulinia lateralis*) in 6 days. Laboratory experiments conducted at Milford have shown that a medium-sized starfish may destroy several 1-year-old oysters per day. In one experiment a single starfish was placed in a 15-gallon aquarium containing 19 1-year-old oysters. Two oysters were eaten by the end of the first day, 4 during the second day, 5 the third day, and 2 the fourth day, after which the experiment was discontinued. In another experiment 2 starfish were placed in an aquarium containing 25 1-year-old oysters. Although no daily record was made of the number of oysters eaten, it was noted that both starfish were feeding continuously during the experiment and that all oysters were destroyed in 3½ days. In still another experiment a small starfish, 1.7 cm. in diameter, was placed in an aquarium with 30 oyster spat ranging in size from 0.3 to 0.9 cm. Twenty-five young oysters were destroyed in 3 days. These experiments showed that many young oysters can be eaten by a starfish in a very short time. On the other hand, large oysters are much better equipped to withstand the attack. On several occasions a number of large oysters placed in the tanks containing hundreds of hungry starfish survived for 6 and 8 weeks despite numerous attempts by starfish to devour them. Large, healthy oysters may successfully resist medium-sized starfish. If their vitality is lowered for any reason, however, they quickly succumb. For example, a score of large oysters was kept out of water for several days and then placed in a tank containing starfish. In a day or two all oysters were opened and devoured. Undoubtedly the weakened state of the adductor muscle rendered them helpless.

It would be erroneous to calculate the probable number of oysters to be destroyed by a single starfish in a year's time by observing its activities in laboratory aquaria for a few days. As will be shown later, the periods of intensive feeding of starfish are often followed by prolonged periods of inactivity. Therefore, conclusions concerning the destructiveness of starfish, based upon limited laboratory experiments, would be of little value.

EFFECT OF TEMPERATURE

To obtain more information regarding feeding habits, a series of experiments was carried out in the summer of 1936, using a large tide-filling outdoor tank, 18 by 20 feet, with a capacity of about 10,000 gallons (fig. 30). The conditions of this experiment closely resembled those existing on natural grounds. Since it has been shown by Romanes (1885), Cowles (1910, 1911), and others that light is a very important factor in determining the movements of starfish, the intensity of light coming from the opposite sides was equalized by putting the tank under a roof and screening the walls. The uniformity of the illumination was then tested by a Weston photoelectric exposure meter.

Starfish manifest decided differences in their feeding habits at different seasons of the year. It was noted that during the prespawning period, from the end of May until July, the majority of animals were indifferent to food. Among hundreds of animals kept under observation in the outdoor tanks only a few individuals could be found feeding at this time. In one of the laboratory experiments, devised to determine feeding activities of starfish during prespawning period, 10 of these animals were placed in an aquarium containing young oysters. The starfish had swollen rays, a condition indicating that their gonads were well developed. Although the experiment lasted 7 days, none of the starfish fed during that time. In other laboratory experiments of a similar nature, feeding starfish were observed very seldom. In all these experiments the starfish were kept in running water with the temperature ranging from 11.0 to 14.5° C.

Soon after the completion of spawning starfish become exceedingly voracious, and continue to be so until the onset of cold weather. In winter and early spring low water temperature noticeably inhibits the feeding activities. This was shown in several experiments conducted during winter in the large outdoor tanks where the water temperature ranged from 0.0° to 6.0° C. In one of these experiments, lasting 11 days, none of the 6 experimental animals fed. In another experiment, extending from February 1 until February 19, 1937, a period of 18 days, 6 starfish were exposed to temperatures ranging from 0.0° to 2.2° C. All animals remained inactive during the entire period. Occasionally, however, among several hundred inert individuals, a single starfish could be observed feeding even at a water temperature near the freezing point.

With the vernal rise of temperature, starfish become more and more active but cease eating with the approach of the breeding period. Judging from these observations, the greatest damage caused by starfish to oyster beds in Long Island Sound occurs from August until December, i. e., between the end of spawning and the onset of cold weather.

FOOD PREFERENCE

To determine which one of the four species of common bivalves of Long Island Sound is most preferred by starfish as food, equal quantities of adult oysters, mussels, hard and soft-shell clams were placed in different corners of the experimental tank and several hours later 25 large starfish, starved for 48 hours or longer, were released in its center. Positions and activities of each starfish were noted by recording at regular intervals the square on the bottom of the tank occupied by each animal (fig. 30).

As a rule the starfish, after being released in the tank, did not move directly toward the mollusks but wandered aimlessly on the bottom for a long time, often passing within a few inches of the food but not attacking it. Occasionally at the end of the experiment more starfish were found on certain foods than on others. The order was usually as follows: (1) Soft-shell clams, (2) oysters, (3) mussels, (4) hard-shell clams. The results were not, however, consistent.

To establish whether the individual animal always prefers the same type of food, several experiments were carried out with 25 starfish placed in the center of the tank and left there for 2 days. At the end of that period all starfish were individually marked by staining one or several of their rays with Nile-blue sulphate according to the type of food upon which they were found. Then the experiment was repeated. At the end of another 48-hour interval a final check was made. The same individuals were often found on different types of food. The results indicate the lack of consistency in attacking one type of mollusk in preference to others.

It has been noted in a number of tests using mussels, soft-shell clams, and oysters that more starfish are found on young mollusks than on older and larger ones of the same species. Equal quantities of bait were used in each experiment. At the end of each experiment more starfish were found feeding on small mollusks. This was clearly shown when oysters or soft-shell clams were used.

In another set of experiments hungry starfish were given a chance to choose between freshly opened and intact mollusks. In these tests two equal volumes of oysters or clams were measured. All the mollusks of one batch were carefully shucked, washed in seawater, and placed in one corner of the experimental tank. The opposite corner was occupied by unshucked mollusks, and a known number of starfish were released in the center. At the end of each experiment both shucked and unshucked mollusks were still alive. There were always more starfish in the corner with the shucked meats than on the intact mollusks.

The ability of starfish to detect food presents an interesting problem which has a direct bearing on the question of their migration. Theoretically it is possible to assume that the presence of food exerts a chemotropic action on the hungry animals and directs their movements. Observations described above may appear to corroborate this assumption. It would however, be erroneous to interpret the results as indicating the chemotropic action of food for it has been observed that hungry starfish placed within a few feet of food did not move in its direction but crawled around for hours before attacking it. Often at the end of a 48-hour experiment as many as 30 percent of the starfish failed to detect the presence of food although they were found crawling near it.

In another series of experiments starfish which had been starved for 10 days were released in the center of the tank 5 feet from the bait. The movements of each individual were studied by recording its position every 20 minutes. In the majority of cases hungry starfish moved away from the food or crawled past it, in many instances passing within 1 to 3 inches of it.

FIGURE 30.—Experimental outdoor tank at Milford, Conn., for a study of the behavior of starfish. The large white square in the foreground is in the center of the tank. Each corner, where starfish or their food is placed, is painted white. The white lines on the bottom and sides are 1 foot apart. Individual squares can be identified by their corresponding numerals and letters on the walls. The use of this tank made possible an accurate check on the movements of the starfish.

By repeating the experiments of Romanes (1885) it was noticed that if a piece of oyster meat was placed within an inch or two of a starved starfish the animal usually, but not always, crawled toward it. If the oyster meat was about 2 feet away the starfish did not show any signs of noticing it.

It appears from these experiments that *Asterias forbesi* does not detect the presence of food until it comes very close to it. If the attacked mollusk is difficult to open, the starfish often leaves it and crawls away. On the other hand, striking by accident an easy prey such as seed oysters, small clams, or exposed meats of large mollusks, the starfish will stay and feed. This accounts for a greater number of starfish found in our experiments on small oysters and on exposed oyster meats than on large intact mollusks. Presumably each starfish had an equal chance to come in contact with any of the bait placed in the tank. However, those which happened to crawl over the exposed meats, or on small mollusks, remained on this easy prey,

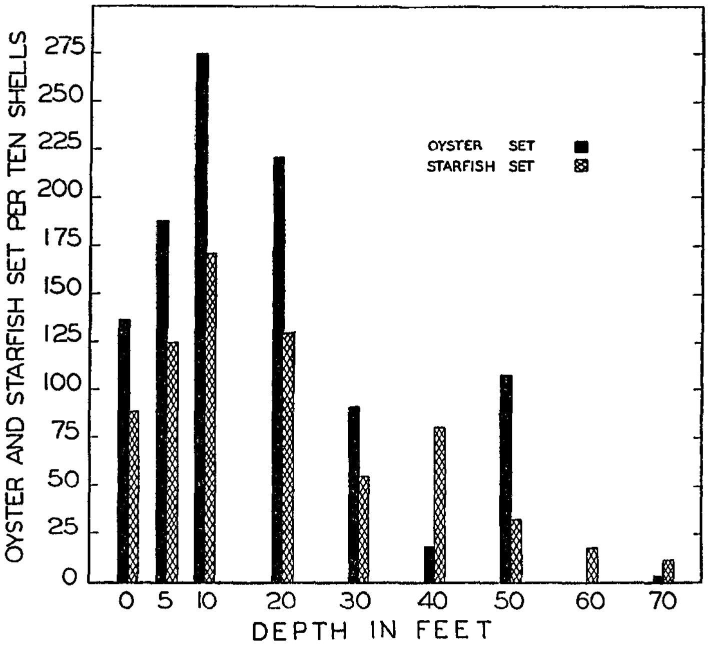

FIGURE 31.—Number of oyster and starfish sets per 100 shells at each of 9 stations of Stratford Point area during the entire season of 1937.

whereas others, striking mollusks well protected by their shells, after a few efforts, abandoned them and crawled away. The experiments suggest that chemotropic reactions are not of primary importance in the search for food by starfish.

The ability of starfish to live without food for long periods of time is remarkable. In one of the experiments several young starfish were starved from October 13 until December 9, a period of almost 2 months. At the end of this period most of the animals appeared to be healthy and quite vigorous.

DESTRUCTION OF OYSTER SPAT

The destruction of small oysters by newly set starfish constitutes a serious problem in the oyster-producing areas for, according to our observations, the entire crop of young oysters might be completely wiped out in a very short time. This possibility becomes apparent from the studies conducted by Loosanoff on oyster beds of Long Island Sound in the summer and fall of 1937, when simultaneous counts of starfish set and oyster spat were made using the shells taken from the collectors placed at nine stations at Stratford Point.

Figures presented in table 19 show that the total number of starfish set here during the entire season of 1937 was only about one-fourth less than that of the oysters. Since the vertical distribution of starfish set closely corresponds to that of oysters (fig. 31), the areas of the bottom containing large numbers of young oysters had almost equally large numbers of their enemies. Setting of oysters in 1937 took place 2 weeks after the setting of starfish. Thus, by the time the first young oysters attached themselves to shells, a great many young starfish were already present on them. It has been found in the laboratory that the newly set starfish may destroy from one to several oyster spat in 24 hours.

TABLE 19.—*Number of oyster and starfish set per 10 shells at each of 9 stations of the Stratford Point series during the entire setting season of 1937*

Station No.	Depth in feet	Set		Station No.	Depth in feet	Set	
		Oysters	Starfish			Oysters	Starfish
1	0	136	88	7	50	108	33
2	5	187	125	8	60	0	18
3	10	275	171	9	70	4	13
4	20	221	129				
5	30	92	55	Total		1,042	712
6	40	19	80				

Under natural conditions several types of food are available for starfish; young oysters do not constitute their only item of diet. Nevertheless, a most conservative assumption that one young starfish during the entire season destroys only one spat would result in the loss of nearly 75 percent of the oyster set. Long Island Sound oystermen often report the complete loss of set although they rarely see the minute pink starfish which caused the damage.

PARASITISM

Working at the Milford Laboratory in search of a natural enemy which may be effective in the control of starfish in Long Island Sound, Piatt (1935) found in the gonads of *Asterias forbesi* a parasitic ciliate, *Orchitophyra stellarum*. Although this parasite is found generally in males, it occurs occasionally in females. The percentage of parasitized males varies according to the locality, being as high as about 20 percent in the region of Stratford Point and as low as 1 percent in New Haven Harbor. Among females only about 1 percent were found to be infected (Burrows, 1936).

The parasite attacks the gonads of starfish, destroying the tissue and rendering the starfish partially or fully sterile. This infection is considered as a natural aid in checking the propagation of starfish in Long Island Sound.

METHODS OF CONTROL

The eradication of starfish on oyster beds has been practiced ever since the cultivation of oysters began. Unless these pests are systematically combated they become so numerous that, in many localities, they entirely destroy the oyster crop. This is especially true for transplanted oyster set and the 1- and 2-year-old oysters.

To ascertain the extent of operations directed against starfish a representative of the Bureau visited and interviewed, in 1935, 22 leading oyster concerns of Long Island Sound. These companies own and lease 42,208 acres of oyster bottom and maintain a fleet of boats.

The information secured shows great diversity in the methods of combatting starfish practiced by the different oyster companies. In a few cases starfishing is carried on for 10 to 12 months per year. In most instances eradication is conducted only when starfish appear in large numbers. Many companies have no special boats for collecting starfish and use oyster boats when the necessity for fighting these animals arises. As far as could be learned, oyster companies confine their activities to their own beds and seldom, if ever, extend their operations to the adjoining unleased and uncultivated grounds. Naturally, such neglected areas remain the centers of starfish propagation.

MECHANICAL METHODS

STARFISH MOP

At present the most common device for destroying starfish is the mop (fig. 20). This mop usually consists of an iron bar from 8 to 10 feet long, to which is attached 12 to 16 large brushes of rope yarn about 5 feet long. The bar is fitted with small iron wheels and is dragged over the bottom by a chain. The chain passes through a pulley attached to posts amidships of the towing boat, and the mop is raised or lowered in the same way as a dredge. The starfish cling to or become entangled in the strands of yarn. Two mops are usually used, one from either side of the boat. Mops filled with starfish are brought up on deck and immediately lowered into long narrow vats filled with boiling water. After a few minutes of exposure the mops are lifted and the dead starfish are picked from their strands.

In some cases, when the bottom is very rocky and uneven, the regular frame cannot be used. For these places a special frame was devised by Capt. Charles Wheeler, of the Connecticut Oyster Farms Co. It consists of two pieces of heavy sheet iron, the larger one, 2 by 5 feet, being attached by four large rings to the triangular smaller piece. Such arrangement permits a certain independence of movement of the two parts. The mop itself is the same as that used with the regular type of frame. It is attached by chains to the 5-foot side of the larger piece of sheet iron. This apparatus slides easily over the rocks, allowing the mop to fall down between them and contact the starfish.

TABLE 20.—*Number of starfish which died within 24 hours after immersion in warm water. Each group used in the experiments consisted of 4 individuals*

Length of exposure	Temperature of water, ° C.				
	35.0	40.0	42.5	45.0	50.0
2 minutes	0	0	2	2	4
4 minutes	0	1	4	4	4
6 minutes	0	4	4	4	4
8 minutes	1	4	4	4	4
10 minutes	1	4	4	4	4

The large quantity of fuel necessary to maintain water at the boiling point renders the killing operation rather expensive. Since it was thought that a temperature lower than the boiling point was sufficient to kill starfish, the idea was tested at Milford by Loosanoff and Engle. Each experiment consisted in subjecting 20 adult starfish (in groups of 4) from the outside tanks—the water temperature of which fluctuated from 8.5° to 10.5° C.—to water temperatures of 35°, 40°, 42.5°, 45°, and 50° C. After allowing the starfish to remain in water at these temperatures for the periods indicated in table 20, they were returned to the outside tanks for further observation. It was found that all the starfish subjected to a temperature of 50° C. for 2 minutes or longer, died. Apparently the use of boiling water is unnecessary. By reducing the temperature of the water from 100° C. (boiling point) to 50° C. the considerable saving in fuel thus effected should result in substantially reduced starfish-eradication costs.

OYSTER DREDGE

During the regular dredging for oysters many starfish are caught in the dredge and destroyed later. In some instances oystermen prefer to use these dredges instead of mops. This practice is in general use in Narragansett Bay.

SUCTION DREDGE

Recently a new device, known as the Flower suction dredge, has been used for the removal of starfish from oyster beds. The basic idea of this dredge is similar to that

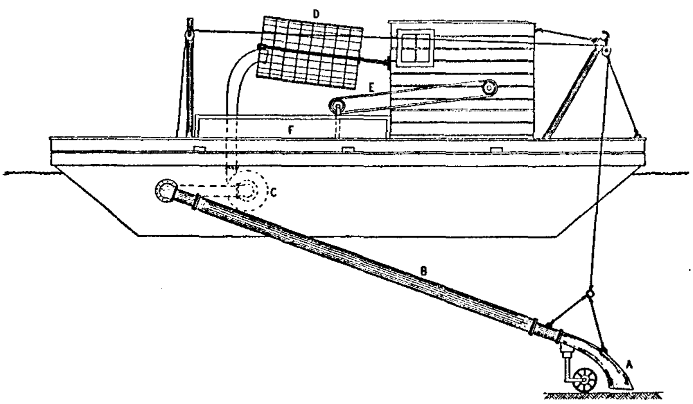

FIGURE 32.—Diagram of Flower suction dredge. A, nozzle; B, pipe; C, pump; D, drum; E, conveyor; and F, sediment tank.

of a regular suction vacuum cleaner. The main parts of the dredge consist of a powerful suction pump which draws objects from the bottom, a nozzle 5½ inches wide and 8 feet long, a metal pipe leading to a large wooden chamber with a rotating wire drum, a conveyor, and sediment tanks (fig. 32).

When in operation the nozzle (A) is lowered to the bottom. An operator can adjust the distance between the bottom and the mouth of the nozzle so that the suction power of the dredge is either increased or decreased. In this manner the dredge can be adjusted to pick up everything found on the bottom or only light objects such as starfish, fragments of shells, etc. On a hard bottom the nozzle can be supported on two wheels which are adjustable to any desired angle.

The material sucked from the bottom is carried through a 6-inch flexible pipe (B) which is made of alternating pieces of metal and hard rubber. After passing through the pump (C) the material ascends through another pipe and enters the drum (D) which is enclosed in a boxlike structure to prevent the blowing of spray. When in operation the drum rotates. Objects too large to pass through the mesh are forced down and finally drop on the conveyor (E), which deposits them in a designated place. Small objects pass through the mesh and drop in the sediment tanks (F). The size of the articles desired to pass through the screen into the sediment tanks is controlled by the size of the mesh of the wire drum.

The efficiency of the dredge is very high. In places where starfish are very abundant, 15 bushels of them can be brought up in about 10 minutes. This yield is much greater than that of a regular starfish boat, the maximum efficiency of which, in Long Island Sound, does not exceed 100 bushels per day.

CHEMICAL CONTROL

Since mechanical control of starfish on oyster beds is expensive and only partially effective, the possibility of employing some toxic substance for their eradication suggests itself. Starfish are easily vulnerable to poisons dissolved in sea water. Although the body is enclosed in a skeleton of articulating calcareous plates beset with rows of blunt spines or ossicles, and appears to be rigid and well protected, its surface is covered with a delicate membrane. From between the ossicles protrude the thin contractile branchiae which, when fully extended, provide for a gaseous exchange between the sea water and body fluids. The delicate membrane covering and the branchiae are in direct contact with the sea water and can easily be affected by various chemicals dissolved in it. These anatomical features make the starfish much more vulnerable than the oyster which, by keeping its shell closed, protects its body from the injurious effects of poisons.

The application of chemicals in the protection of oyster bottoms against starfish was first suggested by Woods (1908), and later carried out by Herman D. Pausch (Coe, 1912, p. 37) who found that quicklime constituted an efficient barrier which could not be crossed by starfish. He recommended the placing of lime in paper bags and dropping them along the boundary line of the bed to be protected. The use of quicklime, however, was neglected by the oystermen until 1937 when, at the suggestion of Mr. H. B. Flower, experiments carried out by V. L. Loosanoff and J. B. Engle (1938), at the Milford Laboratory, proved that the scattering of this substance over the infested bottoms is effective in starfish control. Since several other chemical methods have been under investigation it appears desirable to present briefly the results of all laboratory and field tests performed by the Bureau of Fisheries during recent years.

During 1930–32 the possibility of starfish eradication by the use of copper sulphate was studied by L. Palmer, under the direction of P. S. Galtsoff. Numerous laboratory experiments and field tests were made at the Cold Spring Harbor Laboratory of the Long Island Biological Association and on private oyster bottoms in Long Island Sound and Narragansett Bay. In 1935 and 1936 the effect of various chemicals on starfish was studied by K. Rice and P. S. Galtsoff, at the U. S. Fisheries Station at Woods Hole, Mass.

EXPERIMENTS WITH COPPER SULPHATE

Since the toxic effect of copper sulphate on various aquatic organisms is generally known, a series of experiments was carried out with the view of determining the practicability of using this salt in the eradication of starfish. The toxicity of copper sulphate was studied by applying the salt in solution; scattering its crystals over the bottom; by incorporating the copper sulphate in an organic gel from which it would gradually diffuse into sea water, thus increasing the time the copper salt would remain at the bottom; and by using a mixture of copper sulphate with nitre cake.

The first set of experiments (table 21) was carried out in glass tanks of from 5 to 6 liters capacity, filled with a known volume of sea water to which a strong solution of $CuSO_4$ was added to produce the desired concentration. The determination of the death point presented a certain difficulty. In many instances the animals under the effect of the poison, after being transferred to pure water, remained motionless for 34 hours and still survived. On the other hand it was noticed that after a treatment some of the starfish appeared to be normal and continued to move for a day or two. Then their rays began to drop off and the body to disintegrate. In view of this experience only those starfish which remained motionless for 2 days and had begun to disintegrate were considered dead. Those which showed partial disintegration but were able to move were regarded to have survived the treatment although it was fully realized that some of them might have died later. It was, however, impractical to keep them under observation for more than 2 days.

TABLE 21.—*Lethal effect of various concentrations of $CuSO_4$ on starfish. Five starfish were used in each experiment*

[Temperature, 23° C.; salinity, 24 parts per mille; pH, 7-9]

Concentration (parts per million)	Exposure time in minutes necessary to kill all starfish of given diameter			
	0.1-2.0 cm.	2.1-6.0 cm.	6.1-10.0 cm.	10.1-15.0 cm.
1				(1)
5				(1)
10	5	20		150
20	3	15		110
50	1.3	12	15	75
100	1	10	12	35
500	0.25	2	4	5
1,000	0.1	1.5	1	3

[1] Alive after 24 hours.

For practical purposes of starfish control the concentration of copper sulphate used over the oyster bottom must be as low as possible because of the cost of the material and the danger of killing oysters, food fishes, and other marine organisms. To determine the sensitivity and limits of tolerance of starfish to dilute solutions of copper sulphate, a series of experiments was conducted at Woods Hole, Mass. Several tanks of 2½ gallons capacity each were filled with sea water containing known concentrations of $CuSO_4$. Three starfish and one oyster were placed in each tank and the water was continually aerated. Salinity fluctuated between 30.5 and 31.5 parts per mille and temperature between 18.5° and 21.1° C. The results of this experiment are given in table 22.

TABLE 22.—*Effect of copper sulphate solution in sea water on starfish and oysters*

[Three starfish and one oyster in each tank]

Concentration (parts per million)	Condition of test specimens						
	First day	Second day	Third day	Fourth day	Fifth day	Sixth day	Seventh day
0.07	(1)	(1)	(1)	(1)	(1)	(1)	(1)
0.15	(1)	(1)	(1)	1 starfish dead			2 starfish and 1 oyster dead
0.31	(1)	(1)	1 starfish dead	2 starfish dead	all starfish dead	1 oyster dead	
0.62	1 starfish dead	all starfish dead	1 oyster dead				
1.25	all starfish dead	1 oyster dead					
Control	(1)	(1)	(1)	(1)	(1)	(1)	(1)

[1] All test specimens alive.

Although starfish survived in the weakest concentration, 0.07 part per mille of $CuSO_4$, they were obviously weakened and immediately after treatment were not in a condition to attack oysters. The characteristic effect of copper poisoning on a starfish kept in stronger concentrations showed itself in muscular weakness and the inability of the animal to turn over when resting on the aboral side. When such an attempt was made, each arm twisted but failed to raise the body and the animal gradually slumped into a curious coiled knot. In addition to the muscular weakness there was definite lack of coordination in the movements of the rows of tube feet. Often the mouth relaxed and the stomach was everted. Eventually the arms sloughed off from the body and the entire animal disintegrated, although sporadic contractions of the tube feet continued in separated fragments.

Since the concentration of 0.15 part per million was found to be effective if permitted to act over a period of several days, it seemed desirable to try to find some way to place copper salt on an oyster bed in such a form that it would slowly diffuse, creating concentrations lethal to starfish but harmless to oysters. After several attempts it was found that copper sulphate in 10-percent solution can be combined with ordinary commercial flaked glue and sand. The resultant gel sinks rapidly to the bottom and the copper salt slowly diffuses until nothing is left but the gel itself, which soon disintegrates. Small pieces of this preparation, approximately one-third of an inch cube, were cut and used as the basic units. Experiments were carried out in tanks having a continuous flow of water at the rate of one complete change every 5 hours. As was expected, the results of these experiments show that the killing power of this copper and glue preparation diminished each successive date. It was found, however, that under conditions of the experiment, effective lethal concentrations could be produced by a reasonable amount of material.

Converting the laboratory experimental data into unit terms it has been estimated that 15.3 pounds of copper sulphate and 15.3 pounds of glue made into 10-percent gel and distributed evenly would be sufficient to maintain a lethal dosage for starfish for a sufficiently long time over 1 acre of sea water 1 foot deep. The conditions of the experiments involve a quiet change of water and do not allow for rapid currents and other sources of agitation. Unfortunately, the authors were not able to carry out this experiment in the field and have therefore had no chance to verify the adaptability of the method to natural conditions.

Field tests in eradicating starfish by copper sulphate were made in 1931–32 by Louise Palmer, who worked in cooperation with several oyster companies operating in Long Island Sound and Narragansett Bay. Copper sulphate was applied as a solution pumped through a T-shaped pipe over the bottom, in the form of crude crystals (blue vitriol) scattered by hand from a slow-moving power boat, or in small paper bags holding 1 ounce each. To increase the solubility of copper salt in sea water a mixture of copper sulphate with nitre cake (crude sodium acid sulphate) was used in several experiments. The addition of nitre cake served to make the solution more acid and consequently to retard the precipitation of copper salts in the sea water. The amount of copper salt used in field tests varied from ¼ to 1 barrel per acre.

The results of all the experiments in which either copper salts alone or its mixture with nitre cake was used show that in no case did the treatment kill more than 10 percent of the starfish present on the oyster bottom. There was, however, a material decrease in their number due to their migration away from the treated area. In a few instances the shells of the oyster became discolored and in one case there were indications of death of oysters. In view of the fact that in all the tests only a small percentage of starfish were destroyed and the majority were only forced to leave the bottoms, the methods described above cannot be recommended for the control of the pest over a large territory.

EXPERIMENTS WITH VARIOUS METALLIC SALTS

In an attempt to find a specific poison which would prove fatal to starfish but harmless to oysters and other aquatic life, many experiments were carried out with various metallic salts. Many of the heavy metals were automatically eliminated because of their excessive cost or their general high toxicity and the danger involved in applying them in natural waters. Various chromium salts, studied in concentrations ranging from 0.08 to 10.0 parts per million, were found to have but little effect.

Since zinc sulphate was found to be toxic to starfish in preliminary tests, an experiment was carried out with zinc and glue cakes prepared in the manner described above for copper and glue gel. The flow of sea water through a tank of 1.94 cubic feet capacity was so regulated as to effect a complete change of water every 3 hours. Four starfish and two zinc and glue cakes, each containing 0.15 g. zinc sulphate, were placed in each tank. The cakes were mixed with sand to keep them on the bottom. By the end of the first day all starfish were weakened and unable to turn over. One died on the fifth day.

The starfish, with an extensive vascular system, was thought to be sensitive to changes in the balance of the several salts normally occurring in sea water. This possibility was investigated in a series of experiments which proved that the addition of chlorides of potassium, magnesium, and calcium, in concentrations of from 0.16 to 1.25 parts per million to stagnant aerated sea water, was not destructive to the starfish during a 4-day period of exposure. One animal only in a group of 15 was killed; all others, although weakened by the exposure, recovered when placed in running sea water.

EXPERIMENTS WITH CO_2 AND FREE CHLORINE

The increase in the CO_2 tension in sea water greatly weakens the starfish, and prolonged exposure in water saturated with this gas produces a narcotizing effect. Experiments were carried out in tanks through which a steady stream of CO_2 gas was bubbled. Death occurred only on the third day of exposure. Oysters placed in the same tanks with starfish apparently suffered no ill effects.

The effect of free chlorine on starfish was studied by Palmer in 1930. She found that concentrations of 10 and 20 parts per million in which starfish showed no ill effects were, however, lethal to Fundulus upon exposure of less than 5 minutes. A summary of Palmer's experiments is given in table 24.

TABLE 23.—*Effect of free chlorine on starfish*

Concentration (parts per million)	Exposure (minutes)	Temperature, °C.	Remarks
1,000	15	23.5	Dead.[1]
500	20	24.0	Recovered in 24 hours.
250	5	18.5	Recovered.
100	25	20	Motionless 4 hours, then recovered.
20	60	26	Recovered in 23 hours.
20	30	26	Recovered in 4 hours.
15	60	25	Recovered in 30 minutes.

[1] Small starfish about 2 cm. in diameter killed in 1 minute.

Results of the experiments with various salts and gases show that the attempt to produce on the oyster bottoms concentrations high enough to be lethal to starfish but harmless to other aquatic life presents considerable, if not insurmountable, difficulties. The possibility of using copper sulphate or zinc sulphate glue cakes scattered over the oyster bottom is indicated by the laboratory experiments. There arises, however, a question of the desirability of large-scale application of a method which would result in introducing metal salts into the sea, the accumulation of which may eventually prove disastrous to other aquatic animals and plants. Chemical control based on the application of water-soluble substances can therefore be restricted to emergency conditions and should not be extensively used over a large area of coastal waters.

EFFECT OF CALCIUM OXIDE

Better results could be expected from a method based on the use of insoluble, or only slightly soluble, material harmful to starfish when in direct contact with its body. The solution of this problem was found in the modification of the old method of using quicklime (calcium oxide), first suggested by Wood (1908).

Calcium oxide has the valuable advantages of being only slightly soluble in sea water and in having an almost immediate effect upon starfish. Because of its low solubility, a comparatively small quantity is sufficient to cover the oyster bottom.

The method studied by Loosanoff and Engle at the Milford Laboratory, and employed by the F. M. Flower Oyster Co., consists in spreading quicklime in the form of powder or lumps of any desired size over oyster bottoms infested with starfish. As the chemical sinks to the bottom, it falls onto the aboral surface of starfish and becomes embedded in the ciliated epithelium covering the animal. The caustic action of the lime creates lesions in the delicate skin membrane. The lesions grow by spreading in all directions and involving the branchiae and other surface structures. After several days they penetrate through the body wall, the internal organs become exposed, and death follows very shortly. Starfish which are not directly hit by the falling particles eventually come in contact with it by crawling on the bottom. In the course of time the oral surfaces of the starfish become affected and disintegration begins. It has been observed that animals with large lesions are usually attacked by other starfish and crabs which quickly kill and devour them.

All the starfish in the outside experimental tanks at Milford, where the experiments were carried out, died within 5 to 10 days after being treated with powdered calcium oxide applied at the rate of 300 pounds per acre of bottom. In the spring of 1938 experiments were carried out on the oyster beds of Long Island Sound, where starfish were abundant. Both powdered and coarser grades of lime were used. Although the latter form is less effective in killing the starfish, it was found to retain its effectiveness for a longer period of time than the powdered material. On 25 acres of starfish-infested oyster bottom treated with coarse lime at the rate of 480 pounds per acre, as many as 80 percent of the starfish were found to be affected 1 week after the beginning of the treatment. The efficiency of quicklime treatment depends both upon its uniform distribution and the quantity used over the treated area. The determination of the minimum amount of lime necessary to destroy all starfish over an acre of oyster bottom, and the most practical method of its application, are subjects of extensive studies now being carried out at the Milford Laboratory.

Being immediately effective and easy to apply, this method is considered to have great practical possibilities. It should be of particular value in exterminating starfish on public or abandoned oyster bottoms, which are the centers of starfish propagation in the oyster-producing areas of New England and the Middle Atlantic States.

Quicklime can also be used to great advantage when oyster set is transplanted from one bed to another. Transplanting is usually done in the fall when young starfish feeding on oyster spat are still very small and cannot easily be noticed and culled out. By spreading several handfuls of powdered lime over each dredge load of oysters, the majority of starfish among the oyster set will be killed. This method will prevent transplanting starfish from one area to another.

Of special importance is the fact that in the concentrations harmful to starfish, quicklime does not seriously affect other forms of marine life. For instance, oysters kept for a period of 6 months in water to which large quantities of lime were added at regular intervals, survived and continued to grow. On the other hand, planktonic forms including fish, lobsters, and oyster larvae may be killed by contact with lime particles. Therefore, the use of lime should be confined to seasons when these larvae are not present in the water.

UTILIZATION OF STARFISH

Several attempts have been made to utilize starfish as fertilizer. Wheeler (1914) states that starfish examined at the Rhode Island Experiment Station were found to contain 20.3 percent of mineral matter. The fresh, undried starfish contained 9.62 percent of lime, 0.23 percent of potash, 0.20 percent of phosphoric acid, and 1.9 percent of nitrogen. The value of these ingredients in a ton of fresh starfish, computed on the basis of prices prevailing in 1914, ranged from $6 to $7.50 per ton. In February 1938, the Connecticut Agricultural Experiment Station kindly analyzed for the authors samples of starfish from Long Island Sound. The results of the analyses are given in table 25.

TABLE 24.—*Chemical composition of one dozen starfish, moist basis. February, 1938* [1]

Constituents	Percentage
Moisture	74.88
Ash	10.90
Total nitrogen	1.27
Total phosphoric acid	.22
Total water-soluble potash	.81
Chlorine	.51
Lime (CaO)	5.88
Magnesia (MgO)	.57

[1] Analysis No. 8113 of the Connecticut Agricultural Experiment Station.

At present starfish are utilized in the manufacture of fertilizer by one of the companies operating in Virginia. The difficulty experienced by the manufacturer is primarily concerned with the impossibility of obtaining a sufficiently steady supply of raw material. Fishermen engaged in catching starfish in the lower Chesapeake Bay claim that when the yield drops below 200 bushels per day per boat, fishing is unprofitable. An abundant supply, therefore, is available only during the spring when large numbers of starfish are usually found in these waters. So far as the authors know, no attempts have been made to utilize the starfish in the Northern States. In France, Belgium, and Canada (Vachon, 1920) starfish are made into fertilizer, and during the World War they were used as a feed. According to C. J. Kole (1919), a sample of starfish meal contained: Albumen, 31.6 percent; fat, 6.9 percent; moisture, 12.1 percent; ash, 34.9 percent; and sand, 3.9 percent (Chemical Abstracts, vol. 13: 1106).

In recent years considerable interest has been aroused in this country in the reduction of starfish into a meal suitable as an ingredient of mixed feeds for farm animals. In correspondence with the Bureau of Fisheries (1937–38), one of the leading fish-meal producers of Norfolk, Va., states that he has installed machinery for the reduction of from 50 to 100 tons of starfish per day and that several hundred tons of starfish meal have been sold in the vicinity of Norfolk. Following is an analysis showing the approximate chemical composition of this product:

	Percent
Moisture	10.10
Nitrogen 5.80 percent, equivalent to protein	36.25
Fibre	1.84
Salt	0.64

RECOMMENDATIONS

Studies of the distribution and biology of starfish conducted by the Bureau of Fisheries in 1935–38 provide information much needed for the effective application of control methods. As the results of the surveys made in Buzzards Bay, Narragansett Bay, and Long Island Sound, it has become evident that there is no general, well-defined migration of the starfish. No concentration of hordes of these animals was found in the deep regions adjacent to these bodies of water, but in each of them starfish were found aggregated in the inshore areas where they remained throughout the year. The movements of large quantities of starfish usually originate from these centers of high concentration. The extent of their migration is, however, limited. These facts have become apparent by studying the migrations of marked starfish released in Long Island Sound and by observing the behavior of the starfish population at the head of Buzzards Bay, in the Sakonet River, the Eastern Passage of Narragansett Bay, and in the western part of Long Island Sound. From these centers of propagation the animals spread to adjoining bottoms. It is therefore evident that eradication efforts should first be applied to these focal centers.

In many instances the centers of infestation are located on abandoned oyster beds or public bottoms left entirely unattended by the oystermen, who confine their efforts to their own grounds. This fact constitutes the greatest weakness in the present method of control, which is both expensive and inefficient, not so much because of the mechanical deficiency of starfish mops and dredges as because of the lack of coordination and organization of individual efforts. It would cost the oystermen of Long Island Sound much less to join forces and send their fleets of starfish boats to clean out the abandoned private or public bottoms at the western end of the Sound instead of indefinitely dredging or mopping their own lots. Progress in controlling starfish will be possible when this fact is recognized by both State authorities and by the individual oystermen. The present investigation provides sufficient evidence that, in combatting the starfish, each body of water should be considered in its entirety. Good results are not to be expected if control efforts are exercised in only a small portion of an area, without due attention being given to contiguous bottoms.

In the States of Massachusetts and Rhode Island the problem is simplified because the natural boundaries of Buzzards and Narragansett Bays coincide with the State lines. In both localities the starfish can easily be placed under control through the cooperative action of State and local oystermen. In Long Island Sound starfish control is an interstate problem which should be solved by a joint action of all interested parties.

As to the technical methods of control, certain new developments appear very promising. Chemical control by using quicklime scattered over the infested bottoms was found to be very efficient and this method deserves careful consideration by the oystermen. The simplicity of operation, the harmlessness to oysters, and the cheapness of the product vouchsafe its success. Detailed studies of the best method of applying quicklime on adult and young starfish, and its limitations and probable dangers to aquatic life, are now being continued and will be reported separately.

The use of highly toxic substances, such as copper sulphate, in the control of starfish is not recommended, as they are inefficient and dangerous to aquatic life.

SUMMARY

1. It is estimated that in the State of Connecticut direct damages caused by starfish and the cost of protecting oyster bottoms exceed $500,000 annually. In Massachusetts the destruction of scallops by starfish was primarily responsible for the shrinkage of the industry from $795,000 in 1929 to $142,000 in 1931. Heavy losses of oysters due to depredations by starfish were reported to occur regularly in Buzzards and Narragansett Bays and Long Island Sound.

2. Only one species, *Asterias forbesi* Devor, is important as an oyster pest.

3. Since a sudden increase in starfish population on oyster bottoms was generally regarded by the oystermen as an invasion, a comprehensive survey of the distribution of starfish at different seasons of the year was made in Buzzards and Narragansett Bays and in Long Island Sound. Additional information was obtained in lower Chesapeake Bay.

4. Uniform methods used in the course of the investigation consisted in taking quantitative samples of starfish population by dredging at stations located from 1 to 3 miles apart and covering the entire areas of the bays and the Sound. Temperature and salinity were recorded at each station.

5. Throughout the year 90 percent of the starfish population in Buzzards Bay was found to be confined to shallow water at the head of the bay and in the inshore areas. Distribution of starfish was primarily influenced by the presence of food. No extensive migrations of starfish from deep to shallow water, or vice versa, were noticed, although slight redistribution of starfish population within the inshore areas was observed. The distribution of starfish was not correlated with the changes in temperature and salinity observed at different seasons and at different stations.

6. Large animals were predominant at the head of the bay. This fact is clearly indicated by the differences in the median and mean sizes of the starfish collected in four different sections of Buzzards Bay in June, September, December, and April (table 5). This phenomenon is attributed to the greater rate of growth of starfish in the areas abundant in food.

7. Two surveys of Narragansett Bay disclosed the presence of two concentrations of starfish in the inshore areas of the bay. Between September and December there was no significant change in their distribution.

8. Three surveys of the distribution of starfish in Long Island Sound showed large concentrations of this animal in the western part of the Sound, especially along the Long Island side.

9. In Long Island Sound starfish were found at all depths from low-water mark to 250 feet, but the majority of them were found near the shores in comparatively shallow water not exceeding 40 feet. The middle portion of the Sound was practically devoid of starfish as were certain sections of the shores in the eastern part of the Sound.

10. Throughout the period of observation there were no marked changes in starfish distribution. No general seasonal migration of starfish from shallow to deep water, or vice versa, occurred in Long Island Sound.

11. Starfish in Long Island Sound were numerous where the bottom contained large numbers of mollusks or their shells. The absence of starfish was nearly always associated with the absence of mollusks.

12. Within the range observed in Long Island Sound, distribution of starfish was not correlated with salinity and temperature.

13. Animals from 5 to 8 cm. in diameter comprised the most numerous size group of starfish for all parts of the Sound.

14. In the Chesapeake Bay starfish (*Asterias forbesi*) were found living in water with a salinity ranging from 18.37 to 28.31 parts per mille. Within this range no correlation between salinity and distribution of starfish could be observed. Oyster bottoms found in the areas of lower salinity were not attacked by starfish. The distribution of starfish in the bay was apparently correlated with the presence of the small clam, *Mulinia lateralis*, upon which it feeds.

15. Spawning of starfish in Long Island Sound begins after the water temperature reaches 15.0° C. and continues from the middle of June until the end of August. Ripe starfish can be induced to spawn early in the season by raising the temperature of the water to about 20.0° C. Attempts to induce spawning by addition of sperm or egg suspension usually failed.

16. In 1937, setting of starfish in Long Island Sound occurred at all depths from mean low-water mark to 70 feet. It continued from July 2 until September 23. At shallow- and medium-depth stations, setting began and ended from 10 to 21 days earlier than in deep water.

17. Starfish set heavily at depths ranging from 5 to 20 feet, with the heaviest setting occurring at a 10-foot level. The intensity of setting was found to be the heaviest on or near the areas with the densest population of adult starfish.

18. The growth of starfish depends upon the amount of available food. Well-fed laboratory animals reached the size of 8.0 cm. 4 months after setting. The age at which starfish become sexually mature depends upon their size. Rapidly growing animals develop and discharge sexual products by the end of the first year of their lives.

19. The movements of starfish are quite slow and irregular. In winter they slow down considerably or entirely stop.

20. A detailed study of starfish distribution in a chosen area of 20 square miles of Long Island Sound bottom showed no definite inshore or offshore migration during the different seasons of the year. This conclusion was further corroborated by observing the movements of starfish stained with Nile-blue sulphate and released in the Sound. The farthest distance traveled by any of the animals was approximately 5,000 feet, or less than 1 nautical mile, in 10 months' time. There was a tendency to stay in more or less the same depth of water, preferably in 15–25 feet. Their movements took place in all directions and no seasonal migration could be observed.

21. Feeding habits of the starfish are described. Experimental evidence shows that *Asterias forbesi* does not detect the presence of food until it comes very close to it.

22. Starfish are very voracious eaters, capable of destroying several young oysters per day. Observations showed that in some sections of Long Island Sound the majority of oyster spat are eaten within the first few days of their existence.

23. Mechanical methods of controlling starfish by using dredge, mop, and suction dredge are discussed.

24. Experimental results obtained in using various chemicals are discussed. The scattering of powdered calcium oxide (quicklime) over the infested bottoms appears to be a practical method of controlling starfish. Further studies regarding the application of this method are being continued.

25. Utilization of starfish as fertilizer is discussed.

26. Since, in many instances, the most intensive starfish infestation was found on abandoned oyster bottoms and on public beds, the unorganized individual efforts of the oystermen are not sufficiently effective to combat this pest. For a successful

operation of control measures each body of water should be considered in its entirety and all the centers of infestation within its boundaries destroyed. This work can be carried out by joint efforts of State and private organizations.

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