The Distribution of Eggs and Larvae of the Anchovy, *Stolephorus purpureus* Fowler, in Kaneohe Bay, Oahu, with a Consideration of the Sampling Problem[1]

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INTRODUCTION

A small species of anchovy, *Stolephorus purpureus* Fowler,[3] known locally as the "nehu," is used extensively as livebait in the skipjack (*Katsuwonus pelamis*) fishery of Hawaii. Although the nehu is caught in several different baiting areas throughout the Territory, it is fished most heavily and is taken in largest quantity in Kaneohe Bay, on the east shore of Oahu. In the daytime the fish are caught by surround nets in shallow, turbid water alongshore, often close to the mouths of streams. After dark they are caught by night lighting in deeper and less turbid water farther out in the bay.

Without doubt, the availability of nehu is one of the main factors governing the size of the skipjack catch. In recent years, coincident with an increased fishing effort, there has been an alleged decrease in the availability of nehu in the most important baiting area—Kaneohe Bay. The question has been raised as to whether or not this decrease indicates overfishing of the nehu population.

In 1948, an intensive study of the nehu of Kaneohe Bay was initiated to determine essential biological information which might lead eventually to knowledge of the level of fishing intensity for maximum sustained yield. The present report deals with one phase of this study, namely, the distribution of nehu eggs and larvae throughout the waters of the bay. The investigation must be regarded as preliminary in nature. It was undertaken partly to determine an efficient sampling procedure for future work, and partly to obtain general information on the early life history of the nehu and the distribution of eggs and larvae.

Acknowledgments: The chief responsibility for the field work devolved upon Mr. Lester Zukeran, skipper of the University of Hawaii's research vessel *Salpa*, who located the stations, navigated the ship over the courses, and assisted in the hauling and washing-down of the nets with unending patience and skill.

Two large plankton nets were loaned to us through the courtesy of Mr. Vernon E. Brock, Director of the Division of Fish and Game, Territorial Board of Agriculture and Forestry.

Several graduate students of the University of Hawaii assisted in various phases of the work. Mr. Kenji Ego assisted in Surveys 1 and 2, Mr. Daniel Yamashita in Surveys 1*a*, 1*b*, 2, 3, and 4, and Mrs. Bertha Cutress in Surveys 3 and 4. The monotonous and difficult job of microscopic examination of the plankton samples, including the identification and segregation of the eggs and larvae and the measurement of the larvae, was undertaken with dispatch and efficiency by Mrs. Cutress, assisted on occasion by Mr. Yamashita. Chlorinity and oxygen determinations were made in part by Miss Winnifred Tseu and in part by Mr. Yamashita.

I wish to express my sincere thanks to those

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[3] The status of the generic name has been discussed by Gosline (1951).

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PHYSICAL FEATURES OF KANEOHE BAY

Kaneohe Bay (Fig. 1), on the windward (east) shore of Oahu, is about 7 miles in length and about 2 miles in width. It lies in a general northwest-southeast direction and has a total area of about 12 square miles.

For the most part, a continuous but irregularly indented coral reef follows the shoreline and averages about 400 yards in width. It is broken at the mouths of streams by mud flats. The main body of the bay is studded with coral reefs of various sizes and shapes. At low tide these, and also the shoreside reef, are either awash or are covered by about a foot of water; at high tide they are covered by 3 or 4 feet of water. In some places, e.g., the southern sector of the bay, the reefs have been removed by dredging. Deducting the area of the coral reefs and flats from the total, the navigable water area is about 6 square miles.

The southern sector of the bay, which averages about 40 to 45 feet in depth, is protected from the open sea by Mokapu Peninsula. The middle sector of the bay is partially protected from the open sea by coral reefs and by a large sand flat, known as Sand Island, which is partly exposed at some phases of the tide. Within the middle sector, the channels between the reefs average about 40 feet in depth. The northern sector of the bay is also partially protected from the outer sea by sand shallows and coral reefs, although not to the same extent as the southern and middle sectors. Its average depth is less than that of the other two sectors, about 15 to 20 feet.

Thus, apart from a few shallow channels, Kaneohe Bay is virtually cut off from direct interchange with the outer ocean. Although surface water will flow over the shallows and enter the bay, propelled by the strong northeast trade winds, the bay would be expected to have a variety of simple to complex internal circulatory systems, each depending on the configuration of the shoreline, the presence of reefs, the strength of the wind, the phase of the tide, and the amount of fresh water entering the bay from several small streams.

In the southern and middle sectors, the water has a brownish tinge, indicating the presence of silt and, perhaps, plankton. It is quite cloudy alongshore where a strong turbulence is created by the usual onshore wind. In the northern sector, the water close to shore is also somewhat brownish and cloudy. However, the blue ocean water, entering through the main northern channel, impinges on the bay water and, on occasion, forms a definite line of demarcation.

STATIONS AND SURVEYS

Twenty-three stations in representative locations were selected from a chart of Kaneohe Bay, nine (Stations 1 to 9) in the southern sector, eight (Stations 10 to 17) in the middle sector, and six (Stations 18 to 23) in the northern sector (Fig. 1). The stations were not spot locations; rather, they were straight or sinuous courses followed by the research vessel *Salpa* in towing plankton nets. The straight courses were followed in the more open parts of the bay; the sinuous courses were necessary at stations located among the coral reefs. As nearly as possible, the same course was followed at each station during successive surveys.

Four main surveys were undertaken on the following dates: (1) September 6, 7, and 8, 1949, (2) December 27, 28, and 29, 1949, (3) March 16, 17, and 18, 1950, and (4) June 21, 22, and 23, 1950. In each survey, the stations of each sector were worked on successive days. In addition, two interim surveys were made in the vicinity of Station 4 as follows: (1*a*) November 25, 1949, and (1*b*)

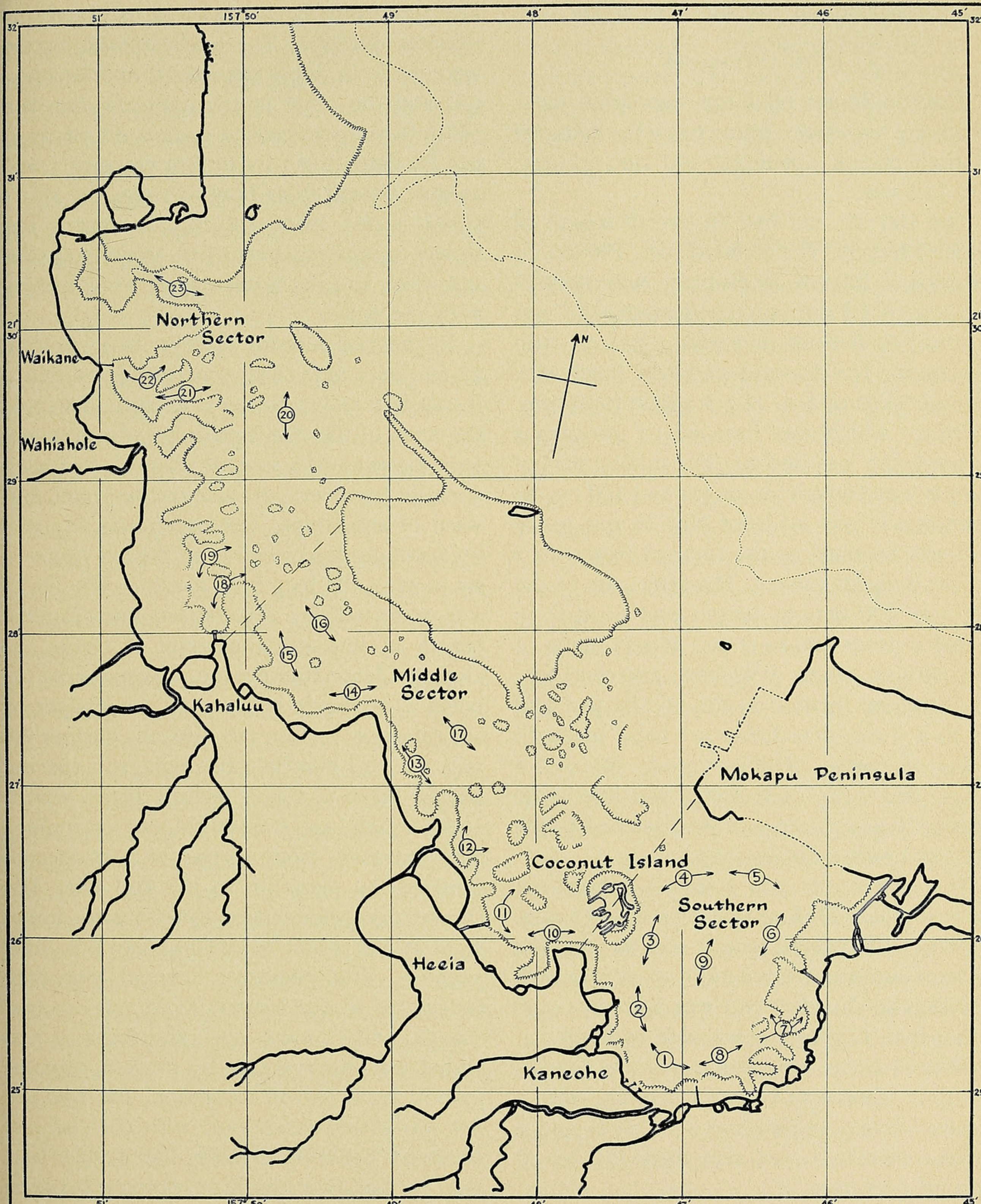

FIG. 1. Map of Kaneohe Bay showing place names, sectors, and stations.

December 8, 1949. Casual hauls were also made irregularly throughout the year at various stations in the southern sector.

NETS AND HAULS

Three different plankton nets were used, which are hereafter referred to by the diameter of their mouth openings: 100 cm., 22 cm., and 12.3 cm.

The 100 cm. net had an overall length of about 5 meters. The forward part, 180 cm. in length and 100 cm. in diameter, was made of fish net of 1.5 cm. stretched mesh, and was fastened to the net ring with a 25 cm. strip of canvas. The forward part was lined with an inner skirt of No. 24 grit gauze (0.81 mm. aperture) which was fastened to the canvas forward, but was free aft. The middle part of the net was 100 cm. in length and 100 cm. in diameter. It was made of No. 24 grit gauze and was fastened to the forward part with a 20 cm. strip of canvas. The after part of the net was 190 cm. in length and tapered in diameter from 100 to 9 cm. It was made of No. 40 grit gauze (0.47 mm. aperture) and was attached forward to the middle part and aft to a 9 cm. detachable net band by small strips of canvas. The cod end, 30 cm. in length and 9 cm. in diameter, was also made of No. 40 grit gauze, and was fastened to the net band with a canvas strip.

The 22 cm. net was a simple conical net made of No. 2 Dufour bolting silk (0.35 mm. aperture). Its overall length was 50 cm. The forward part was fastened to the net ring with canvas, and the after end was tied with tape rather than having a detachable cod end.

The 12.3 cm. net was a regular Clarke-Bumpus (Clarke and Bumpus, 1940), with a closing device (which was not used) and a current meter. It was also made of No. 2 Dufour bolting silk.

In the four main surveys two nets, the 100 cm. and either the 22 cm. (Surveys 1, 3, and 4) or the 12.3 cm. (Survey 2), were hauled simultaneously at slow speed just below the surface. The large net was towed from the boom, which was slung out on the starboard side, whereas the small net was towed directly astern. Each haul was of exactly 10 minutes duration. The hauls at each station were made in duplicate, one in one direction (A) and the other in the opposite direction (B) following a reversed course. As nearly as can be determined by timing chips of wood as they passed from bow to stern, the ship's speed varied from 1.8 to 2.2 knots. The slower speeds resulted when towing against the wind, and the faster speeds when towing with the wind.

In the two interim surveys, two identical 22 cm. nets were used, one towed just below the surface and the other at a depth. To avoid the wash of the ship's propeller, the towlines were fastened to a spar which projected horizontally from the port side of the vessel, forward of amidships. The depth was adjusted by fastening lead weights to the net ring and by varying the length of towline. The depth was estimated by calculation, knowing the length of line and the angle of stray. The closing Clarke-Bumpus net was not used for hauls at a depth because of the danger of snagging on the uneven bottom. Further details on haul number, direction, and spacing will be given in a later section of this report.

After each haul, the 100 cm. net was washed with sea water from a pressure hose to concentrate the plankton in the cod end. The smaller nets were jerked upward and downward in the water to accomplish the same purpose. The plankton material was then transferred to quart jars (100 cm. net) or pint jars (22 and 12.3 cm. net), and formalin was added for preservation. To prevent contamination from station to station, the 100 cm. net was towed inside-out, with the cod end removed, between stations. The smaller nets were washed thoroughly in sea water between hauls.

In a few cases, when an exceptionally large catch was made with the 100 cm. net, a small quantity of plankton was lost in attempting to transfer the material from the cod end to the jar. Loss from this source would not affect the general conclusions appreciably. During the course of each day's operation, there was a steady accumulation of inert organic material on the silk of the 100 cm. net. It was impossible to remove this either by use of the pressure hose or by towing the net inside-out between stations. It could be removed only by scrubbing the net with a brush at the end of the day. This would probably cause a small but progressive decrease in efficiency from station to station within days. During the first 2 days of Survey 1, barnacles on the ship's bottom caused small rips in the silk of the 100 cm. net, which doubtless decreased its efficiency. These were sewn prior to the third day of Survey 1, and snagging of the net was henceforth avoided. The original old, weak grit gauze was replaced with new for Surveys 3 and 4.

Apart from towing the nets in an identical manner and for exactly the same length of time for each haul, no serious attempt at quantitative sampling was made. In Survey 2, meter readings were taken with the 12.3 cm. net. In Surveys 3 and 4, the meter of the 12.3 cm. net was towed behind the boat, and readings were taken for each haul. However, except where indicated, adjusted data are not presented because (1) comparable adjustments are not available for all surveys, (2) the adjusted data, where available, do not differ greatly from the unadjusted data, and (3) the variation between identical hauls at the same place from day to day probably would be of much greater magnitude than the variation induced by slight differences in quantity of water strained from haul to haul on the same day.

PHYSICAL AND CHEMICAL DATA

During each of the main surveys, the temperature of the surface water at each station was recorded to the nearest tenth of a degree Centigrade. In addition, for Surveys 2, 3, and 4, a sample of the surface water at each station was taken and later analyzed for chlorinity (p.p.m.) by the Mohr method. The data are given in Table 1.

In the interim surveys, temperature, chlorinity, and oxygen determinations were made at three depths. The oxygen content (ml./l., adjusted to 20° C.) was determined by the Winkler method. The data are given in Table 2.

EXAMINATION OF PLANKTON SAMPLES

The plankton samples were examined under the binocular microscope by transferring the material, a small quantity at a time, to a Petri dish. Nehu eggs were removed and counted (Tables 3 and 4) according to three categories, "normal," "damaged," and "agglutinated," as defined below. Nehu larvae were removed, counted (Tables 5 and 6), and measured to the nearest tenth of a millimeter by means of a micrometer eyepiece. Standard length was defined as the distance from the tip of the snout to the end of the vertebral column (Table 12). Notes were made on the quantity of plankton in each bottle and on the relative abundance of the dominant organisms.

As the number of nehu eggs per sample was relatively small, the entire sample was examined rather than only a known fraction. This was a time-consuming procedure, usually requiring several man-hours per sample. Segregation of the nehu eggs and larvae was complicated by the presence of large numbers of chaetognaths and ctenophores which had to be teased apart. Despite this difficulty, it is believed that the counts include practically all nehu eggs and larvae in the samples.

Usually most of the eggs were "normal" in appearance—the developing embryo could be seen clearly and was surrounded by a transparent perivitelline space. In some, classed as "damaged," the inner membrane was ruptured and the yolk and shattered embryo had invaded the perivitelline space in varying degree. Obviously these had suffered mechanical injury during capture. In others, classed as

TABLE 1

SURFACE TEMPERATURE AND CHLORINITY IN KANEOHE BAY ACCORDING TO STATION AND SURVEY

STATION	TEMPERATURE (CENT.)				CHLORINITY (P.P.M.)		
	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 4	SURVEY 2	SURVEY 3	SURVEY 4
1	26.0	23.5	23.9	25.1	18.91	19.19	19.37
2	25.7	23.5	23.9	25.3	18.79	19.22	19.30
3	25.8	23.5	23.9	25.2	18.87	19.22	19.41
4	25.7	23.5	23.8	25.1	18.98	19.32	19.41
5	25.7	23.5	23.7	25.2	19.13	19.38	19.42
6	25.9	23.5	23.5	25.2	19.13	19.32	19.51
7	26.2	23.5	24.0	25.6	19.10	19.38	19.47
8	26.3	23.6	24.4	26.0	19.13	19.32	19.23
9	26.2	23.6	24.0	25.3	19.06	19.35	19.42
10	25.8	23.0	23.8	25.0	18.91	19.14	19.32
11	26.0	22.7	23.8	24.9	18.58	18.95	19.29
12	26.0	23.0	23.8	24.3	18.73	18.93	18.82
13	26.0	22.9	24.0	24.8	18.87	18.97	19.32
14	26.5	23.2	23.8	25.0	19.02	19.14	19.37
15	26.6	23.3	23.8	25.2	19.06	19.34	19.41
16	26.5	23.2	23.9	25.0	19.13	19.32	19.45
17	26.2	23.2	23.9	25.0	19.06	19.21	19.36
18	26.2	23.1	24.2	24.6	19.03	19.23	19.23
19	26.5	23.0	24.1	24.8	18.95	19.26	19.27
20	26.4	23.2	24.4	24.8	19.20	19.30	19.42
21	26.5	23.1	24.7	24.9	19.09	19.21	19.20
22	27.0	23.1	24.8	24.8	19.02	18.99	19.01
23	26.8	23.0	24.8	24.8	19.11	19.36	19.06
Mean	26.2	23.2	24.0	25.0	18.99	19.22	19.31

"agglutinated," disintegration of the yolk and embryo had occurred and the material filling the shell had a whitish color, as if decomposition had been under way for some time.

IDENTIFICATION OF EGGS AND LARVAE

Nehu eggs are oval in shape, bluntly ovoid at the ends, and about twice as long as wide.

TABLE 2

TEMPERATURE, CHLORINITY, AND OXYGEN ACCORDING TO DEPTH DURING SURVEYS 1*a* AND 1*b*

SURVEY	DEPTH	TEMPERATURE	CHLORINITY	OXYGEN
	feet	*centigrade*	*p.p.m.*	*ml./l.*
1*a*	2	23.7	19.29	5.00
	10	23.5	19.40	4.97
	20	23.4	19.33	5.00
1*b*	5	22.8	19.38	5.12
	20	22.6	19.48	5.18
	32	22.5	19.57	5.46

Measurements of 20 eggs from the hauls gave an average length of 1.36 mm. and an average width of 0.61 mm. The yolk contains no oil globule. The shape and size of nehu eggs readily distinguish them from most other round or slightly oval fish eggs found in the plankton. Absence of an oil globule distinguishes them from others of about the same size and shape which belong to an unknown species and which were found on one occasion in a tow taken outside of the bay by Dr. A. H. Banner.

All nehu eggs taken in the tows were at about the same stage of development. The embryo extended approximately one-half to three-quarters of the distance around the yolk; somites were visible in some specimens; the head was taking shape around the lobes of the brain; and the developing eyes were visible but not conspicuous. Less advanced eggs in the blastodermal cap stage, and more advanced eggs closer to the hatching stage, were not encountered. It has since been found (Yamashita, MS.) that spawning takes place at night, mostly from about 10 P.M. to midnight, and that development from fertilization to hatching occurs in about 24 hours. This explains the rather uniform stage of development of the eggs, for in all tows they were taken during the same 5-hour period of the day—from about 9 A.M. to 2 P.M. Similar observations have been made by Delsman (1929) who pointed out that night spawning and rapid embryonic development are typical of tropical species of *Engraulis* and *Stolephorus* occurring in Javanese waters.

Nehu larvae have been hatched in small shallow dishes of sea water from eggs taken in plankton hauls (Yamashita, MS.). The newly hatched larvae, about 2 mm. in length, have a large, crescent-shaped yolk sac attached to the ventral surface of the body from head to vent. This is gradually absorbed until, at 36 hours after hatching, only a small round ball of yolk remains at the "throat." During these early stages the larvae may be recognized fairly readily by their size, the slender elongated body form, the shape and position of the yolk sac when present, the reticulated appearance of the myotomes, the origin of the dorsal fin fold at the posterior end of the head, and the position of the anus, which is from two-thirds to three-quarters of the distance along the body. At the more advanced stages, the chief diagnostic characters are the slender body form, the reticulated appearance

TABLE 3

NUMBER OF NEHU EGGS PER 10-MINUTE SURFACE HAUL WITH THE 100 CM. NET ACCORDING TO SURVEY, STATION, AND DIRECTION (A AND B), AND SUMMARY

STATION	SURVEY 1		SURVEY 2		SURVEY 3		SURVEY 4		MEAN PER CENT OF SURVEY TOTAL
	A	B	A	B	A	B	A	B	
1	–	–	–	–	–	–	5	11	0.16
2	–	–	–	–	–	15	–	3	0.07
3	233	314	21	107	89	347	6	29	5.12
4	1,930	956	383	490	4,180	4,781	127	296	48.63
5	769	116	419	332	38	2	262	259	18.41
6	30	10	3	3	1	–	3	2	0.28
7	2	–	3	2	–	–	8	2	0.17
8	–	1	–	–	–	–	53	27	0.82
9	6	3	3	2	23	149	123	17	1.97
10	–	2	7	2	8	4	–	–	0.15
11	–	1	7	5	1	–	–	–	0.16
12	3	5	3	0*	5	3	–	–	0.09
13	56	172	10	4	55	113	4	2	1.51
14	223	117	18	5	14	8	326	150	6.50
15	111	113	18	21	8	22	125	121	3.94
16	8	8	27	1	73	34	166	122	3.65
17	495	141	21	23	31	15	39	30	3.74
18	262	143	–	–	2	–	–	–	1.50
19	–	–	–	–	–	–	15	11	0.27
20	310	205	–	–	–	1	45	33	2.71
21	12	–	–	–	–	–	8	1	0.14
22	–	–	–	–	–	–	1	–	0.01
23	–	–	–	–	–	–	–	–	0.00
Totals	4,450	2,307	943	997	4,528	5,494	1,316	1,116	100.00

* Part of haul lost.

TABLE 4

NUMBER OF NEHU EGGS PER 10-MINUTE SURFACE HAUL WITH THE 22 CM. NET (SURVEYS 1, 3, AND 4) OR THE 12.3 CM. NET (SURVEY 2), ACCORDING TO SURVEY, STATION, AND DIRECTION (A AND B), AND SUMMARY

STATION	SURVEY 1		SURVEY 2		SURVEY 3		SURVEY 4		MEAN PER CENT OF SURVEY TOTAL
	A	B	A	B	A	B	A	B	
1.......	–	–	–	–	–	–	1	–	0.17
2.......	–	–	–	–	–	1	–	–	0.04
3.......	37	83	3	6	6	22	–	2	7.02
4.......	244	193	7	26	217	279	11	15	46.14
5.......	130	15	27	20	5	–	13	17	21.52
6.......	2	1	–	–	–	–	–	–	0.07
7.......	–	–	–	–	–	–	1	–	0.17
8.......	1	–	–	–	–	–	4	3	1.19
9.......	6	7	1	–	–	14	10	1	3.05
10.......	–	–	1	1	–	–	–	–	0.54
11.......	–	–	–	–	–	–	–	–	0.00
12.......	1	5	–	–	1	–	–	–	0.20
13.......	4	28	–	–	–	10	–	–	1.25
14.......	26	9	–	–	–	–	20	6	5.22
15.......	12	19	–	–	1	1	5	6	2.70
16.......	1	–	–	–	1	3	9	7	2.87
17.......	72	18	–	1	3	2	6	4	4.43
18.......	29	8	–	–	–	–	–	–	0.93
19.......	1	–	–	–	–	–	–	1	0.19
20.......	22	16	–	–	–	–	2	5	2.13
21.......	–	–	–	–	–	–	1	–	0.17
22.......	–	–	–	–	–	–	–	–	0.00
23.......	–	–	–	–	–	–	–	–	0.00
Totals...	588	402	39	54	234	332	83	67	100.00

of the myotomes, the position of the anus, the projecting lower jaw (up to about 15 mm.), and the lateroventral position of the pectoral fins.

Many of the larvae taken in the tows were damaged to a varying extent. In young larvae the yolk was often torn from the yolk sac, and the fin fold was usually shredded. In older larvae part of the head, including the eyes, was often missing. This complicated the problem of identification. More serious, however, is the possibility that some nehu larvae, broken into fragments, were not recognized as such and were not included in the counts.

VARIABILITY OF THE DATA AND RELATIVE EFFICIENCY OF THE NETS

It will be recalled that, in sampling, two nets were hauled simultaneously, first in A direction and then in B direction at each station. Following the method of Winsor and Clarke (1940), the data may be used to investigate the components of variance and the relative efficiency of the nets. Analyses were made for the egg catches of each survey, using three criteria of classification—stations, haul order, and nets. To approximate normal distributions, the data were transformed to logarithms. The method of analysis is explained by Snedecor (1948: 11.14). Unfortunately, because of the small numbers taken, it was necessary to omit data from many of the stations. The stations included are as follows: Survey 1—3, 4, 5, 13, 14, 15, 17, 18, and 20; Survey 2—3, 4, and 5; Survey 3—3, 14, 16, and 17; and Survey 4—4, 5, 8, 9, 14, 15, 16, 17, and 20. The results are given in Table 7.

TABLE 5

NUMBER OF NEHU LARVAE PER 10-MINUTE SURFACE HAUL WITH THE 100 CM. NET ACCORDING TO SURVEY, STATION, AND DIRECTION (A AND B), AND SUMMARY

STATION	SURVEY 1		SURVEY 2		SURVEY 3		SURVEY 4		MEAN PER CENT OF SURVEY TOTAL
	A	B	A	B	A	B	A	B	
1.......	16	30	1	3	–	5	1	–	3.58
2.......	3	3	2	–	4	8	2	18	5.50
3.......	14	9	4	–	–	3	2	6	2.66
4.......	23	23	14	4	1	7	6	6	6.59
5.......	45	39	26	14	2	2	9	9	10.09
6.......	90	50	25	24	3	2	25	21	14.21
7.......	57	115	15	16	2	15	6	3	14.74
8.......	53	105	5	2	3	–	4	6	7.75
9.......	25	13	5	5	3	4	10	4	5.40
10.......	2	–	7	8	–	5	13	17	5.12
11.......	1	–	18	13	–	1	1	4	3.60
12.......	–	–	7	3*	–	1	4	4	1.81
13.......	–	–	5	1	3	–	3	3	1.91
14.......	2	–	3	2	–	2	43	28	6.14
15.......	–	–	6	1	–	–	33	20	4.38
16.......	–	–	–	2	–	2	6	7	1.72
17.......	3	–	5	–	–	–	13	13	2.40
18.......	1	–	2	4	–	1	1	2	1.10
19.......	–	–	3	2	–	–	1	1	0.61
20.......	–	–	–	–	–	1	–	1	0.38
21.......	–	–	–	–	–	–	–	–	–
22.......	–	–	–	–	–	–	–	–	–
23.......	–	–	–	–	–	1	–	–	0.31
Totals....	335	387	153	104	21	60	183	173	100.00

* Part of haul lost.

As there were obviously large differences in egg catches, both between stations and between nets, the large mean squares for stations and nets were expected. The mean square for haul order was relatively large in Surveys 1, 2, and 4, but includes a large S×H (station by haul) interaction component, and cannot be regarded as generally significant. Moreover, the (geometric) means for A and B hauls (converted from logarithms) do not show a consistent difference from survey to survey:

SURVEY	A	B
1....................	101.4	67.0
2....................	35.2	61.5
3....................	36.7	48.6
4....................	28.5	20.1

Greater interest is centered in the interactions. In all four surveys the S×H interaction is large, and in Surveys 1 and 4 it is highly significant. This demonstrates a lack of consistency in the relative catches of A and B hauls from station to station, due to causes other than chance variation. In all surveys, the S×N (station by net) interaction is relatively large, at least larger than the residual variance S×H×N, but in no case is it statistically significant. It probably includes a real component of variance, σ_{SN}^2, which is of small magnitude. For the present, however, it may be assumed that the catches of the two nets, apart from order of haul, bear a consistent ratio to each other from station to station. The H×N (haul order by net) interaction is small; in fact, it is smaller than the S×H×N interaction in all surveys except the third. In other words, for the same station the catches made in A and B order for each of the two nets are somewhat more consistent than might be expected on the basis of chance

TABLE 6

NUMBER OF NEHU LARVAE PER 10-MINUTE SURFACE HAUL WITH THE 22 CM. NET (SURVEYS 1, 3, AND 4) OR THE 12.3 CM. NET (SURVEY 2) ACCORDING TO SURVEY, STATION, AND DIRECTION (A AND B), AND SUMMARY

STATION	SURVEY 1		SURVEY 2		SURVEY 3		SURVEY 4		MEAN PER CENT OF SURVEY TOTAL*
	A	B	A	B	A	B	A	B	
1	3	–	–	–	–	–	–	–	1.51
2	–	–	–	–	–	–	–	–	–
3	1	–	1	1	–	–	1	–	7.72
4	4	12	–	–	–	–	–	–	8.08
5	3	9	1	2	–	1	–	1	15.84
6	8	4	–	2	–	–	4	2	23.69
7	–	3	2	1	–	–	–	–	9.21
8	4	4	–	–	–	–	–	–	4.04
9	8	1	–	–	–	–	1	–	6.63
10	–	–	1	–	–	–	–	–	2.56
11	–	–	1	–	–	–	–	–	2.56
12	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–
14	–	–	1	–	–	–	3	2	12.98
15	–	–	–	–	–	–	1	–	2.08
16	–	2	–	–	–	–	–	–	1.01
17	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	1	–	2.08
20	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–
Totals	31	35	7	6	–	1	11	5	99.99

* Omitting Survey 3.

variation, i.e., nets towed simultaneously seem to yield partially correlated data.

Before presenting further data to assist in the interpretation of the significant S×H interaction, the relative efficiency of the nets will be considered. The (geometric) mean relative efficiency may be calculated from the logarithmic data. Thus, for Survey 1, the sum of the logarithms of the catches for the 100 cm. net (A and B hauls) is 42.8000, and for the 22 cm. net it is 26.2514. The difference, 16.5486, divided by the number of paired hauls, 18, is 0.9194. The catch ratio, 22 cm. net/100 cm. net, is the antilog of −0.9194 ($\bar{1}$.0806), or 0.1204.

Modifying the formula presented by Winsor and Clarke (1940), the standard error of the ratio involving two nets is given, in logarithms, by

$$\sqrt{\frac{1}{N} \cdot 2(\sigma_{SHN}^2 + k_1\sigma_{HN}^2 + k_2\sigma_{SN}^2)}$$

where N is the number of paired hauls, and k_1 and k_2 are the number of items associated with the respective variance components. In our data (except that of Survey 3), σHN^2 is considered to be 0, rather than a negative quantity. The variance components σSHN^2 and $k_2\sigma SN^2$ constitute the mean square for the S×N interaction. Thus for Survey 1, the standard error of the ratio, in logarithms, is

$$\sqrt{\frac{1}{18} \cdot 2(0.02157)} = 0.0490.$$

The confidence interval, mean ±2 s.e., may be calculated in logarithms and then converted, giving 0.0961 and 0.1509.

The following data have been calculated for each survey:

SURVEY	CATCH RATIO	CONFIDENCE INTERVAL	THEORETICAL CATCH RATIO
1.......	0.1204	0.0961–0.1509	0.0484
2.......	0.0558	0.0300–0.1037	0.0151
3.......	0.0614	0.0338–0.1115	0.0484
4.......	0.0688	0.0552–0.0874	0.0484

In the above tabulation, the theoretical ratios are those for the areas of the net mouths: 100 cm. net, 7,854.0 cm.^{2}; 22 cm. net, 380.13 cm.^{2}; 12.3 cm. net, 118.82 cm.^{2}.

The observed catch ratios differ significantly from the theoretical ratios for all surveys except the third. The smaller nets (22 cm. and 12.3 cm.) are relatively more efficient than the large net (100 cm.). This is in contrast to the results of Winsor and Clarke, although the data are not directly comparable as they were dealing with motile organisms. The exceptionally large ratio in Survey 1 is doubtless due mostly to loss of eggs from the 100 cm. net when small rips developed, as already explained. The reason for the larger-than-expected ratios in the other surveys is less clear: the straining area of the large net was relatively greater than that of the small nets; the apertures of the mesh in all nets were sufficiently small to retain the eggs, with the possible exception of that of the forward and middle parts of the large net. In these parts it is possible, although not likely, that eggs could have escaped in an end-on position. The efficiency of the large net may have been decreased by loss of plankton during transfer to containers, or by progressive clogging within days, as noted in a previous section.

TABLE 7

ANALYSIS OF VARIANCE OF EGG CATCHES IN SURVEYS 1 TO 4 ACCORDING TO STATIONS, HAUL ORDER, AND NETS

SURVEY	SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE
1	Stations (S)	8	4.28258	0.53532
	Haul order (H)	1	0.27991	0.27991
	Nets (N)	1	7.60712	7.60712
	S×H	8	1.70812	0.21352**
	S×N	8	0.17259	0.02157
	H×N	1	0.00371	0.00371
	S×H×N	8	0.09480	0.01185
2	Stations	2	1.61393	0.80696
	Haul order	1	0.17610	0.17610
	Nets	1	4.71316	4.71316
	S×H	2	0.20601	0.10300
	S×N	2	0.10856	0.05428
	H×N	1	0.00006	0.00006
	S×H×N	2	0.09495	0.04748
3	Stations	3	11.85402	3.95134
	Haul order	1	0.05958	0.05958
	Nets	1	5.87432	5.87432
	S×H	3	0.34663	0.11554
	S×N	3	0.13537	0.04512
	H×N	1	0.05907	0.05907
	S×H×N	3	0.11017	0.03672
4	Stations	8	3.08473	0.38559
	Haul order	1	0.20672	0.20672
	Nets	1	12.15801	12.15801
	S×H	8	1.00648	0.12581**
	S×N	8	0.19387	0.02423
	H×N	1	0.00283	0.00283
	S×H×N	8	0.10926	0.01366

** Highly significant.

VARIATION IN CATCH WITH ORDER (DIRECTION) OF HAUL

Following Survey 1, Surveys 1*a* and 1*b* were undertaken to investigate in more detail the obviously large differences between A and B hauls at the same station, and also to study variation in egg and larva distribution with depth. To illustrate the differences between A and B hauls it might be noted from Tables 3 and 4 that at Station 4, the 100 cm. net caught 1,930 eggs in the A haul (one direction) and only 956 eggs in the B haul (opposite direction); similarly at the same station, the 22 cm. net took 244 eggs in the A haul and 193 eggs in the B haul. It is the lack of consistency in these differences from station to station which produces the large and significant S×H interaction demonstrated in the preceding section. The differences, which in many cases depart significantly from an expected difference of 0 (using a Chi-square test) may be due to differences in volume of water strained in A and B hauls, to non-random distribution of the eggs, or to both factors.

Surveys 1*a* and 1*b* were both undertaken in the vicinity of Station 4, which had yielded relatively large numbers of eggs in Survey 1. Each A and B haul was of exactly 10 minutes' duration. Two identical 22 cm. nets were towed simultaneously, one just below the surface and the other at a depth.

In Survey 1*a* an attempt was made to run four replicate hauls (I to IV), each replicate including an A and a B haul, and each haul including two depths, thus yielding 16 samples. Each A haul was in a southwesterly direction, with the wind, whereas each B haul was in a northeasterly direction, against the wind. The distance travelled in A hauls, about 3,000 feet, was greater than in B hauls, about 2,400 feet, due to the greater speed attained when travelling with the wind. In the A hauls it was necessary to diverge from the usual Station 4 course to miss the reefs off the southeast side of Coconut Island. Before starting the B hauls, the ship was run along the east shore of the island in order to assume the usual Station 4 course, as illustrated in Figure 2. The resulting data are shown in Table 8, and the analysis of the data, after transformation to logarithms, is shown in Table 9. In the latter, the data were adjusted to an average distance of 2,700 feet in an attempt to overcome one source of variation. This would correct for differences in volume of water strained in A and B hauls only if there were no change in the efficiency of the nets with change in speed.

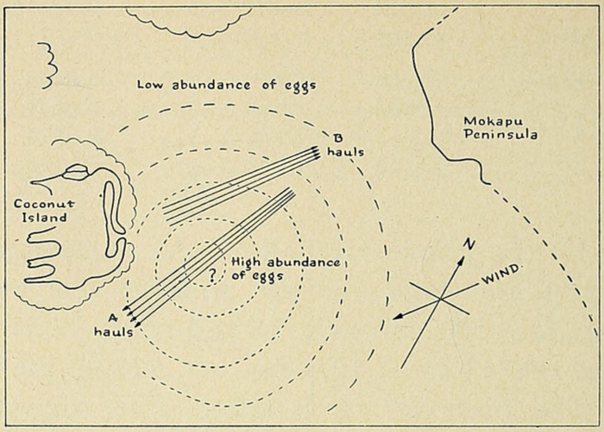

FIG. 2. A portion of the southern sector of Kaneohe Bay in the vicinity of Stations 4 and 5, showing the location of A and B hauls in Survey 1*a*, and indicating the presumed distribution of the eggs (broken isolines).

The adjusted egg catches are as follows:

REPLICATES	A		B	
	surface	*deep*	*surface*	*deep*
I........	148	130	79	37
II........	520	456	29	35
III........	323	302	106	64
IV........	306	254	56	46

As shown by the analysis (Table 9), there are no significant differences between the (geometric) mean catches for replicates (87, 125, 160, and 119, respectively). However, there is a highly significant difference between the means for haul order or direction (A, 277; B, 52), despite the correction for distance travelled. It is most unlikely that this is due to a change in net efficiency with speed, as the A hauls, at the faster speed, had the higher mean counts; efficiency would be expected to decrease with increase in speed. The analysis also shows a significant R×H

TABLE 8

NUMBER OF EGGS AND LARVAE ACCORDING TO HAUL ORDER (DIRECTION), AND DEPTH FOR SURVEY 1*a* IN THE VICINITY OF STATION 4

HAUL	DEPTH OF TOW		NUMBER OF EGGS		NUMBER OF LARVAE	
	SURFACE	DEEP	SURFACE	DEEP	SURFACE	DEEP
	feet	*feet*				
IA	1	6	165	144	–	1
IB	2	10	70	33	–	3
IIA	1	6	578	507	1	1
IIB	2	10	26	31	–	1
IIIA	1	10	359	336	–	1
IIIB	2	17	94	57	–	1
IVA	1	10	340	282	1	1
IVB	2	17	50	41	1	4
Totals			1,682	1,431	3	13

(replicate by haul order) interaction, i.e., variation other than that due to chance in the differences between A and B catches from replicate to replicate. Both the difference between the catches in A and B hauls and the large R×H interaction can be most plausibly attributed to non-random horizontal distribution of the eggs, as will be explained later.

In Survey 1*b* an attempt was made to cover the area in the vicinity of Stations 4 and 5 in a grid formation with one series of three substation hauls (I to III) spaced at intervals and following a general east-west direction, and a second series of three substation hauls (IV to VI) also spaced at intervals but following a general north-south direction. Each substation was represented by an A and a B haul, and each haul included a surface and a deep sample. In the first series, the A hauls were easterly, against the wind, and the B hauls were westerly, with the wind. In the second series, the A hauls were southerly and the B hauls were northerly, both crosswise to the wind, as illustrated in Figure 3. Deviations from a rectangular grid pattern were necessary because of danger of snagging the deep net on intervening shallows. On one occasion (Haul IIA) the deep net struck the bottom and was torn; it was replaced by another identical net in later hauls. No adjustment was made to compensate for loss of plankton in this haul, but the error introduced will not materially affect the conclusions of either this section or the one which follows. It was estimated that the ship travelled 2,400 feet during A hauls and 3,000 feet during B hauls in the first series, and that it travelled 2,700 feet in both A and B hauls in the second series. The data for each of the 24 samples are given in Table 10, and the analysis of the data, after adjustment to a mean distance of 2,700 feet and transformation to logarithms, is given in Table 11.

The adjusted egg catches are as follows:

SERIES	SUB-STATIONS	A		B	
		surface	*deep*	*surface*	*deep*
1	I	89	69	88	84
	II	21	6	46	44
	III	3	2	17	23
2	IV	191	133	146	124
	V	120	84	141	97
	VI	58	52	53	51

TABLE 9

ANALYSIS OF VARIANCE OF EGG CATCHES IN SURVEY 1*a* ACCORDING TO REPLICATE DOUBLE HAULS, HAUL ORDER (DIRECTION), AND DEPTH

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE
Replicates (R)	3	0.14504	0.04835
Haul order (H)	1	2.11768	2.11768**
Depth (D)	1	0.03796	0.03796
R×H	3	0.33144	0.11048*
R×D	3	0.02159	0.00720
H×D	1	0.00669	0.00669
R×H×D	3	0.02470	0.00823

* Significant.
** Highly significant.

TABLE 10

NUMBER OF EGGS AND LARVAE ACCORDING TO HAUL ORDER, AND DEPTH FOR SURVEY 1*b* IN THE VICINITY OF STATION 4

HAUL	DEPTH OF TOW		NUMBER OF EGGS		NUMBER OF LARVAE	
	SURFACE	DEEP	SURFACE	DEEP	SURFACE	DEEP
	feet	*feet*				
IA	2	19	79	61	1	1
IB	1	16	98	93	1	1
IIA	2	19*	19	5*	–	–
IIB	1	16	51	49	3	4
IIIA	2	20	3	2	1	2
IIIB	1	17	19	26	4	4
IVA	1	17	191	133	–	–
IVB	1	16	146	124	–	1
VA	1	17	120	84	–	1
VB	2	18	141	97	–	1
VIA	2	17	58	52	6	1
VIB	2	18	53	51	2	1
Totals			978	777	18	17

* Net hit bottom; some damage to net and loss of plankton.

As shown by the analysis of the data (Table 11), there are significant differences between substations, which are due mostly to the large difference between series. The difference between the (geometric) means for haul order (A, 35; B, 63) is not significant: in Series 1 the means differed to some extent (A, 13; B, 42), whereas in Series 2 they were similar (A, 96; B, 94). However, there is a significant interaction, now designated as S×H (substations by hauls), showing lack of consistency in the differences between A and B hauls from substation to substation. Again, the results may be most plausibly explained on the basis of non-random horizontal distribution of the eggs.

To explain the foregoing results satisfactorily it is necessary to assume only that there is a focus of abundance of eggs in the vicinity of Station 4, with gradients of decreasing abundance extending outward in all directions. The nature of the egg distribution which is postulated to have occurred during Surveys 1*a* and 1*b* is illustrated in Figures 2 and 3. Transection of the area at various distances from the focus would cause the great variability in catch and would readily account for the observed significant differences and interactions. As will be shown later, the presence of a focus of abundance of eggs in the vicinity of Station 4 is also demonstrated by the results of the general surveys.

It seems likely that non-random distribution of the eggs occurs at all stations. Slightly different gradients of abundance are passed through in making A as compared with B hauls, often causing large differences in the number of eggs caught. A similar situation may also occur in the case of larvae, although the differences between A and B hauls are, in general, less pronounced and persistent. Be-

TABLE 11

ANALYSIS OF VARIANCE OF EGG CATCHES IN SURVEY 1*b* ACCORDING TO SERIES, SUBSTATIONS, HAUL ORDER, AND DEPTH

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE
Substations (S)	5	4.91036	0.98207*
Between series	1	2.60827	2.60827
Within series	4	2.30209	0.57552
Haul order (H)	1	0.38457	0.38457
Depth (D)	1	0.07549	0.07549*
S×H	5	0.81374	0.16275**
S×D	5	0.04786	0.00957
H×D	1	0.04437	0.04437
S×H×D	5	0.05212	0.01042

* Significant.
** Highly significant.

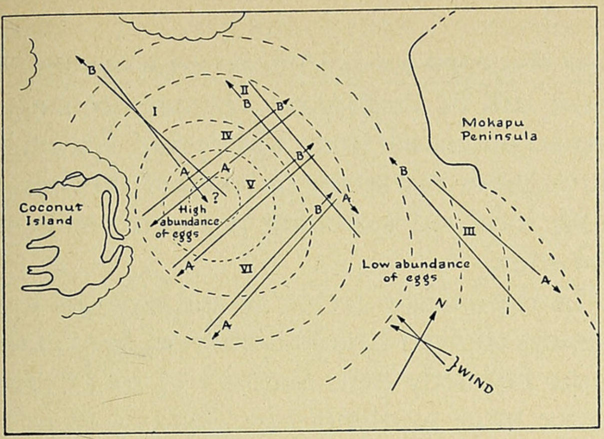

FIG. 3. A portion of the southern sector of Kaneohe Bay in the vicinity of Stations 4 and 5, showing the location of A and B hauls in Survey 1*b*, and indicating the presumed distribution of the eggs (broken isolines).

cause of the small numbers of larvae taken in the samples, a similar detailed analysis of the data was not undertaken.

Obviously, the peculiar non-random distribution of the eggs should be taken into consideration in designing a program of quantitative sampling for future work.

VERTICAL DISTRIBUTION OF EGGS AND LARVAE

The vertical distribution of eggs and larvae was studied only at Station 4 during Surveys 1*a* and 1*b*, the details of which have been discussed in the previous section. Unfortunately, it was not possible to sample efficiently over a range of depth. In analyzing the results (Tables 9 and 11), the surface samples, from 1 to 2 feet, are compared with those at "a depth," the depth ranging from 6 to 17 feet in Survey 1*a* (Table 8) and from 16 to 20 feet in Survey 1*b* (Table 10). The (geometric) mean catches of eggs in the adjusted data may be compared in the following tabulation:

HAULS	SURVEY 1*a*	SURVEY 1*b*
Surface	134	54
Deep	107	41

In both surveys there were more eggs at the surface than at a depth. There were no significant interactions involving depth in either Survey 1*a* (R×D and H×D) or Survey 1*b* (S×D and H×D). The significance of the difference between surface and deep hauls was tested by comparing the mean square for depth with an error term derived by pooling the sums of squares and degrees of freedom for the last three components in each of Tables 9 and 11. The difference approached significance for Survey 1*a* and was significant (P less than 0.05) for Survey 1*b*. It may be concluded that there are slightly more eggs at the surface than at a depth. It seems likely that there is a gradient of decreasing abundance from surface to bottom, although this cannot be affirmed positively from the present data.

The variation of temperature, chlorinity, and oxygen with depth for Surveys 1*a* and 1*b* is shown in Table 2. The results for Survey 1*b*, in particular, suggest that there may be a relationship between the vertical distribution of the eggs and the vertical distribution of these physical factors. Temperature decreases with depth, whereas both chlorinity and oxygen increase with depth. At the present stage of investigation it is idle to speculate as to the nature of the possible relationship.

The numbers of larvae taken in the various hauls of Surveys 1*a* and 1*b* were small. In 1*a*, fewer larvae were caught at the surface than at a depth, whereas in 1*b*, slightly more were caught at the surface than at a depth. No significant change in larva distribution with depth can be demonstrated with the present data.

HORIZONTAL DISTRIBUTION OF EGGS AND LARVAE

It has been shown that there are highly significant differences between the catches of eggs made from station to station, apart from differences between hauls at the same station. Accordingly, in the gross analysis to follow, the count at each station is assumed to be representative of a particular abundance level at each station.

Distribution of Eggs

To show the general distribution of eggs throughout the bay, the number (A plus B hauls) taken at each station was expressed as a percentage of the total number caught in each survey, and the four percentages for each station were averaged. This gave the data in the last column of Tables 3 and 4. The results for the 100 cm. net are portrayed graphically in Figure 4.

The following tabulation shows the general distribution of eggs according to sector and net:

SECTOR	LARGE NET		SMALL NETS	
	per cent of total	*mean per cent per station*	*per cent of total*	*mean per cent per station*
Southern	75.63	8.40	79.37	8.82
Middle	19.74	2.47	17.21	2.15
Northern	4.63	0.77	3.42	0.57

The results show that eggs were most abundant in the southern sector, less abundant in the middle sector, and least abundant in the northern sector. The results for Surveys 1, 2, and 3 were fairly consistent with the above averages. In Survey 4, however, most eggs were found in the middle sector.

Examination of the temperature and chlorinity data of Table 1 shows no apparent correspondence between their distribution and that of the eggs. For example, the average temperature (four surveys) for the three sectors were respectively 24.7, 24.5, and 24.7°C.; the average chlorinities (three surveys) for the three sectors were respectively 19.23, 19.11, and 19.16 p.p.m.

In the southern sector of the bay, all four surveys showed a peak of abundance of eggs in the vicinity of Stations 4 or 5 (Fig. 4, Tables 3 and 4). Both the interim surveys and casual sampling between surveys indicated the persistence of this peculiar distribution. There is no apparent relationship between the distribution of eggs (Table 3) and the distribution of temperatures and chlorinities in the southern sector (Table 1). The explanation of the focus of abundance of eggs in the northeast part of the southern sector is uncertain. It seems most likely that the eggs are held there in the eddy of a current, but information on this possibility must await a study of the circulation of water in the bay. If it is found that the eggs are held in an eddy system, it must still be discovered whether nehu eggs are accumulated from widespread spawning throughout the sector or whether they result from localized spawning near the center of the eddy.

In the middle sector of the bay, all four surveys showed larger numbers of eggs in the more northerly part, Stations 13 to 17, than in the more southerly part, Stations 10 to 12 (Fig. 4, Tables 3 and 4). Although on the average the maximum concentration was at Station 14, the peak of abundance varied from station to station with survey. For example, the largest number of eggs was encountered at Station 17 in Surveys 1 and 2, at Station 13 in Survey 3, and at Station 14 in Survey 4. This is in contrast to the relatively stable condition found in the southern sector of the bay. Variation in abundance at a station from survey to survey may be related to variation in the number of spawning fish, to variation in the current system in the middle sector, or to both factors. Judging from the topography of the middle sector, the current system would probably vary to a considerable extent with strength and direction of the wind and with phase of the tide.

In the northern sector of the bay, eggs were encountered in fair numbers only during Surveys 1 and 4. In Survey 1 they were relatively abundant at Stations 20 and 18, and in Survey 4, at Stations 20 and 19. On the average, the greatest abundance was at Station 20, which is located in the main ship channel toward the outside reefs. Either no eggs or very few eggs were taken at Stations 21, 22, and 23, which are located among the shoreside reefs in the northernmost part of the bay.

Comparison of Table 1 with Tables 3 and 4 shows no apparent relationship between variation in temperature and chlorinity and variation in egg abundance from station to station within surveys for either the middle or northern sectors of the bay.

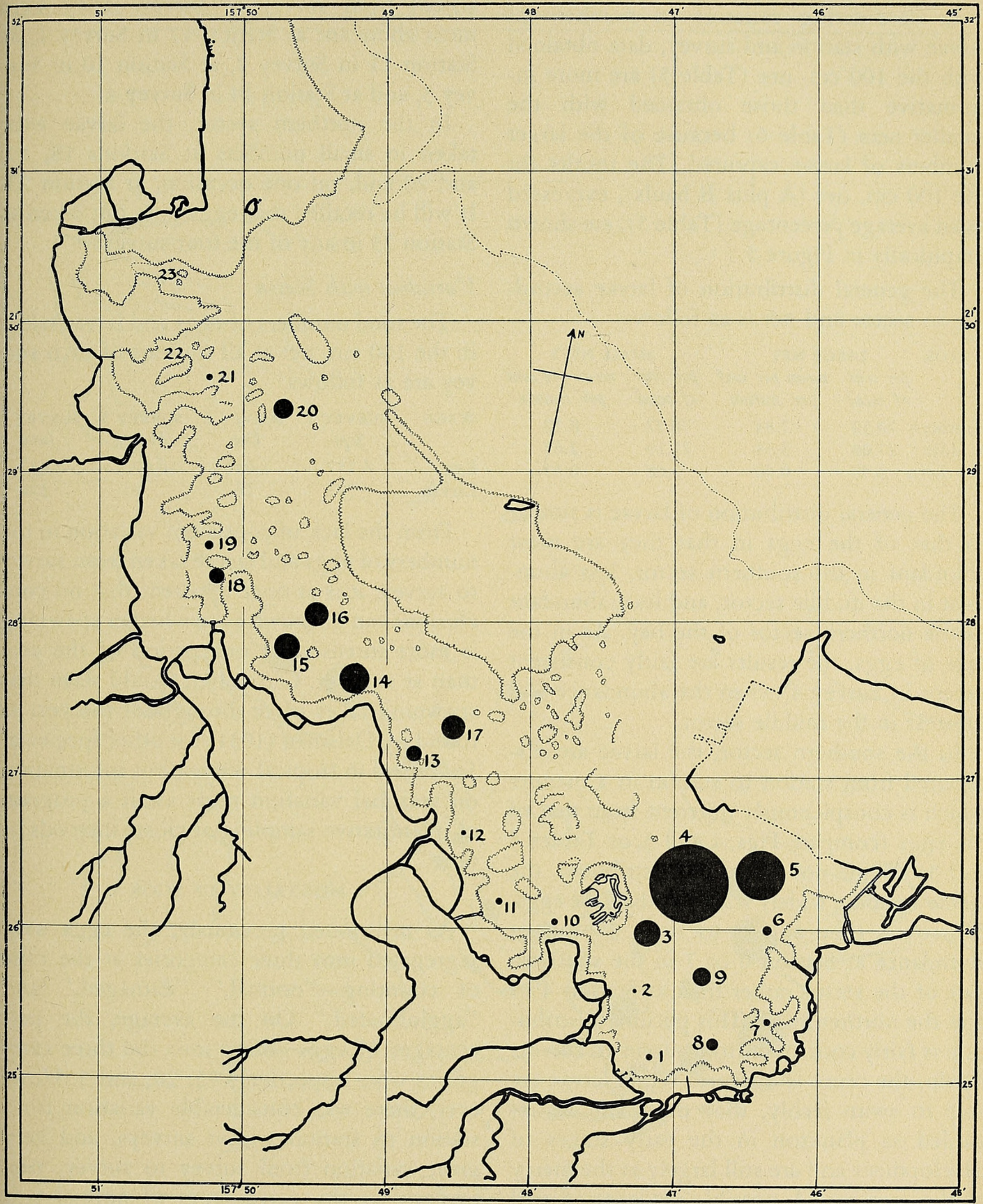

FIG. 4. Map of Kaneohe Bay showing the general distribution of the eggs according to station. The black circles are proportional in area to the number of eggs taken in combined A and B hauls with the 100 cm. net at each station. The distribution is presumed to be continuous between stations, rather than discrete, as shown.

Distribution of Larvae

In considering variation in numbers of larvae with station and survey, data obtained with the 100 cm. net (Table 5) are more informative than those obtained with the smaller nets (Table 6) because of the larger numbers of larvae captured. The results for the 100 cm. net (A plus B hauls), expressed as an average percentage (Table 5), are shown graphically in Figure 5.

The general distribution of larvae according to sector and net is as follows:

SECTOR	LARGE NET		SMALL NETS	
	per cent of total	*mean per cent per station*	*per cent of total*	*mean per cent per station*
Southern	70.52	7.84	76.72	8.52
Middle	27.08	3.38	21.19	2.65
Northern	2.40	0.40	2.08	0.35

The general distribution of larvae is similar to that of the eggs in that they are most abundant in the southern sector, less abundant in the middle sector, and least abundant in the northern sector of the bay. As in the case of eggs, the results are fairly consistent except in Survey 4, when the abundance was greatest in the middle sector.

In the southern sector, the larvae are distributed from station to station in a manner which is conspicuously different from that of the eggs (compare Figs. 4 and 5, or Tables 3 and 5). While not randomly distributed, the larvae are more widely scattered than the eggs. Moreover, they appear to form a peak of abundance at Station 6 or 7 in the southern part of the sector rather than at Station 4 or 5 in the northern part. This peculiar distribution is fairly consistent from survey to survey. Again, the cause is obscure. While larvae are able to swim feebly, they must still be regarded as plankton in the early stages of development and are still largely at the mercy of the currents. A possible explanation will be advanced in a later section which deals with the length composition of the larvae.

In the middle sector of the bay, the larvae again seem to be more widely scattered than the eggs. On the average they were most abundant at Station 14, but this was not consistent from survey to survey. They were most abundant at Station 17 in Survey 1, at Station 11 in Survey 2, at Station 10 in Survey 3, and at Station 14 in Survey 4.

In the northern sector, the larvae were taken in small numbers at Stations 18, 19, and 20 and, on one occasion, at Station 23. It will be recalled that eggs were not taken at Station 23 in any of the four surveys.

Variation with Season

The total numbers of eggs and larvae taken in the 100 cm. net at all stations of each survey are as follows:

STAGE	SURVEY 1 *Sept.*	SURVEY 2 *Dec.*	SURVEY 3 *March*	SURVEY 4 *June*
Eggs	6,757	1,940	10,022	2,432
Larvae	722	267	81	356

From the lack of consistent variation in the numbers of eggs and larvae taken from survey to survey, it is at once apparent that no conclusions can be drawn as to whether spawning is more intensive at one period of the year than at another. Certainly it would seem that spawning takes place throughout the year as found by Delsman (1931) for other species of *Stolephorus* in tropical waters, but information on seasonal variation must await a program of quantitative sampling at closer intervals of time.

MORTALITY OF EGGS

As mentioned previously, the eggs were segregated into three categories at the time of counting—"normal," "damaged," and "agglutinated." On the average, the percentages of eggs falling into the three categories were respectively 75, 20, and 5. However, there was considerable variation from station to station within surveys, and very great variation from survey to survey, particularly in the percentages of normal and damaged eggs. For example, in Survey 3 normal eggs accounted for 40.5 per cent and damaged eggs 58.2 per cent, whereas in Survey 4, normal eggs accounted for 85.5 per cent and damaged eggs 8.8 per cent. The

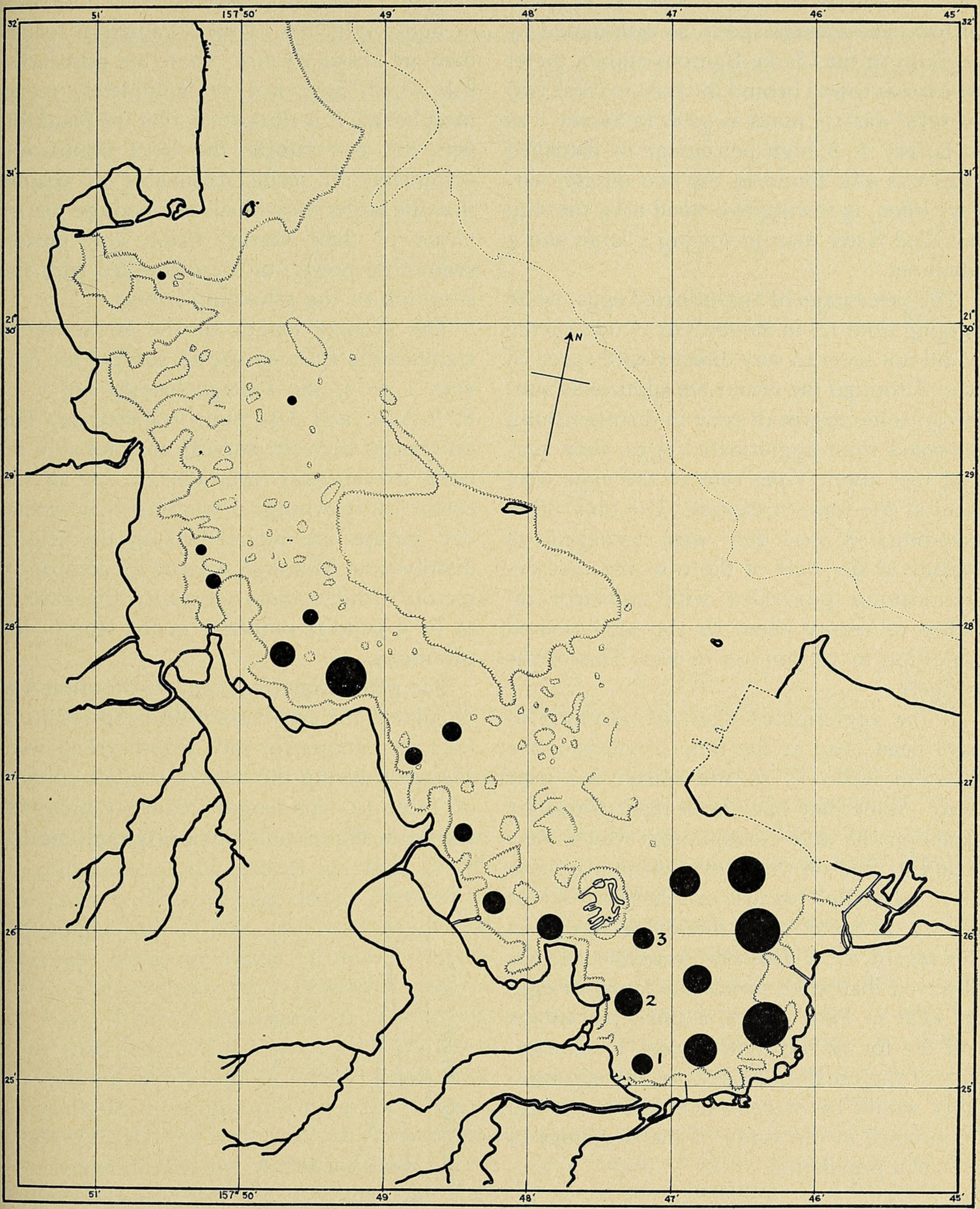

FIG. 5. Map of Kaneohe Bay showing the general distribution of the larvae. The black circles are proportional in area to the number of larvae taken in combined A and B hauls with the 100 cm. net at each station. The distribution is presumed to be continuous between stations, rather than discrete, as shown.

differences between surveys are probably related, in part at least, to differences in speed of tow. The average speed, as determined by readings of the Clarke-Bumpus current meter which was towed behind the boat in these two surveys, was 1.3 times as great in Survey 3 as in Survey 4. A high percentage of damaged eggs was also found in the two interim surveys when, in towing two small nets, the ship travelled faster than in towing a large and a small net.

The percentage of agglutinated eggs, while ranging from 1.3 in Survey 3 to 11.0 in Survey 2, did not seem to vary directly with speed of tow. Although the results are admittedly subject to some degree of error in distinguishing damaged from agglutinated eggs, they suggest that about 5 per cent of the eggs were dead at the time of capture. The only other possibility is that they were damaged on capture at the start of the tow and that decomposition proceeded with sufficient rapidity to reduce them to the agglutinated condition in 10 minutes or less. This seems unlikely.

If the agglutinated eggs are assumed to have been dead at the time of capture, the question arises as to the reason for their death. Some may have been regurgitated by chaetognaths and ctenophores, which were found to feed on the eggs. Others may have died "naturally" because of infertility, lack of vitality, or some other intangible factor. In this regard, D. Yamashita (unpublished) has observed that when normal undamaged eggs are kept in Petri dishes, a small percentage will die for no apparent reason. Determination of the cause and extent of the egg mortality would be of considerable interest and importance in the study of the dynamics of the nehu population.

LENGTH DISTRIBUTION OF LARVAE

The length distribution of larvae taken by both large and small nets is given for each survey in Table 12. It will be observed that the length ranges from 2.5 to 12 mm. Only one individual of larger size (20.5 mm.) was caught. The smallest nehu taken in the seines or night-light nets of the commercial fishermen are about 23 mm. These are post-larval fish which have not yet completely metamorphosed. It is clear, then, that the plankton nets did not sample the larva population completely. It seems reasonable to assume that the larger individuals escaped the net by virtue of their keener vision and greater swimming power, or these coupled with the adoption of the schooling habit.

The average length of the larvae varies significantly from survey to survey; for Surveys 1 to 4, the average lengths are 4.99, 5.73, 5.01, and 3.44 mm., respectively. The differences between surveys are probably related to variation from day to day in the extent of spawning, presuming that several day groups are represented in the length distribution. Although the data for comparing sectors within surveys are scanty, there seems to be a general similarity in the length distributions.

The percentage frequency distribution was calculated for each survey and the resulting four percentages for each length group were averaged, giving the data of the last column of Table 12. The length frequency polygon, shown in Figure 6, is obviously multimodal,

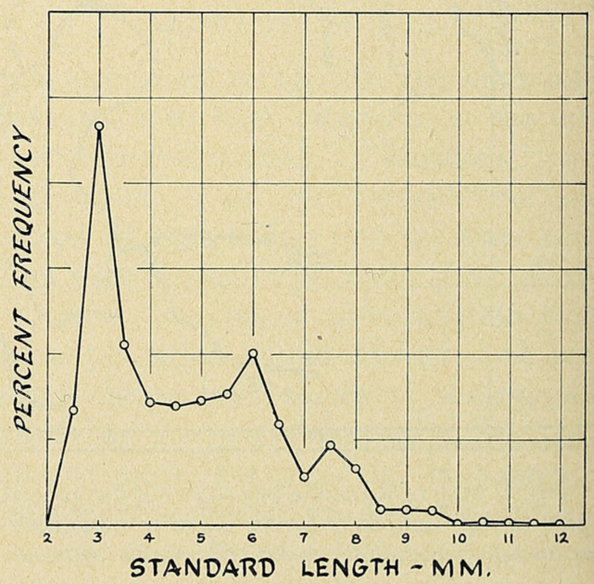

FIG. 6. The per cent frequency distribution of larvae according to length, all data combined.

TABLE 12

FREQUENCY DISTRIBUTION OF LARVAE TAKEN BY ALL NETS ACCORDING TO LENGTH, SURVEY, AND SECTOR (S, SOUTHERN; M, MIDDLE; N, NORTHERN), AND SUMMARY

LENGTH CLASS	SURVEY 1			SURVEY 2			SURVEY 3			SURVEY 4			MEAN PER CENT OF SURVEY TOTAL
	S	M	N	S	M	N	S	M	N	S	M	N	
2.5	27	–	–	–	–	–	8	–	–	28	26	1	7.12
3.0	178	6	1	6	2	–	11	3	–	54	123	4	23.35
3.5	63	–	–	21	4	–	3	2	–	19	43	2	10.27
4.0	57	–	–	10	9	–	–	2	2	11	9	–	7.29
4.5	54	–	–	23	3	4	5	–	–	13	4	–	6.24
5.0	61	1	–	27	5	–	3	1	–	6	2	–	6.81
5.5	73	–	–	20	11	2	3	1	2	3	3	–	7.44
6.0	56	–	–	25	8	2	9	5	–	6	1	–	10.03
6.5	50	–	–	14	12	1	6	–	–	3	1	–	6.33
7.0	41	–	–	5	6	–	1	–	–	3	1	–	2.94
7.5	43	–	–	6	8	2	6	–	–	2	2	–	5.07
8.0	30	1	–	7	6	–	4	–	–	–	1	–	3.56
8.5	9	–	–	2	2	–	1	–	–	–	–	–	0.98
9.0	14	1	–	3	2	–	–	–	–	–	–	–	0.95
9.5	4	1	–	4	1	–	1	–	–	–	–	–	0.95
10.0	3	–	–	–	–	–	–	–	–	–	–	–	0.10
10.5	–	–	–	2	–	–	–	–	–	–	–	–	0.19
11.0	1	–	–	1	–	–	–	–	–	–	1	–	0.19
11.5	1	–	–	–	–	–	–	–	–	–	–	–	0.03
12.0	2	–	–	–	–	–	–	–	–	–	–	–	0.06
–	–	–	–	–	–	–	–	–	–	–	–	–	–
20.5	–	–	–	–	1	–	–	–	–	–	–	–	0.09
Totals*	767	10	1	176	80	11	61	14	3	148	217	7	99.99

* The totals do not agree with those of other tables as some larvae were damaged and could not be measured.

with modes at 3.0, 6.0, 7.5, and possibly 9.0 mm.

In attempting to interpret the biological significance of the modes, it must be remembered that the eggs hatch between 12 midnight and 2 A.M. and that the newly hatched larvae are about 2.0 mm. in length. Since the tows were taken between 9 A.M. and 2 P.M., it seems reasonable to assume that the first mode, at 3.0 mm., includes larvae which are about 9 to 14 hours of age, comprising the 0-day group. Only a few of these, however, had the large yolk sac characteristic of larvae of this age reared in dishes. Some had obviously lost the yolk material when damaged during capture. Others, of 3.0 mm. and larger, appeared to have absorbed the yolk sac almost completely and to have advanced in their general development to a stage 24 hours older, at which the mouth parts are forming. It seems likely, therefore, that the distribution represented by the first mode includes larvae of both the 0-day group (9 to 14 hours) and also the 1-day group (33 to 38 hours).

Once the mouth has formed and the larvae start feeding, more rapid growth might be expected. Thus the modes at 6.0, 7.5, and 9.0 mm. may represent the 2-, 3-, and 4-day groups. This would indicate an absolute growth rate of 1.5 mm. per day. If this rate were maintained, the nehu would become initially vulnerable to the commercial fishery (at a length of about 23 mm.) within about 2 weeks after hatching. If there were a deceleration of growth (which is likely), it may still be assumed that the period between hatching and recruitment is short—a matter of weeks, rather than years as in most temperate zone fishes. The interpretation of the above results is, of course, tentative. More satisfactory data would be provided by a series of collections on successive days at the same stations.

To investigate the length frequency distribution of the larvae in the southern sector in more detail, the number in each length category for each station was expressed as a percentage of the total number caught in each survey. The four percentages for each length group at each station were then averaged. This method of calculation weights the percentages for each station according to the numbers caught at that station within surveys, but gives equal weight to the numbers caught during each survey. The results are shown in Figure 7.

As might be expected when the data are subdivided, the positions of the modes are somewhat erratic. An extra mode, which may represent the 1-day group, occurs at 4.5 mm. in some cases. In general, the smaller and younger larvae are relatively more abundant at Stations 6, 5, and 4 than elsewhere. Larger and older larvae are particularly abundant at Station 7, which is located behind the reefs at the southeast end of the bay. The results suggest that the newly hatched larvae are at first concentrated in the same area as the eggs, Stations 4 and 5, but that as they become larger and older they disperse from this area, with a large number moving in a clockwise direction through Station 6. The mechanism accounting for the peculiar distribution of larvae in respect to both number and length should be investigated.

Examination of the length distribution of the larvae in the middle sector reveals a somewhat similar situation. In general, the larvae at the centers of egg abundance, Stations 13 to 17, are smaller than those away from the centers, Stations 10 to 12. For example, the average length of the larvae in the former was 3.5 mm. whereas in the latter it was 5.3 mm. Again, this indicates a dispersal of the larvae from the areas of spawning.

In the northern sector only a few larvae were taken. Their average length was 4.6 mm.

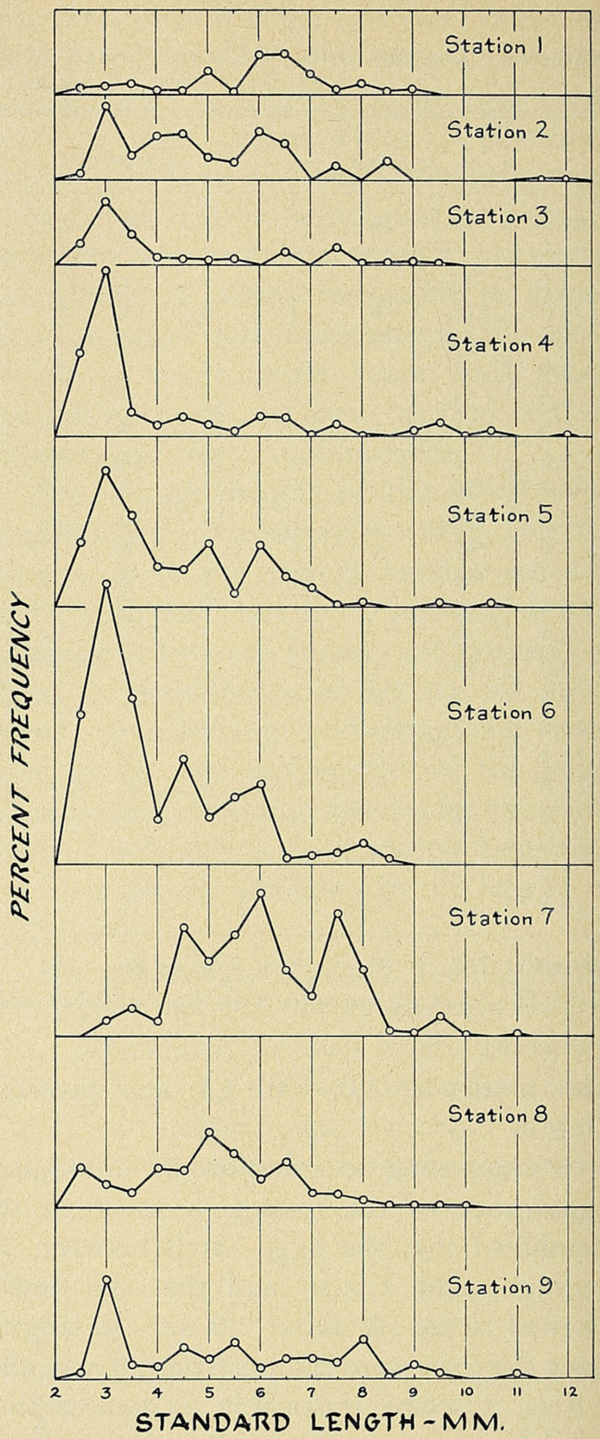

FIG. 7. The per cent frequency distribution of larvae according to length for each station in the southern sector of the bay.

An alternate explanation for the peculiar distribution of larvae in numbers and lengths might be advanced for both the southern and middle sectors. It might be postulated that both eggs and larvae remain close to the scene of spawning, and that the differences between stations are due primarily to erratic spawning at a station from day to day. This possibility cannot be denied, but such evidence as is presently available lends support to the interpretation given previously.

DISCUSSION

One of the objects of the present investigation was to formulate a sampling program for the estimation of egg and larva production throughout the year. Therefore it is in order to consider the design of such a program in the light of the present results. Its scope, however, must be limited by available funds.

The 100 cm. net is too large to be handled conveniently from a small vessel. The 22 cm. net is too small to give numbers of eggs and, particularly, larvae of sufficient magnitude for precise statistical analysis in a haul of reasonable time duration. Therefore a net of intermediate size, perhaps 50 cm. mouth diameter, is recommended. The net should be constructed of No. 40 grit gauze, and should be equipped with a current or flow meter and a detachable cod end. In design, it might follow that of the Hensen egg net.

Because of the small variability between catches of nets hauled simultaneously and the large variability between individual hauls, it would be more efficient to make several hauls with one net than to make one haul with several nets. For the same amount of work (chiefly involved in sorting plankton) four short hauls at one station, each of 5 minutes' duration, each spaced in regular fashion about the station, and each following a close, circular course, would be more informative than the sampling design followed in the present investigation.

Because of the slight but apparently consistent difference in egg abundance between surface and deep samples, horizontal tows at the surface, rather than either simultaneous surface and deep tows or oblique tows, could be used. However, the vertical distribution of the eggs should be subject to further investigation to determine the nature of the abundance gradient and its variation in time and space.

For a study of variation in abundance of eggs in the southern sector, one station located in the vicinity of Station 4 might suffice, provided it were sampled according to the above plan. Samples should be taken at close intervals of time throughout the year, say two per week. With a program such as this it should be possible to obtain information on both short-term and long-term fluctuations in the abundance of eggs. If the horizontal and vertical gradients of abundance, and their variation, could be established with precision, it should be possible to calculate the absolute abundance of eggs with reasonable accuracy. Interpolation in time and integration of the results would then lead to an estimate of total egg production for the southern sector which, according to this preliminary work, includes about 75 per cent of the total eggs spawned in Kaneohe Bay.

The sampling of eggs in the middle sector of the bay presents greater difficulty because of the lack of consistent variation from station to station with time. At least two, and preferably more than two stations should be included. With limited funds, it would be more efficient to make fewer hauls per station and to include more stations. A possible compromise might be to make two hauls at each of Stations 14 to 17 once a week.

Sampling for eggs in the northern sector might be neglected without any great loss of information, for the eggs occurring there form only about 4 per cent of the total. However, if included, it might be sampled at Station 20, two hauls, once a week.

If carried out as outlined, the above program would produce 936 samples per year. In addition, it would be desirable to check horizontal distribution at all stations and vertical distribution at certain key stations, e.g., Stations 4 and 16, at least at quarterly intervals, thus producing an additional two to three hundred samples. The total, about 1,200 samples, is regarded as the minimal number necessary for a reasonably accurate estimate of the production of nehu eggs in Kaneohe Bay.

The above program would provide data on variation in the abundance of eggs and, therefore, on variation in the abundance of the sexually mature portion of the fishable stock. Coupled with information on mortality and catch, it could lead to predictions of abundance of the mature population at various levels of fishing effort.

Estimation of larva abundance from plankton hauls is more difficult because of the widespread but non-random distribution of the larvae and their increased ability to escape the net as they become larger. Special stations for the estimation of larva abundance might be established, e.g., Station 7 in the southern sector, but this would greatly increase the number of samples to be collected and sorted. It might be possible to measure the abundance of larvae more accurately and with less effort by another method of collection—quantitative night-light traps. This possibility is now under investigation.

The reasons for the peculiar distribution of eggs and larvae in Kaneohe Bay are unknown, although presumably the distribution is related to the prevailing current pattern. A hydrographic study of the current system in all sectors of the bay at various times of year and under various weather and tide conditions is highly desirable.

The investigation was confined to the waters within Kaneohe Bay. There is the possibility that nehu eggs may also occur in coastal and offshore waters outside the bay. The presence of anchovy eggs in offshore waters has been reported for other species, e.g., the Australian anchovy, *Engraulis australis*, investigated by Blackburn (1941), the California or Northern anchovy, *Engraulis mordax*, investigated by Marr and Ahlstrom (1948), and several species of *Engraulis* occurring along the coast of Java and Sumatra, investigated by Delsman (1929). Furthermore, the eggs of several species of *Stolephorus* were also found offshore by Delsman (1931) in the last-named tropical locality. On the other hand, our local anchovy, the nehu, does not characteristically occur in the open ocean. As pointed out by Tester and Hiatt (in press), it appears to be confined to the bays and inlets where the water is somewhat more turbid and less saline than that of the open sea. As far as can be determined, nehu eggs have not yet been recovered from offshore waters adjacent to Hawaii by other agencies in the Territory who have made plankton hauls for pelagic fish eggs. Although it seems likely that nehu eggs do not occur extensively in offshore waters, the possibility that they are carried to or spawned in the open sea should be investigated.

The early life history of the nehu appears to be similar to that of the tropical anchovies studied by Delsman (1929 and 1931). In both, spawning takes place throughout the year, spawning occurs at night, there is a rapid embryonic development with an incubation period of 24 hours or less, and there is rapid growth during the larval stages. Two general features—continuous spawning and rapid development—present new problems in the field of fishery management.

SUMMARY

An investigation of the distribution of anchovy or "nehu" eggs and larvae in Kaneohe Bay, Oahu, Territory of Hawaii, was conducted during 1948 and 1949. It was exploratory in nature, and was designed partly to determine an efficient sampling program and partly to obtain information on the horizontal, vertical, and seasonal distribution of the eggs and larvae.

In each of four surveys (September, December, March, and June) 23 stations were sampled. Of these, nine were in the southern sector, eight in the middle sector, and six in the northern sector of the bay.

Three nets with respective mouth diameters of 100, 22, and 12.3 cm. were used. The large net and one of the two small nets were towed

simultaneously at each station, first in one direction and then in the opposite direction, just below the surface. In addition, two interim surveys were undertaken to investigate the horizontal and vertical distribution of the eggs and larvae at one station in more detail.

Nehu eggs and larvae were identified and nehu larvae were measured. The bluntly ovoid eggs, typical of several species of anchovy, were readily recognized. Some were obviously damaged during tows; others, amounting to about 5 per cent, were apparently dead at the time of capture.

A study of variability of the data revealed heterogeneity between stations, haul order (A and B), and nets, together with a significant interaction between stations and haul order. From the same analysis, it was found that the small nets were relatively more efficient than the large net, but that this could be attributed in part to loss of plankton from the latter because of rips which developed during one survey, and perhaps also to poor technique in handling the catch in the others.

Two interim surveys were undertaken at one station to determine the reason for the difference between A and B hauls and also to study the variation with depth. Both the heterogeneity in haul order and the interaction between stations and haul order could be explained on the basis of non-random distribution of the eggs. Apparently there was a focus of abundance of eggs, and gradients of decreasing abundance extending outward in all directions. Slight variation in the course followed by the vessel in making the hauls would produce large variation in catch because the egg concentration would be transversed at different distances from the focus.

The eggs were slightly more abundant toward the surface than at a depth. A gradient of decreasing abundance with depth was postulated.

Both eggs and larvae were present in all four surveys, showing that spawning takes place throughout all seasons of the year. Whether it is generally more intensive during the summer than during the winter remains to be determined.

Both eggs and larvae were generally most abundant in the southern sector of the bay, less abundant in the middle sector, and least abundant in the northern sector.

Neither eggs nor larvae were randomly distributed within sectors. In the southern sector there was evidently a focus of abundance of eggs in the northerly part. This peculiar distribution is probably related to the current pattern, with the eggs being held in an eddy. There are indications that the larvae are distributed in a similar manner to the eggs when first hatched, but that they gradually disperse as they become larger and older, and tend to become concentrated in the southern part of the bay. In the middle and northern sectors there were several foci of abundance of eggs, their presence and location probably depending on the time and place of spawning and the prevailing current system.

Several modes were evident in the length frequency distribution of the larvae. These were tentatively interpreted as day groups, and indicated an absolute growth rate of about 1.5 mm. per day during the initial growth period. The results suggest a remarkably short period between hatching and recruitment to the fishery, and a rapid overturn in the population, a situation which is probably typical of anchovy populations in tropical waters.

Based on the results of this preliminary work, a sampling program designed to measure total annual egg production in Kaneohe Bay was suggested. Details of gear, stations, and hauls were briefly discussed. It was recommended that, if possible, some other method of collection be used to determine the abundance of larvae.

The investigation was confined to the waters of Kaneohe Bay. Although it is considered unlikely that nehu eggs occur in large quantity in waters outside the bay, the possibility should be investigated in the future.