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THE PRODUCTION OF HALIBUT EGGS ON THE CAPE ST. JAMES SPAWNING BANK OFF THE COAST OF BRITISH COLUMBIA 1935 - 1946

By

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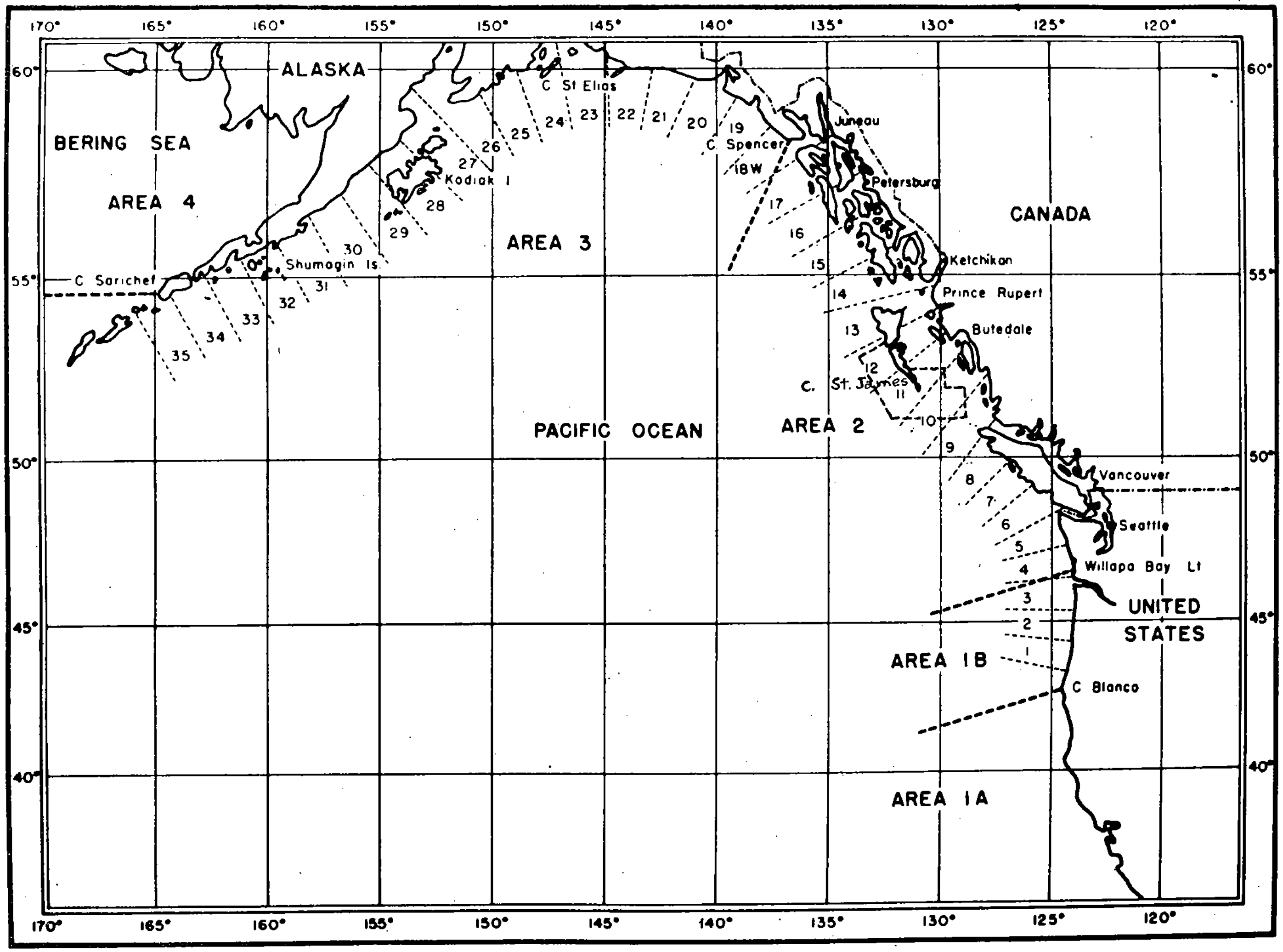

FIGURE 1. Pacific Coast of North America north of 35° N. latitude showing regulatory areas as established by the International Fisheries Commission and statistical areas as defined in Report No. 1 of the International Fisheries Commission. The area about Cape St. James enclosed by the broken line is the area sampled for halibut eggs.

INTRODUCTION

The International Fisheries Commission was established in 1923 by a treaty concluded in March of that year between the United States and Canada. The Commission established a staff of scientists and began investigations of the halibut of the Northeastern Pacific in 1925 with the objective of determining the causes of the declining yield of that fish and to seek for possible methods of rehabilitating the stock.

By 1928 sufficient information had been accumulated to confirm the need for conservation measures and as a consequence a new treaty was signed in 1930, which enabled the Commission to divide the convention waters into areas, to limit the catch that could be taken from each area, and to fix the size and character of gear that could be used for halibut fishing. It also provided that the fishing fleet must furnish information to the Commission on the catch, the amount of gear fished and on the location of fishing. The most important so-called chicken grounds in Area 2 inhabited by immature halibut were closed. The regulations adopted by the Commission under this new treaty consisted primarily of limiting the catch to the level to which it had fallen in 1930 and 1931*. Since the catch in 1931 must have been less than the stocks present at that time could produce, an immediate increase occurred in abundance of fish on the banks and the Commission was not required to impose further restrictions in order to obtain recovery of the stock. While the first restriction of the fishery in 1931 was not through Commission action, the subsequent stabilization of the catch at the level of 1930 and 1931 was, and this stabilization of catch and the resultant continued restriction of fishing intensity has been responsible for the continued recovery of the fishery.

In 1937 a third treaty was concluded which provided additional flexibility in the regulations in order to increase the scope of operation of the fishing boats by permitting the capture of some halibut incidental to the fishing for other species. Also, by restricting vessel clearance for the fishing grounds as the catch limit was approached, more effective control of the total catch was obtained. These regulations had little effect on the basic measures for conservation.

Investigation of the nature of the halibut populations of the Pacific Coast have shown that they are separated into two major groups of populations with the boundary between lying approximately at Cape Spencer (see Figure 1). Tagged mature fish, released in various locations along the entire coast west of Cape Spencer in present regulatory Area 3 were found to move relatively freely between banks in that area. However, off the coast of British Columbia and Southeastern Alaska in present regulatory Area 2 the movements were generally confined to a random distribution within the confines of the small bank on which

*Because the Commission did not restrict fishing any more than it had already been restricted by the fall in market price in 1931, some have felt that the recovery of the fishery in later years had occurred automatically without benefit of any real regulatory action.

the fish had been tagged. The number of recoveries of tags which had moved between the two large areas was small in proportion to the chances of recovery expressed in terms of intensity of fishing. (See Table 6, Thompson and Herrington, 1930.) This contrast in habits of the fish in the two areas was found to be associated with the age and size of fish which predominated in the stocks. To the westward in Area 3 was found a substantial proportion of mature fish and these were found to undertake major migrations between the spawning grounds in the northern and eastern parts of the Gulf of Alaska and the feeding ground farther west. Few mature halibut were found in Area 2 off British Columbia and Southeastern Alaska and the young were primarily non-migratory.

Additional evidence of the separation of the two stocks of halibut at Cape Spencer was derived from a study of the variations in yield of the fishery during the years prior to 1930 (Thompson, Dunlop and Bell, 1931). The populations in the two areas had declined roughly in proportion to the age and intensity of the fisheries that they had supported. But the decline in Area 2 had begun earlier since the fishery had begun earlier there and the catch per skate had dropped to a lower level than it had in Area 3. On the other hand the catch per skate of fish on the more recently exploited and more remote banks in Area 3 showed plainly that they had been affected by the fishery in other parts of Area 3. The first catches on those banks showed approximately the same catch per skate that was found at the same time in the rest of Area 3 which had already suffered a considerable decline (Figure 22, page 63, Thompson, Dunlop and Bell, 1931). Differences in the growth rates of the fish in the two areas corroborated the results obtained from tagging (Dunlop, Ms.). The separation of the two stocks was further substantiated by differences in body proportions of fish taken in the two areas (Bell, Ms.). The Area 3 fish grow more slowly than do those in Area 2 and the latter have on the average smaller heads than do the western fish.

A widespread search for the pelagic eggs and larvae of the halibut produced by the relatively large spawning populations remaining in Area 3 between 1927 and 1930 indicated that few were carried into Area 2, so that in both older and younger stages the two stocks seemed to be practically independent (Thompson and Van Cleve, 1936). The concept of separation of the halibut populations in the two areas during their early life history was supported by an investigation of the ocean currents in the Gulf of Alaska (see Reports 4 and 10, International Fisheries Commission). Since the eggs and young of halibut had been found to be extremely scarce in Area 2 the lack of an outside source of young meant that the halibut stocks in that area must be self supporting and that their rehabilitation would depend upon whatever gains could be made in those stocks alone.

The nature of the problems involved in rehabilitating the halibut stocks was clarified further through a study of the changes in the catch per unit of effort used as a measure of abundance, the total catch, the mortality rates estimated from tagging experiments, and growth rates obtained from detailed studies in that field (Thompson, Dunlop and Bell, 1931; Thompson and Bell, 1934; and Dunlop, Ms.). On the basis of a simple hypothesis relating these variables as in problems of compound interest the same changes that had been observed in the catch per skate and total catch were reproduced in a theoretical stock with remarkable accuracy by merely varying the fishing intensity as it had varied in the fishery. It was apparent that the fishery was the dominant factor in determining not only the population size of the Pacific halibut but also in establishing the level at which the total yield could be stabilized. This has been amply borne out in the years since 1931 by the continued increase of catch per skate with the continued restriction of total catch along the lines that correspond closely with the original theory. Even the total yield has increased, with indications of a higher level of stabilized abundance and an increase in the reproductive potential of the population on the banks (Thompson, 1950 and 1952, Dunlop and Bell, 1952).

The basic problems in the early stages of regulation were to increase, insofar as possible, the production of young and then to maintain it at a high level and, subsequently, to make the best possible use of the greater number of recruits. The accomplishment of these objectives required regulations and the success of the latter depended upon the establishment of an adequate system of observation to follow closely their effects. Three lines of observation were followed intensively by the Commission:

(1) The measurement of abundance of fish of catchable size from the catch per unit of effort or catch per skate of gear. This method was established early in the investigations as the most natural outgrowth of basic information that was available from the records of operations of the Pacific halibut fishery.

(2) The measurement of internal changes in the population from size and age composition of market landings. When sold, halibut are separated into trade categories of small, medium and large. Since this separation is based upon the personal judgement of cullers, and practices vary in different places and under different conditions, its accuracy is insufficient to assess the nature of the catch. Therefore a system of sampling the catches when landed was instituted in 1934 at the various ports and has been carried on ever since. Both of these methods of observation (catch per skate and market measurements) depend upon the fishery and measure only that part of the halibut population which is exploited.

(3) As a third approach, a measure of the changes in the population was sought which would not depend upon the fishery. The quantitative measurement of the varying numbers of eggs produced on the principal spawning banks was chosen in the hope that it would give some indication of changes in the spawning population on the grounds off the coast of British Columbia.

During the winter of 1934-35 a program was begun to follow changes in the production of halibut eggs in Area 2. Practical considerations forced limitation of concentrated plankton work in search of halibut eggs to a small area that could be covered adequately by one boat during the two or three months of heaviest spawning. Because of weather and other restrictions on operating time, the final program was limited to repeated net hauls over one spawning area with hydrographic observations whenever possible. The area sampled was approximately 11,000 square miles and was covered by a grid of 65 stations which were 10 miles apart in the region of greatest egg catches and 15 miles apart in the other sections of the area (Figure 2).

Theoretical consideration of the changes in spawning stock and in the resultant numbers of ova produced (Thompson and Van Cleve, 1936) indicated that minor changes in fishing intensity, if continued for sufficient time for the exploited populations to reach stability of numbers, would result in changes in abundance of spawn that would be of sufficient magnitude to be relatively easy to measure. Combining the effect of rate of growth, rate of survival from natural death, and rate of survival from fishing, it was shown that a decline of 14 per cent in fishing intensity would double the weight of twelve-year-old fish surviving (i.e. would at least double the egg production), presuming no change took place in the other mortality rates.

In 1929 over 621,000 skates of gear were fished in Area 2. In 1933 the amount of gear ran, fell to 437,000 skates, a decline of about 30 per cent. There was little doubt therefore that the changes that had taken place in the fishery over a period of only four years should have been sufficient to increase the spawning stock and hence the number of eggs spawned.

Detection of these changes hinged upon the possibility that the eggs could be sampled adequately and that no other factors would affect the sampling or apparent abundance of the eggs on the banks sufficiently to mask the changes that would result from variations in the size of the spawning stock.

ACKNOWLEDGMENTS

During the eleven years of operations reported upon below, eighteen biologists besides the authors have participated in the field work, and these men played a vital role in the success of the arduous work at sea. Special mention should be made of Mr. Olaf E. Eriksen, formerly with the International Fisheries Commission, who accompanied the field party for seven of the eleven years as a technical assistant. Mr. Jacob Engdahl (deceased) was for five years captain of the chartered vessel used for this work, while Mr. Conrad Knutsen was captain for three seasons and accompanied the boat in various other capacities in all the other years. Mr. Rasmus Bergsnes (deceased) was captain for two years and Mr. Peter Jacobsen for one year. The Commission is deeply indebted to all of these men for their interest and cooperation in making a success of the field operations.

The work was begun by the senior author under the direction of Dr. W. F. Thompson, then Director of Investigations of the International Fisheries Commission, and was continued under the direction of Mr. H. A. Dunlop who became director of the Commission in 1940. The junior author took over the

work in 1941 and carried it on until December 1946. The analysis of data and writing of the report have comprised a joint project of the two authors. The senior author is now Director, School of Fisheries, University of Washington; the junior author, Assistant Director, Applied Fisheries Laboratory at the same institution.

Mr. H. A. Dunlop and Mr. F. H. Bell of the staff of the International Fisheries Commission have assisted in many ways, not the least of which was by furnishing data concerning other phases of the investigation, and they as well as Dr. W. F. Thompson, now Director of the Fisheries Research Institute, University of Washington, have performed the essential task of critically reviewing the manuscript.

REGION SAMPLED

A quantitative study of the production of halibut eggs required first the establishment of a practical method of sampling. It was also necessary to determine with some accuracy the area and time of spawning as well as the variations in distribution of the eggs during development in order to develop an effective pattern of sampling.

In order to obtain a picture of the number of eggs being produced in Area 2 it would have been necessary either to sample all parts of this area in which spawning occurs or to sample a spawning ground that was representative of conditions in the entire area. The present report includes only the preliminary phases of such an investigation covering the development of a simple and practical method of assessing the variations in numbers of eggs produced each year on one spawning bank.

From surveys made prior to 1934-35, most of the spawning of halibut in Area 2 had been found to be concentrated on two banks; the "Whaleback" which lies westward of the north end of Graham Island, and "Cape St. James", which lies close inshore around the southern tip of the Queen Charlotte group. Operations were tried on both and the "Whaleback" area was found to be a poor place to work. Lying from 30 to 50 miles offshore it was a long run from the nearest shelter and with the frequent storms and continual cloudiness there were no means of checking position or in fact of maintaining the boats' position within working range of the bank. The Cape St. James grounds were therefore used by force of circumstances. Since they lie within a few miles of shore the net haul sections could be run on and off shore with a positive check on location continually maintained. Because the work has been limited to the Cape St. James grounds the results are representative of the conditions in Area 2 only insofar as those conditions are reflected in the Cape St. James spawning stock.

The area chosen for concentrated study is shown in Figure 2 on which is plotted the general plan of net haul stations which was followed each season from December, 1934, to February, 1946, except for the winter of 1943-44.

During this period 1,080 stations were occupied. The area sampled is approximately bounded by 51° N. latitude on the south and by 52° 15′ N. latitude on the north in Hecate Strait and by 53° N. latitude on the west coast of the Queen Charlotte Islands. The east-west boundaries are 129° and 133° W. longitude respectively. The relationship of this area to the region of distribution of halibut is shown in Figure 1.

Results of net hauls over a period of eleven seasons indicate that the population of halibut eggs in the area chosen is apparently isolated from the eggs produced on other spawning banks and, while the currents may carry some eggs out of the area, the numbers carried into the area are not great enough to be measured by the present sampling technique.

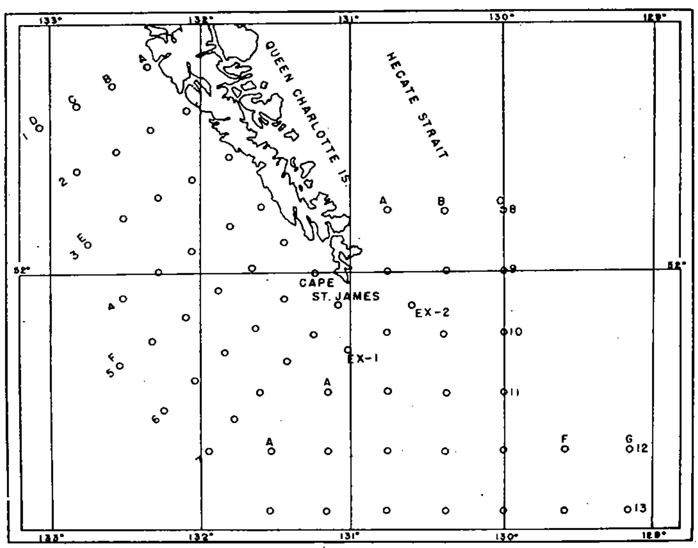

FIGURE 2. General plan of net haul stations on the Cape St. James grounds.

Tagging experiments indicate that the Cape St. James spawning stock is available to the fishery not only at Cape St. James, but for some distance from it. Cape St. James spawning grounds lie between the outermost parts of statistical Areas 10 and 11*. From 856 halibut tagged on these grounds during the spawning season of the winter of 1939-40, 171 tags were recovered up to 1944 of which the location of recovery was known for 166. The numbers recovered in different places are shown in Figure 3. One per cent was recovered at Cape St. James, 63 per cent in the rest of Areas 10 and 11, 27 per cent in Areas 9 and 12, and 9 per cent outside of these limits.

*For statistical reasons it was necessary to consider portions of the coast smaller than the regulatory areas. The coastline was arbitrarily divided into 60-mile sections which were called statistical areas (Thompson, Dunlop and Bell, 1931). Both the regulatory and statistical areas are shown in Figure 1.

Comparison of the number of tags recovered from each of the 60-mile statistical areas from Vancouver Island to Dixon Entrance with the amount of fishing done in each area shows no relationship between fishing intensity and tag recoveries. However, shortening of the fishing season may have had some effect on the selection of particular sizes of fish by the fishery. Recoveries of tags in the Goose Island area indicate that the fish tagged at Cape St. James are not as available now to that fishery as are the immature "residents" of that bank (p. 27) indicating that the present fishery is not sampling the Cape St. James spawning stock in proportion to other stocks in Area 2.

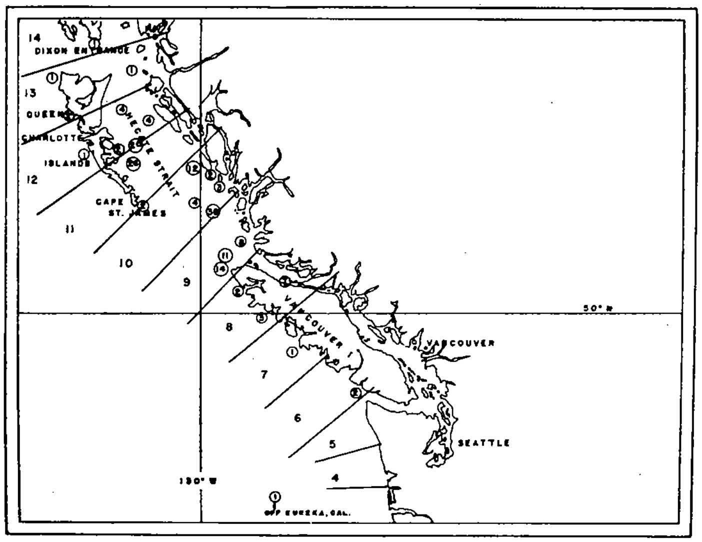

FIGURE 3. Recovery areas of 166 halibut from 856 tagged on the Cape St. James grounds during the winter of 1939-40. Circled numbers are the number of tags per fishing spot recovered by 1944. Other numbers are the 60-mile statistical areas.

Since regulation began in 1932 the commercial fishing season in regulatory Area 2 has become shorter each year. It lasted for 206 days in 1933; was reduced to 104 days by 1940 and to 42 days by 1946. Since the opening of the season has been gradually moved from February 1 in 1933 to May 1 in 1945, the fishery has gradually been confined to the months of May and June. At this time of year the spawning stocks have left the spawning grounds to become dispersed so that they are no longer subject to an intensive fishery. These restrictions on the commercial fishing season have precluded the tracing of tags from the other areas to the spawning grounds off Cape St. James and have resulted in few recoveries on the spawning grounds themselves.

It may be concluded that the present fishery is not sampling the Cape St. James spawning population as intensively as the other populations in Area 2.

Therefore, the measurement of variations in the spawning population through assessing changes in the production of eggs would give results that could not be expected to agree with the changes in catch per skate. Since the spawning population is not being as intensively fished, it is possible that that segment of the Area 2 halibut population is not varying in the same way as are the immature fish.

METHOD OF SAMPLING

In undertaking to sample the halibut eggs quantitatively we had only a rough idea of the levels at which the eggs float. Earlier work on the halibut eggs in the Gulf of Alaska had indicated that these levels varied considerably and presented the possibility that such variations might be associated with differences in the density of the water in which spawning took place as well as with differences in the stage of development of the egg. In addition, since spawning occurred over a considerable period of time and the eggs drift with the ocean currents, the sampling method had to take into consideration the possibility of variations in horizontal distribution as well as in the abundance of eggs at different parts of the spawning season. In the interest of economy of time and because of the lack of sturdy equipment capable of rapidly sampling large volumes of water over a wide range of depths, the type of net adopted was of the simple design used in earlier surveys. The method of hauling the nets (Figure 4) was then standardized to give samples which were comparable, both qualitatively and quantitatively. In addition the locations at which the hauls were taken were standardized and the same area was covered each year in as nearly the same manner as possible.

The nets were modified from those previously used (Thompson and Van Cleve, 1936) only by the addition of an inner throat of No. 14XXX silk grit gauze used as a lining in the anterior section, previously composed only of one-half inch stretch mesh cotton netting. The method of hauling was also similar (*ibid.* p. 88). Beginning with the winter of 1938-39 accurate records of the time of hauling each net at each level were kept with a stop watch so that the catch of each net could be corrected to a standard time of hauling.

Attempts were made to obtain exact records of the depths at which the nets were hauled by using depth gauges similar in principle to that of the Budenberg gauge described in the reports of the Discovery Expedition (Discovery Reports Vol. XIII, p. 102 and pl. XIII). However, these were not successful due largely to faulty construction of the instrument rather than to design. Sufficient data were collected, however, to indicate that the mean depth at which nets were hauled was approximately 84 per cent of the length of the cable out. The relationship of the standard haul pattern to the distribution of halibut eggs with depth was studied by means of electrical devices operating closing nets (Van Cleve, 1937). Temperatures and salinities taken concurrently at these stations showed that the halibut eggs are in general found between depths of 75 and 400 meters, within a range of water densities of 1.02540 to 1.02660. Since these

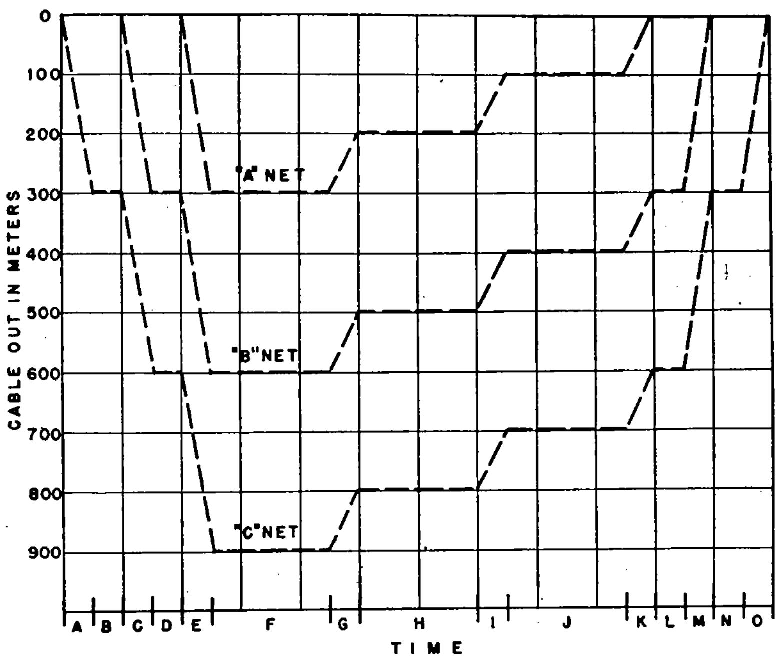

FIGURE 4. Time-Depth Diagram of a Standard Haul.

Time A—"C" net paying out 300 meters.
B—Attaching "B" net.
C—"B" and "C" nets paying out 300 meters.
D—Attaching "A" net.
E—"A", "B" and "C" nets paying out 300 meters.
F—Towing 20 minutes at 300, 600 and 900 meters respectively.
G—Nets up 100 meters..
H—Towing 20 minutes at 200, 500 and 800 meters respectively.
I—Nets up 100 meters.
J—Towing 20 minutes at 100, 400 and 700 meters respectively.
K—Nets up 100 meters.
L—Removing "A" net.
M—"B" and "C" up 300 meters.
N—Removing "B" net.
O—"C" up 300 meters.

NOTE: After 1942, haul depths reduced by 40%.

densities and hence the level of occurrence of the eggs varied considerably the standard pattern of net haul provided the best method of ensuring maximum sampling of the eggs short of the adoption of an elaborate hydrographic program that would have been impractical as to both time and cost. (See Appendix, p. 41, Figure 18.)

Further checks on quantity of water strained by each net were also made by means of current meters mounted within the mouths of the nets. Some difficulty was experienced in obtaining a current measuring instrument rugged enough to stand up under the hard usage to which it was subjected and at the same time sensitive enough to give accurate readings. The machines developed in later years appear to be satisfactory but due to alterations in design and difficulties experienced, the only correction made in the following analysis is for the number of minutes the nets were in the water per meter of cable out at each station. All nets operated at each station are lumped together in making this correction so that the correcting term is given as the number of minutes a single one-meter net was hauled in the water for each meter of cable payed out.

TABLE I. NUMBER OF STATIONS BY THREE-DAY PERIODS TAKEN ON THE CAPE ST. JAMES GROUNDS
From 1934-35 to 1942-43; 1944-45 to 1945-46.

Date (3-day period ending)		1934 —35	1935 —36	1936 —37	1937 —38	1938 —39	1939 —40	1940 —41	1941 —42	1942 —43	1944 —45	1945 —46	Total
Dec.	7	—	—	—	—	7	8	—	—	—	—	—	15
	10	—	—	2	—	11	9	—	4	—	—	—	26
	13	—	—	4	—	16	3	—	3	—	—	—	26
	16	—	—	2	—	14	4	—	10	—	—	—	30
	19	6	—	4	—	19	10	—	6	—	—	—	45
	22	10	—	0	—	0	11	—	5	—	—	—	26
	25	1	—	0	—	0	0	—	0	—	—	—	1
	28	0	—	6	—	0	0	—	0	—	—	—	6
	31	7	—	4	—	0	1	8	0	—	—	—	20
Jan.	3	18	—	13	9	0	7	8	11	—	—	—	66
	6	5	—	3	11	10	15	2	15	—	—	—	61
	9	9	—	6	7	4	8	0	0	—	—	—	34
	12	—	8	4	6	9	7	8	0	3	—	4	49
	15	—	19	6	3	10	10	12	1	3	4	12	80
	18	—	0	4	5	5	14	3	2	0	14	12	59
	21	—	0	9	7	6	0	0	0	0	7	0	29
	24	—	12	3	0	0	0	4	0	4	0	0	23
	27	—	13	6	0	0	0	7	0	2	9	0	37
	30	—	4	5	3	10	17	7	10	1	15	4	76
Feb.	2	—	—	3	10	4	0	1	10	0	2	11	41
	5	13	—	—	6	5	11	6	7	0	0	5	53
	8	12	—	—	4	4	—	4	8	6	5	9	52
	11	3	—	—	16	9	—	10	5	5	1	—	49
	14	8	—	—	1	—	—	0	8	2	0	—	19
	17	3	—	—	0	—	—	10	12	2	0	—	27
	20	—	—	—	8	—	—	20	12	6	5	—	51
	23	—	—	—	11	—	—	3	2	4	4	—	24
	26	—	—	—	1	—	—	14	—	—	1	—	16
Mar.	1	—	—	—	8	—	—	19	—	—	—	—	27
	4	—	—	—	—	—	—	12	—	—	—	—	12
Total:		95	56	84	116	143	135	158	131	38	67	57	1080

SPAWNING SEASON

The distribution of net hauls during the months of sampling is shown in Table 1. The period covered has not been uniform each year. However, considering all years since the beginning of work on the Cape St. James ground, the major portion of the spawning season has been sampled. The average corrected catch of stage 1* and stage 2 eggs per station, calculated over weekly periods, is shown in Figure 5. The average date of capture of stage 1 eggs falls on January 19 and of the stage 2 eggs on January 25 with the standard deviation of each being 15.2 days. December 30 and February 9, the limits of the

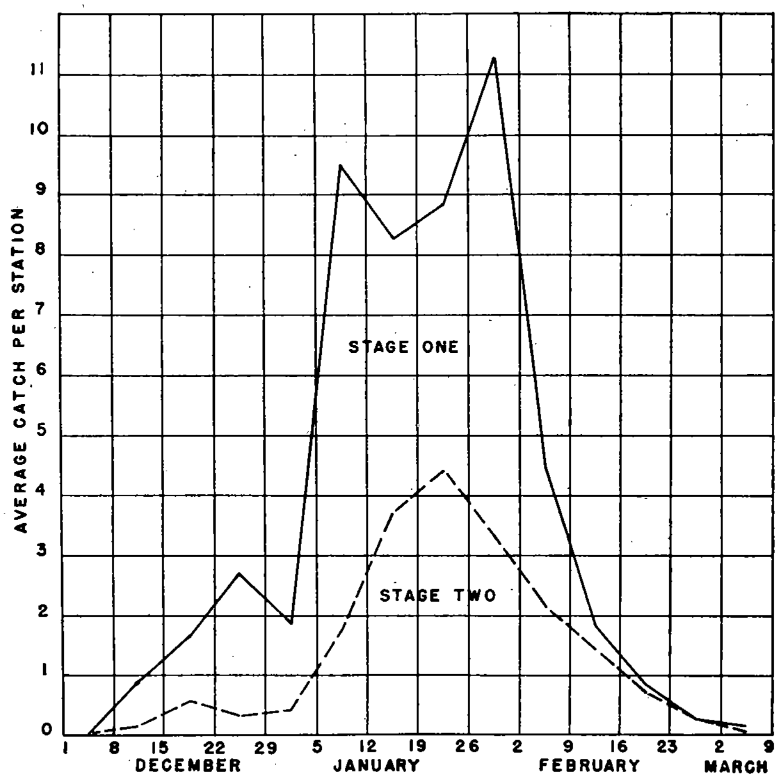

FIGURE 5. The average corrected catch of stage 1 and stage 2 eggs per station per week for all years of sampling on the Cape St. James grounds.

arbitrarily selected sampling period, are 21 days or 1.38 standard deviations either side of the mean so that 83 per cent of the catch should have been taken between those dates (Snedecor, Table 8.6). As a matter of fact, 84 per cent of all stage 1 eggs, weighted for number of hauls taken in all the years of sampling, were caught between December 29 and February 8.

*Stage 1 includes all stages of development up to the closure of the blastopore and stage 2 from the closure of the blastopore to hatching.

Both of the periods before and after the above dates were well sampled. One hundred seventy-six stations (18.5% of total) were taken during the four weeks preceding December 29. Most of these hauls were taken in 1938, 1939 and 1941. Two hundred thirteen stations (22.3% of total) were taken during the four weeks following February 8, principally in 1938, 1941 and 1942.

The net hauls have shown maximum numbers of eggs within the same period each year, indicating that the time of sampling has accomplished the objective of covering the height of the spawning period and in this respect the results should be comparable from year to year.

DISTRIBUTION OF THE HALIBUT EGGS

The distribution of the stage 1 halibut eggs around Cape St. James is shown for each year from 1935 to 1946 in Figures 6 to 16 inclusive. The contour lines enclose areas determined according to the average number of eggs taken at each station locality during the period of December 30 to February 9. These numbers were corrected, as described above (p. 14), for the number of nets used at each station and for the length of time these nets were hauled. The contours were drawn according to the method outlined by Buchanan-Wollaston (1923). (See page 35).

In most years the area in which halibut eggs were caught was encircled by hauls in which no halibut eggs were captured and thus it was possible to draw complete contours for egg catches as low as one per station. Sampling in 1935 and 1936 (Figures 6 and 7) was not widespread enough to complete all contours. In addition, the 1937 stations (Figure 8) were not carried far enough to the southeast of the Cape. Sampling in 1943 was especially deficient because war-time restrictions prevented boat operations after dark.

The contours show the presence of spawning in the immediate vicinity of Cape St. James in every year sampled. A varying amount of spawning is indicated along the western shores of the Queen Charlottes. It extended farthest northwest in 1942 when eggs were taken as far north as station 2157 off the mouth of Rennell Sound (latitude 53° 00′ N.). Since eggs were taken here in the earliest cleavage stages their presence could not have been due entirely to drift. However, a large number of stage 2 eggs were taken that year off Tasu Sound (latitude 52° 45′ N.) and these may have come from farther to the southeast. The effect of drift is also seen in the presence of some eggs south of Cape St. James in 1937 and 1938 with large concentrations in 1940, 1941 and 1945. The presence of a few eggs in the net hauls taken to the southeast of Cape St. James along the edge of the continental slope, especially in 1937, probably is an indication of some spawning along the edges of the banks toward Vancouver Island. The heaviest spawning areas in the Cape St. James region were sampled in all years and there appeared to be very little exchange of eggs with outside areas within the period of development covered in stage 1.

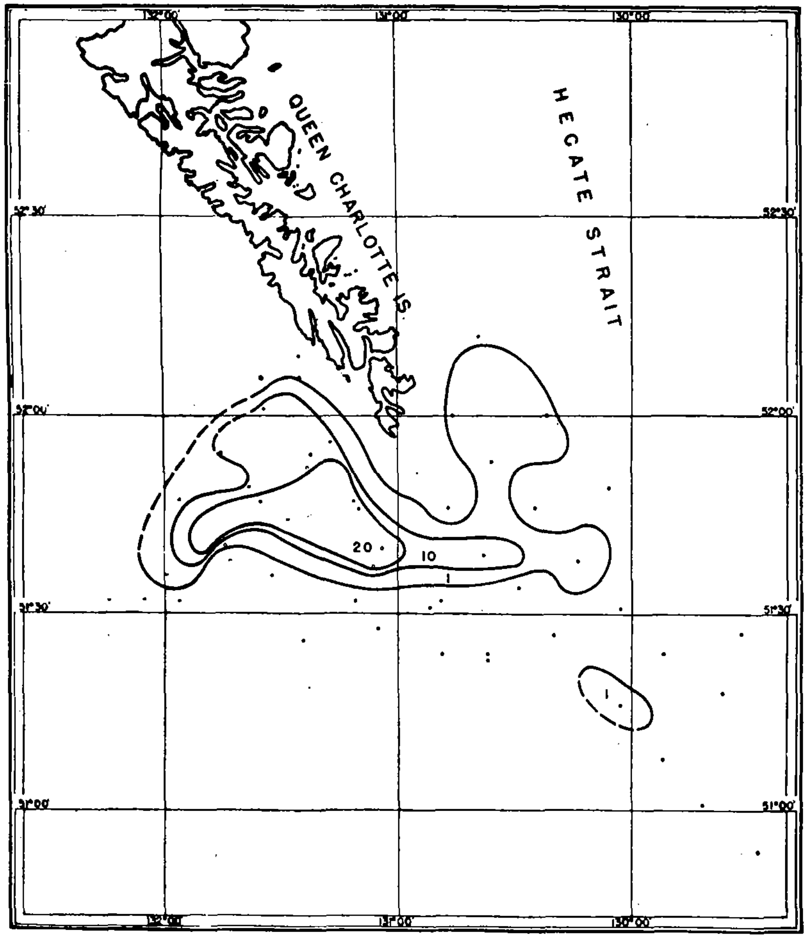

FIGURE 6. Year 1935 — Contour value, 882.

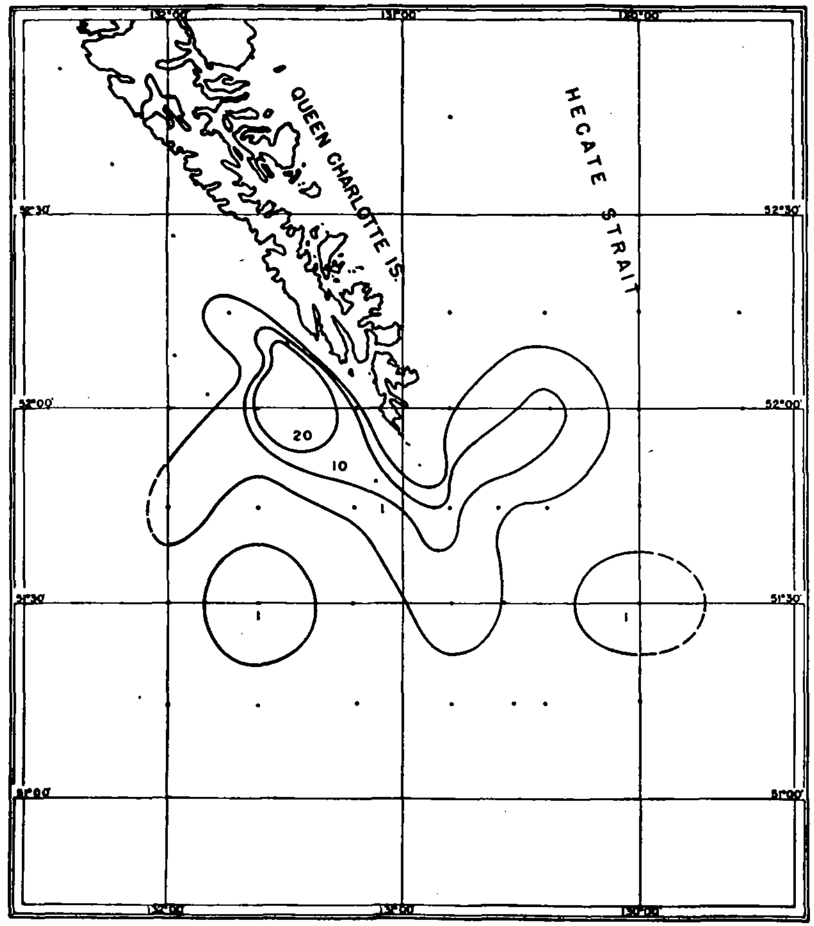

FIGURE 7. Year 1936 — Contour value, 997.

Density contours based upon the average corrected number of stage 1 halibut eggs caught at each station during January (December 30 to February 9). Small circles are the net haul locations.

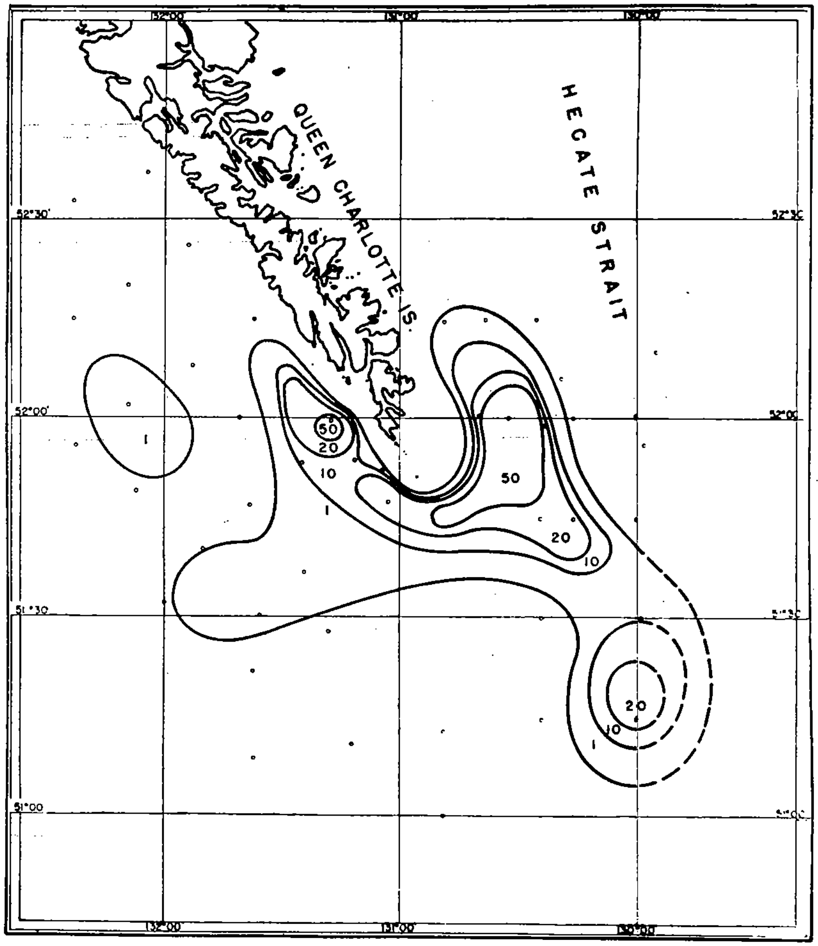

FIGURE 8. Year 1937 — Contour value, 2774.

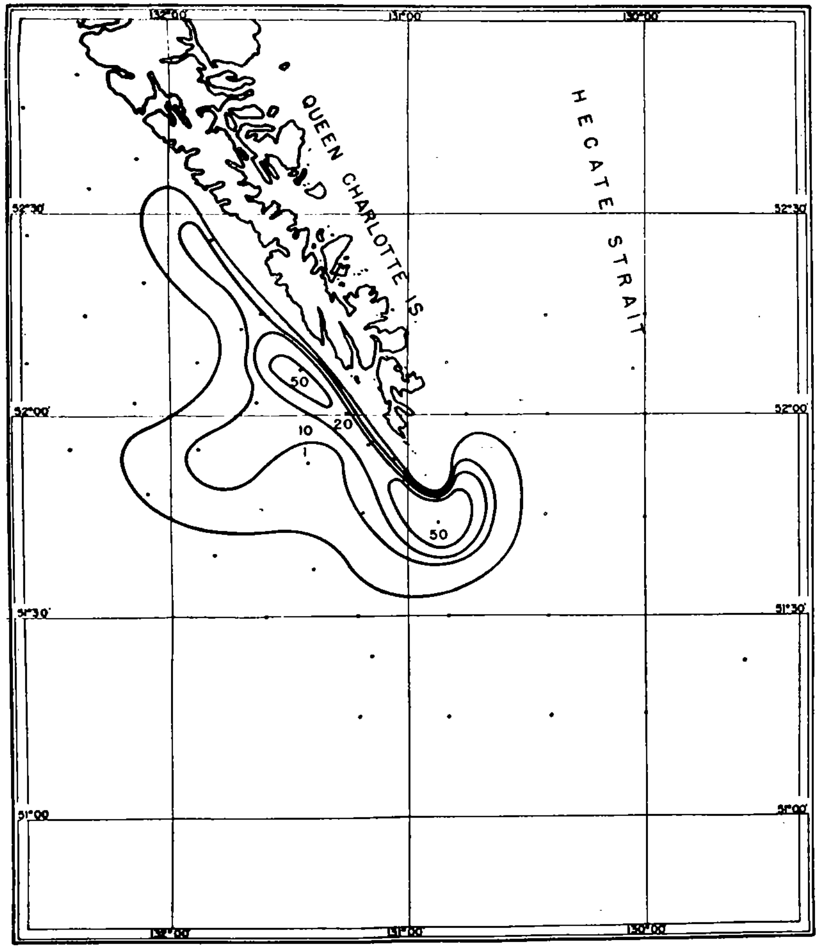

FIGURE 9. Year 1938 — Contour value, 1508.

Density contours based upon the average corrected number of stage 1 halibut eggs caught at each station during January (December 30 to February 9). Small circles are the net haul locations.

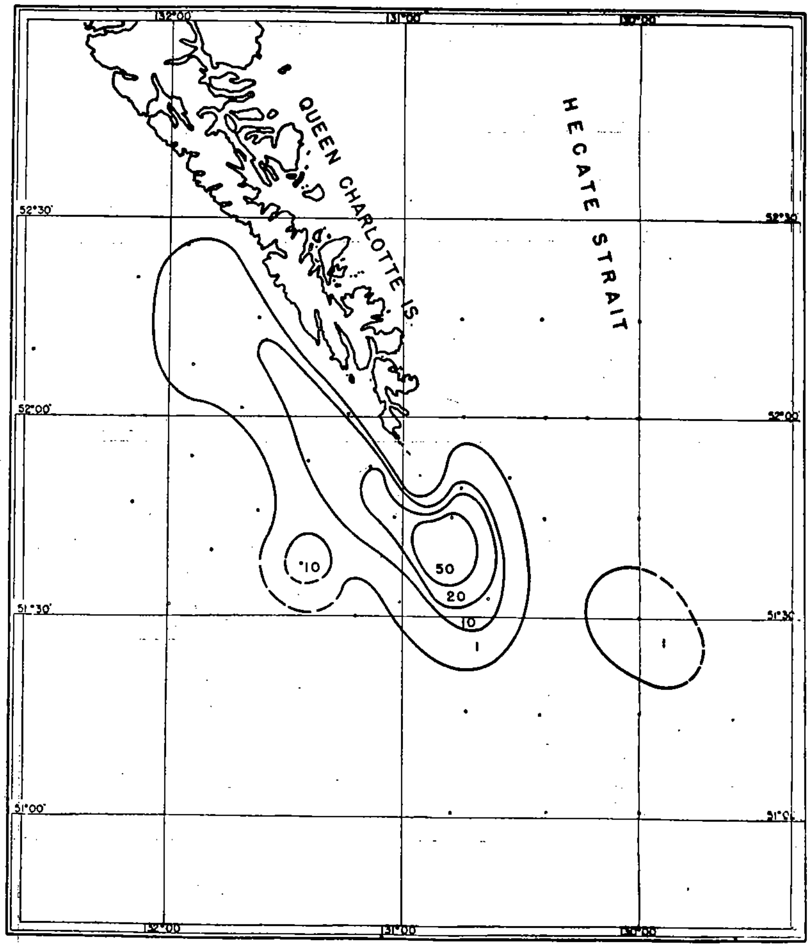

FIGURE 10. Year 1939 — Contour value, 1149.

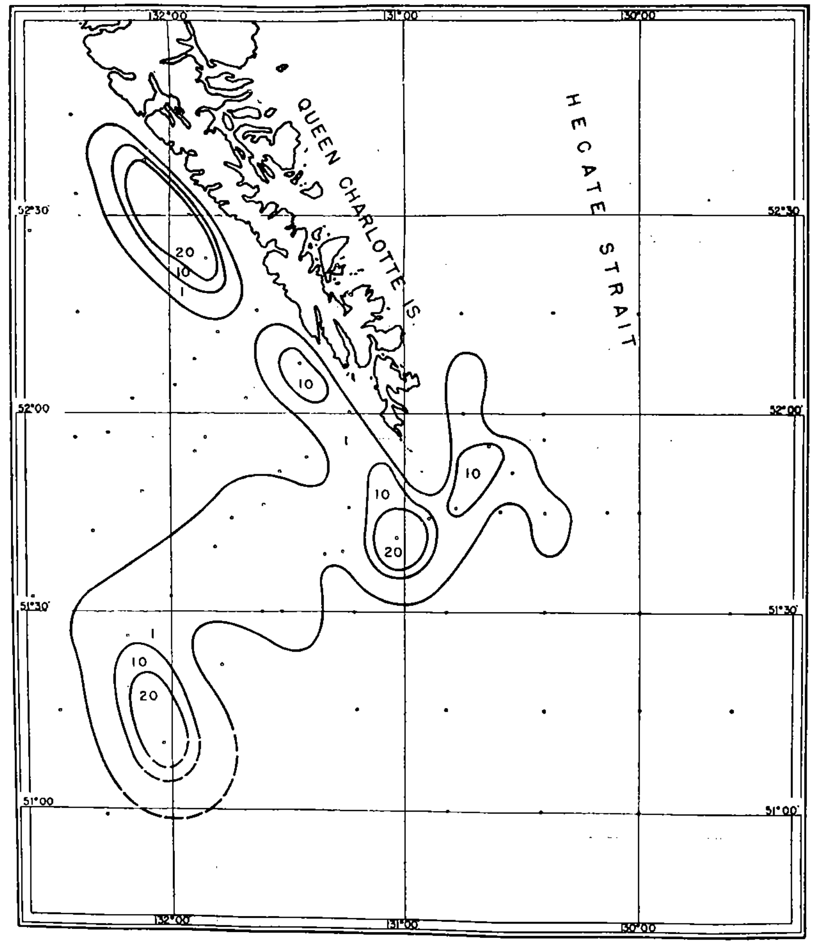

FIGURE 11. Year 1940 — Contour value, 1420.

Density contours based upon the average corrected number of stage 1 halibut eggs caught at each station during January (December 30 to February 9). Small circles are the net haul locations.

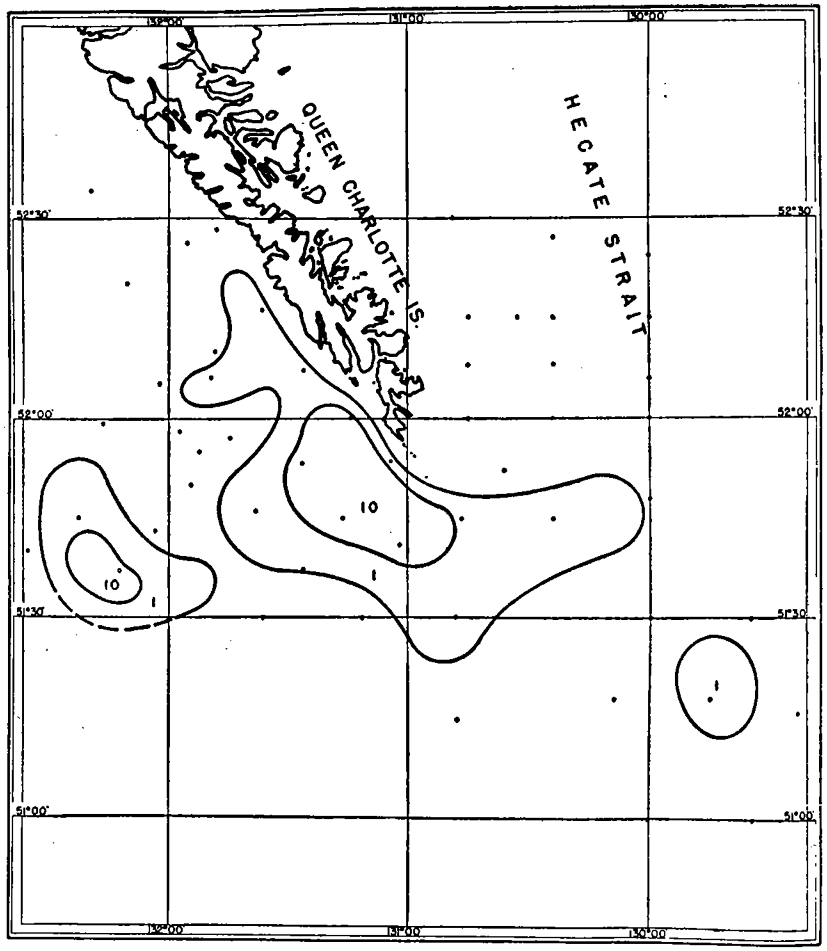

FIGURE 12. Year 1941 — Contour value, 719.

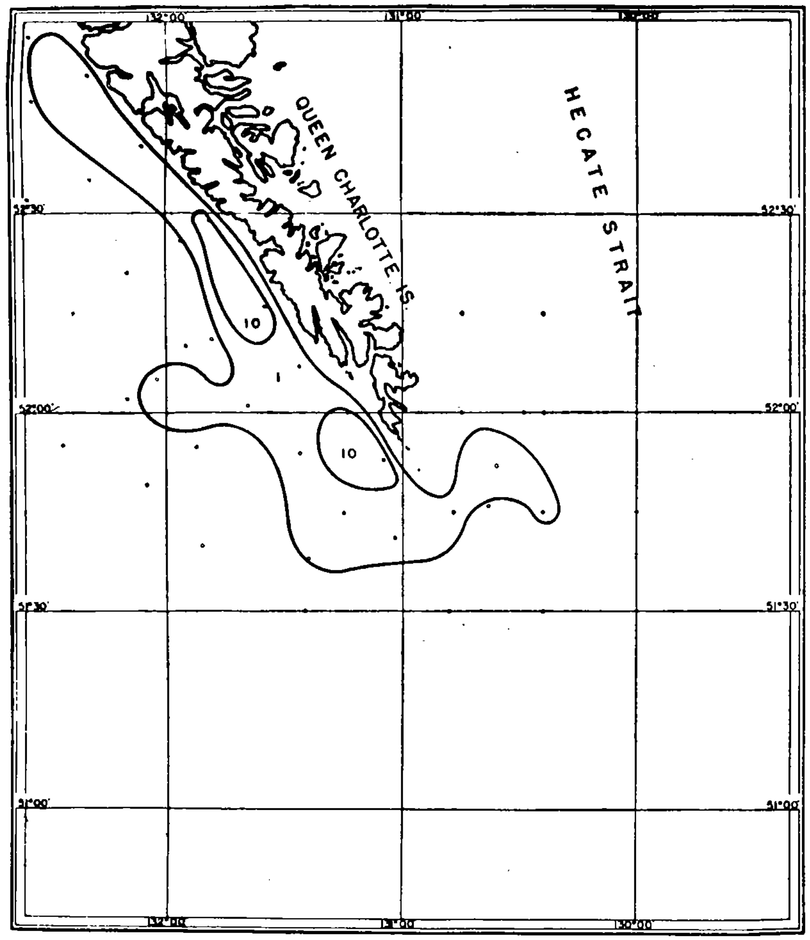

FIGURE 13. Year 1942 — Contour value, 431.

Density contours based upon the average corrected number of stage 1 halibut eggs caught at each station during January (December 30 to February 9). Small circles are the net haul locations.

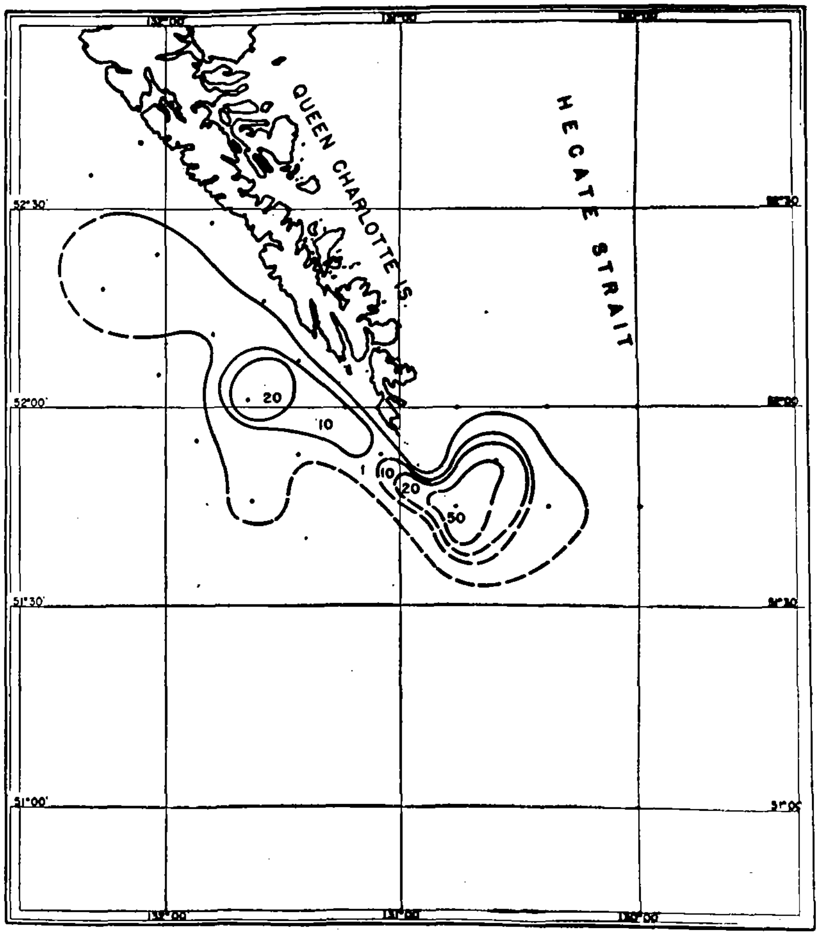

FIGURE 14. Year 1943 — Contour value, 1294.

No boat operations in 1944 because of war restrictions.

Density contours based upon the average corrected number of stage 1 halibut eggs caught at each station during January (December 30 to February 9). Small circles are the net haul locations.

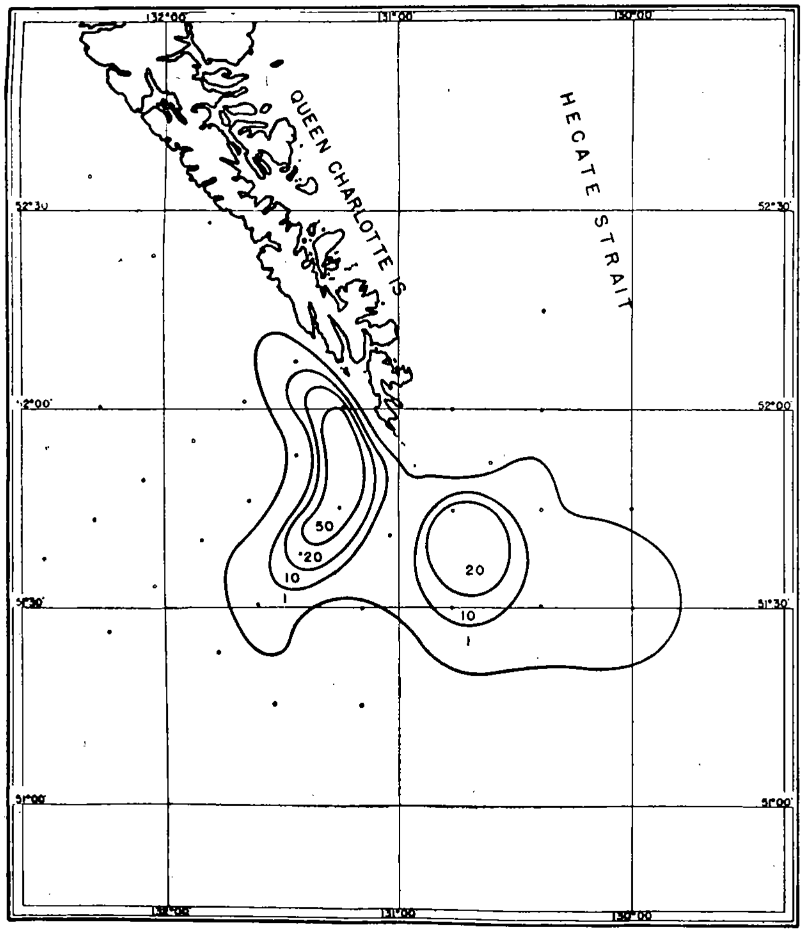

FIGURE 15. Year 1945 — Contour value, 1520.

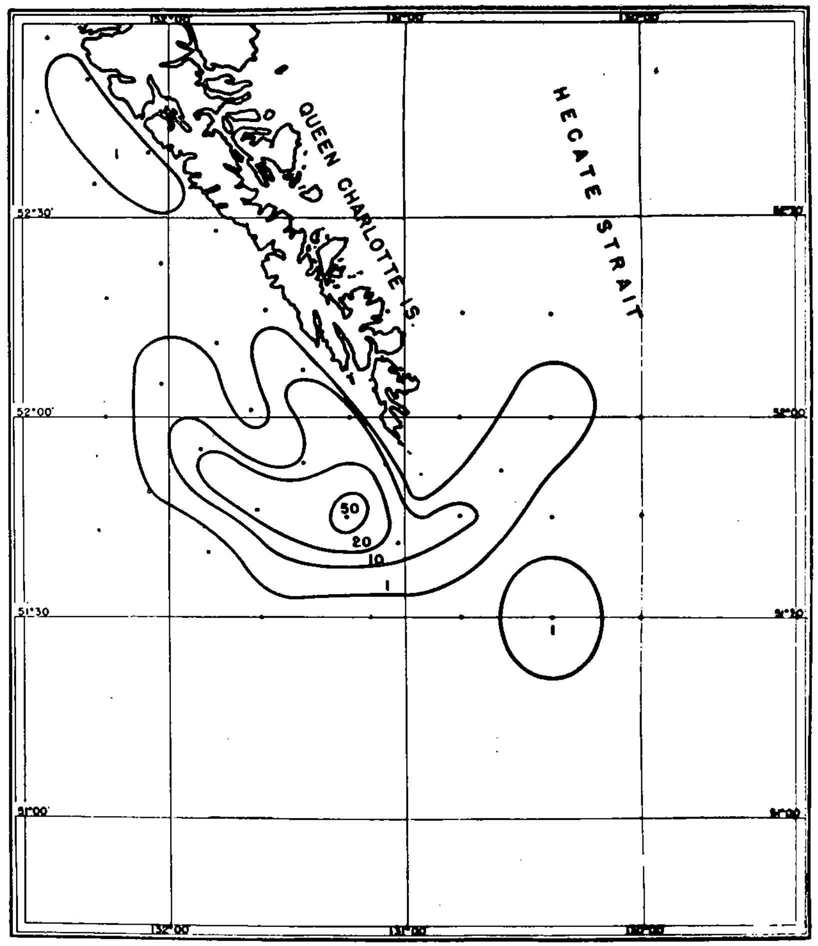

FIGURE 16. Year 1946 — Contour value, 1284.

Density contours based upon the average corrected number of stage 1 halibut eggs caught at each station during January (December 30 to February 9). Small circles are the net haul locations.

PRODUCTION OF EGGS ON THE CAPE ST. JAMES GROUNDS

The relative numbers of eggs produced each year on the Cape St. James spawning banks are shown in Column 1 of Table 2. These were obtained by measuring the areas within each contour with a mechanical integrator. These areas were then weighted according to the average number of eggs taken and summed to obtain a figure for total number of eggs for each year. Consideration of various factors involved in such a sampling procedure as was carried out indicates that the use of the Buchanan-Wollaston method gives results which are more nearly comparable from year to year than either of two other methods that were tried as a means of combining results of each year for comparison with those obtained in other years. (See Appendix, page 36.) No measure of the standard error of the resulting production figures can be obtained on logical grounds without making further assumptions which might or might not have meaning. However, there is some question as to the degree to which any such measure, obtained from net samples, would represent the error of the whole distribution of eggs.

The abundance of eggs as indicated by the numbers of stage 1 ova declined steadily from 1937 to 1942 when it reached a level of approximately 16 per cent of that of 1937. It is possible, however, that production in 1942 was not as low as indicated since two stations taken on January 16 off Tasu Sound caught 121 stage 2 eggs, an unusually large catch. The current trend is generally northwestward along this part of the coast at this season. Therefore it is probable that these eggs did arise from farther southward. In this event the sampling period in 1942 over the area of heaviest spawning may have been too late to include the period of maximum spawning on the Cape St. James grounds. Regardless of whether or not the 1942 results were too low, the trend downward from 1937 ended in that year.

TABLE 2. THREE ESTIMATES OF HALIBUT EGG ABUNDANCE AND RELATED DATA INCLUDING AVERAGE WATER TEMPERATURE IN DEGREES CENTIGRADE AT LEVELS AT WHICH EGGS DEVELOP AND TOTAL NUMBER OF UNCORRECTED HALIBUT EGGS FROM ALL HAULS.

Column:	1	2	3	4	5
Year	Egg Abundance			Water Temp.	Total No. of Halibut Eggs
	Contours	20-Day Average	12 Stations		
1935	882	571	9.4	6.1	741
1936	997	1647	10.9	6.7	633
1937	2774	3161	28.1	5.6	2741
1938	1508	1749	25.0	6.5	1580
1939	1149	1653	14.1	6.4	975
1940	1420	1420	11.0	7.2	759
1941	719	994	7.8	6.9	447
1942	431	785	3.5	7.2	581
1943	1294	3942	26.9	6.0	664
1944	....	....	....	....	....
1945	1520	2410	15.8	....	721
1946	1284	1686	11.9	6.0	714

The 1940 hauls indicated a heavier spawning in that year than in 1939. This result arose largely from a series of hauls that carried the region of distribution about 70 miles south and west of Cape St. James. As long as halibut eggs were observed in the catches, hauls were made farther offshore to be certain of covering completely the region of distribution. Similar precautions in other years did not show as great an extension. This drift of eggs culminated in one station containing 41 stage 1 eggs and this station is largely responsible for the increase of this year over 1939.

In view of the increasing catch per skate in Area 2 since 1930 (Thompson and Bell, 1934; International Fisheries Commission, Report No. 15, 1951), it seems inconsistent that the spawning intensity should decline from 1937 to 1942. There are several possible explanations. It is possible that the changes in spawning intensity from 1937 through 1942 were normal fluctuations due to the reaction of the population and its individuals to changes in the environment, or to other factors that might cause such fluctuations in productivity. Such variations are reported for other species of fish and have been held primarily responsible for the production of dominant year classes (Hjort, 1914). A more logical explanation is found in the changes that have taken place in the halibut population itself. The intense fishery in Area 2 up to 1930 apparently had greatly reduced the numbers of fish of spawning size in this region although the rate of reduction of the larger fish must have been diminished by the closure of the fishery during the spawning season, beginning in 1924. The intensity of fishing declined sharply in 1931 and 1932 to approximately 72 per cent of its 1930 level. As shown by Thompson and Bell (1934), this resulted in an immediate increase in rate of survival of all ages found in the fishery. It probably also resulted in an immediate increase in amount of spawning, although information is lacking. It can be said that by 1937 the effect of the decreased rate of fishing mortality and the resultant increased survival of adults had reached the point where fish that had accumulated, as a result of this increased rate of survival since entering the fishery, began to spawn. This could have produced the heavy spawning of 1937. At about this time, however, the effects of the lack of spawners and the resultant low recruitment in the years prior to 1930 would begin to be felt. This lack of spawning must have caused a decrease in the number of young produced and such a decrease in young would have been felt in the spawning population at about this time. The decline since 1937 then would be ascribed to a decrease in spawners associated with an earlier decline in recruitment of young fish. The progeny from fish spawning in 1931 began to mature in 1939.* From this year on, one could expect an increase in spawning as a result of the increased recruitment of 1931 and later. (See also Thompson, 1950.)

Some support for this hypothesis is found in the analysis of numbers of fish of various sizes weighted by the catch per skate of fish on the Goose Island banks in the years 1933 to 1950 (Bell, Ms.). These figures have been obtained from measurements of fish landed at Seattle. A large number of small fish was found first entering the fishery in 1936. This group increased in size to

*The earliest age of maturity of Area 2 females is 8 years, the average age is 12 years.

1938 and can be traced in the size frequency curves for each year, at least as far as 1943. These fish were largely the result of the 1929, 1930 and 1931 spawnings with the 1929 year class contributing the most (Freeman, Ms.) and the females from these larger year classes would have matured on the average in 1941, 1942 and 1943 at the age of 12 years. This group of fish was probably responsible for the increase in spawning intensity in 1943 and must have resulted from the additional protection afforded the spawning stocks beginning in 1924 with the prohibition of fishing during the spawning season. It is regrettable that no net hauls could be taken in 1944, and data are lacking as to spawning intensity in that year. The sampling of 1945 and 1946 indicated, however, that at least as many eggs were produced in those years as in 1943 and that spawning then was at a much higher level than in either 1940 or 1941.

The size frequencies of halibut from market measurements indicate the presence of another large group of young fish which first appeared in the fishery in 1942 and developed a definite mode in the market measurements in 1943 and 1944. This group would be the result of heavy spawning in 1936. The 1937 spawning also produced a strong year class although not as large, judging from the market measurements, as that of 1936. From this there is an indication that heavy spawning is associated with the appearance of large year classes in the fishery six and seven years later. The large year class produced in 1936 also indicates that the number of eggs calculated to have been produced that year on Cape St. James was too low.

CORRELATION OF EGG PRODUCTION WITH OTHER MEASURES OF ABUNDANCE

Since the fluctuations in numbers of eggs had followed a course that was subject to logical explanation on the basis of what had transpired in the fishery since 1930 and before, it is of interest to examine the degree to which the varying numbers of eggs at Cape St. James corresponds with other measures of the size of the halibut stocks on contiguous banks at appropriate stages of their life history. The values established by the use of contours (Col. 1, Table 2) were used in these correlations.

Since the size frequencies of young fish entering the fishery on the Goose Island banks (Freeman, Ms.) seemed to show some agreement with the numbers of eggs produced during the years in which they were spawned, the correlation between numbers of eggs and numbers of recruits resulting from those eggs was calculated. Using the figures calculated for the years 1934 to 1943, a correlation of only .006 was obtained. In making these calculations the number of eggs produced in 1935 was correlated with average catch per skate of 7-year-old recruits on the Goose Island ground in 1942 and the 8-year-olds in 1943*. Corresponding comparisons were made for the later years.

*As determined by age frequencies, it is not before the eighth or ninth year that all age groups are fully available to the fishery.

As the size of the spawning stock increases and the numbers of eggs produced each season grows, it may be expected that the effects of factors which limit the survival of eggs and young may still cause great irregularities in the number of eggs present over the grounds at one time, but if a large enough surplus is produced the average level of recruitment may still be stabilized at a high level. The correlation was determined between the average water temperature calculated for the Cape St. James area for the depths at which the eggs are found for each year from 1935 to 1943. These temperatures (Table 2, Col. 4) were taken at hydrographic stations established during the course of the net sampling program. The correlation of —.641 (5% pt., .632) is of doubtful significance but is remarkable considering the variability of the data from which the average temperatures were obtained (Table 5), in relation to the conditions under which the eggs actually exist. The negative relationship is a result of the greater rate of development at the higher temperatures which for any one rate of spawning would tend to decrease the time that each egg would spend in stage 1 of development (up to closure of blastopore) and hence would decrease the number of stage 1 eggs present on the banks at any sampling time. On this hypothesis the partial correlation coefficient was calculated between number of recruits and number of eggs, eliminating the effect of temperature on the abundance of eggs. The resulting coefficient of .061 is not significant.

The correlation between the numbers of eggs produced and the relative numbers of spawning fish in the Cape St. James area could not be tested directly since no reliable measure of the abundance of spawners was available from the fishery. However, in the commercial landings the "large" fish (60 lbs. and over) are listed separately from medium and small fish and their abundance as measured by the catch per skate could be roughly determined. The pounds of "large" were obtained from dealers' records of purchases. The total number of skates of gear run each year in each area were determined as by Thompson, Dunlop and Bell (1931) by dividing the total catch of that area by the catch per skate determined from the records of those boats which kept usable logs (approximately 75% of the fleet). The relative weights given to the catch taken in each statistical area were determined by the number of tags recovered from the tagging experiments carried out at Cape St. James in December of 1939 and January 1940 after these tag recoveries had also been weighted by fishing intensity. The estimates for the abundance of "large" in statistical areas 4-8, 9, 10, 11, and 12 were derived in the manner described above. The correlation between these figures and the numbers of eggs was only +.397 and could not be considered significant for 9 degrees of freedom.

COMPARISON OF MORTALITY RATES ON CAPE ST. JAMES AND GOOSE ISLAND BANKS

The abundance of "large" used in the correlation above represents primarily large females since few males are found weighing over 60 pounds. The fecundity of the halibut increases in approximately direct proportion to the weight of the female (Kolloen, 1934), therefore the number of eggs produced should be linearly related to the total weight of females spawning. The lack of correlation between numbers of eggs produced on the Cape St. James spawning grounds and the catch per skate of "large" halibut in Area 2 may mean either that the stock measured is not representative of the fish which spawn at Cape St. James or that the measurement of that stock is not accurate. Evidence in favor of the former explanation is found in the returns from 499 halibut tagged on the "Sylvia Spot," 10 to 15 miles east of Cape St. James, during the spawning season of 1940. These indicate that the fishery is not sampling the spawning stock from this bank in the same proportion as it is the smaller and immature halibut. During the fishing season of 1940 following tagging in January of that year, 9 per cent of the tags were recovered. Assuming no loss of tags this would be a first estimate of the rate of capture of the spawning stock ("rate of exploitation," Ricker, 1944). It is interesting that the value of μ computed by formula (22) of Ricker (1948) from the returns of the second and third fishing seasons after tagging, gives a value of .1099 which compares favorably with that obtained from the first season's returns. In calculating the value of μ from the later recoveries a survival rate of .555 (obtained from the second and third years' recoveries) was used. This survival rate would correspond to an exponential mortality rate of .589 or with an annual natural mortality rate of 10 per cent (exponential rate of .105) would give an annual rate of fishing of about 38 per cent. This would correspond to a rate of capture or exploitation of about 36 per cent. If the 9 per cent rate of capture were correct, using the same methods of calculating the different mortality rates (Ricker, 1944), the annual natural mortality rate would be increased to 37.5 per cent, which is far higher than any available data indicate to be possible.

Other measures of the values of the various mortality and fishing rates may be obtained from two other tagging experiments which were carried out on the Goose Island fishing grounds in May 1936, and May and June of 1947. Returns from the tagged fish released on the Goose Island banks in May 1936 give a value of .2072 for μ, and a value of .2840 for p (exponential rate of fishing). Corresponding values for the 1947 experiment were found to be $\mu = .1662$ and $p = .2228$. The decrease in μ between 1936 and 1947 could be expected from the decrease in fishing intensity that occurred during this period in Area 2. A total of 458,000 skates of gear were fished in Area 2 in 1936 and 336,000 in 1947. Using the relationship developed by Baronov and later used by Thompson and Bell (1934) and Ricker (1944), $\frac{f_2}{f_1} = \frac{\log(1-m_2)^*}{\log(1-m_1)}$, the expectation of capture, μ, in 1947 should have been .1554. The difference between this figure and .1662 obtained from the tags recovered from the 1947 tagging experiment is well within the limits of error of the data. On the basis of the number of skates of gear run in Area 2 in 1940, using 1936 as the base year, the value of μ in the former year should have been .2061. The low value for μ obtained from the 1940 tags released at Cape St. James indicates that the fish of that spawning stock are

*In this formula f_1 is the total number of units of gear fished in year 1 and f_2 is the corresponding figure for year 2; m_2 and m_1 refer to the annual rates of fishing mortality in the appropriate years.

not as available to the fishery as are those on the Goose Island grounds where the heaviest fishing in Area 2 occurs. The catch per unit of effort in Area 2 therefore probably does not give a usable measure of the abundance of spawning fish at Cape St. James. Market measurements based on the Goose Island fishery will also be affected by under-sampling of the spawning fish. This under-sampling is not indicated by the lower rate of annual mortality calculated from the distribution of 8 to 13-year-old halibut in the market measurements. Using the average abundance of 8 year classes of halibut (the 8-year-old fish landed in 1935 to 1942 inclusive, etc.), an annual mortality rate of .4411 was calculated by fitting a line to the logarithm of the frequencies. However, the age classes included in this computation comprise only the very youngest mature females and give no picture of the rate of decline of the older spawners in the catch. The number of halibut older than 12 years which appear in the catches from Goose Island are too small to be usable for determination of rates. It would appear that in order to obtain a more representative picture of the fish stocks in Area 2 the market samples should be expanded to cover grounds other than the Goose Island bank—preferably they should sample fish from all banks in proportion to the catches taken from them. Such samples still might not give a representative picture of Area 2 stocks if the fishery does not sample the entire population in a representative manner.

Determination of whether or not the variation in numbers of eggs produced each year on the Cape St. James spawning banks would give a more accurate picture of variations in the population of spawning halibut in Area 2 will have to be tested by other means. At present the most promising method would probably be a series of simultaneous tagging and egg sampling programs at Cape St. James supplemented by further work to determine the relationship between spawners there and elsewhere in Area 2.

The lack of correlation between egg abundance and catch is not surprising. The production of eggs was originally chosen as a measure of changes in the stocks which would be independent of the sampling of the fishery. Its accuracy as a measure of the absolute size of the spawning population remains to be determined. Since the catch per skate includes only those sizes of fish available to the fishery, its changes could hardly be expected to agree with the changes in egg abundance unless the changes in spawning population agreed with changes in the rest of the population. In addition the correlation could only occur if the Cape St. James spawning ground was representative of the entire area over which the correlated material was gathered.

The investigation has accomplished the purpose of demonstrating the feasibility of sampling the halibut eggs at Cape St. James and has also demonstrated a recovery in the production of spawn beginning in 1942. The variations in egg abundance from 1937 to 1946 followed closely the early rise in abundance of halibut and the later drop and eventual change to an upward trend in egg production that was indicated by the various other measures of abundance of mature halibut in Area 2. The small numbers of eggs found in the Cape St. James area indicate that the spawning population there was still very small in 1946. Periodic samples from time to time would show whether this population is continuing to increase provided the sampling in any one year is adequate to yield a dependable value for production. Catches of halibut eggs in the Gulf of Alaska in 1928 were as high as 244 eggs per net using the same net and a similar method of hauling, and the single haul of 577 eggs taken off Cape St. James in 1937 indicates that the method and equipment used were capable of catching these organisms. Catches of other pelagic eggs have been as high as 47,000 per net per haul. The validity of the sampling method is also indicated by the consistent picture of distribution that results from each year's hauls (Fig. 6 to 16). With recovery of the halibut spawning stock in Area 2 to optimum size, it should be possible to obtain larger numbers of eggs. Calculated annual egg production figures could then be expected to be more consistent, with smaller relative errors. With the small egg catches observed, such errors might have been great enough in the 1937-1946 hauls to have destroyed the significance of any correlation with size of the resulting year classes. With the progressive restriction of the fishing season to a shorter time interval each year as the catch per skate increases, it will be more and more necessary for the Commission to find some method that will measure changes in that part of the population that the fishery may not be exploiting. The assessment of changes in abundance of eggs at Cape St. James may well serve to indicate changes in the spawning stock in Area 2, and if properly standardized can provide an invaluable additional check on the condition of the halibut stocks in this area that should be sensitive to changes caused by both the fishery and the environment.

SUMMARY

1. The Cape St. James spawning grounds were sampled with one-meter Michael Sars plankton nets each winter from 1935 through 1946, except in 1944. A total of 1080 stations were occupied. Catches were corrected for duration and depth of hauling.

2. Mature halibut tagged on Cape St. James grounds were recovered along the coast of British Columbia, but a disproportionate number were returned from fishing areas close to Cape St. James indicating that the spawning stock there is drawn primarily from the fishing grounds within a radius of about 150 miles from the place of tagging.

3. The spawning season is from December to March with a peak of spawning in mid-January. The egg catches used for measuring the abundance were limited to those taken in hauls made between December 30 and February 9, when 84 per cent of the stage 1 eggs (up to closure of blastopore) were caught. Halibut eggs were usually found 75 to 400 meters below the surface in water of specific gravity from 1.02540 to 1.02660.

4. No major drift of halibut eggs into or out of the area around Cape St. James was noted. Distribution of eggs within the area was consistent from year to year.

5. The greatest egg abundance was in 1937 after which the abundance declined for five years; during the last three years of sampling, egg abundance increased.

6. Correlation of egg abundance with recruits (7 and 8-year-olds on Goose Island) is not significant. Variations in abundance of eggs correspond with changes that have occurred in the stock although correlation between egg abundance and the spawning stock as determined from catch records and market landings was not significant. Measures of fishing rates indicate that the spawning stock on Cape St. James is not as available to the fishery as the stock on Goose Island. It is probable that with the present fishing season, the catch per skate in Area 2 does not give an accurate measure of the abundance of spawners at Cape St. James. The correlation of egg abundance and water temperature was negative and significant at the 5% level. The partial correlation between egg abundance and recruits independent of temperature was not significant.

7. Further studies of the relation of the halibut population presently exploited by the fishery to the stock inhabiting the rest of Area 2 are needed. This work should be correlated with further measurements of the abundance of halibut eggs off Cape St. James. A logical extension of this work would be an investigation of the production of halibut eggs elsewhere in Area 2 and its relation to the egg production at Cape St. James.

APPENDIX

THE ACCURACY OF SAMPLING

The methods of testing the accuracy of sampling egg populations proposed by Buchanan-Wollaston (1935) and Sette (1943) cannot be applied to the halibut egg catches because the halibut egg distributions are too deformed as compared with that of a normal frequency surface.

On the Cape St. James grounds the halibut spawn at depths between 100 and 350 meters. Since the catch of halibut eggs in closing nets is limited to about the same depth range, it may be that the eggs remain at about the level at which they are spawned. Their horizontal distribution is limited inshore by the abutment of those levels against the continental slope. The maximum density of eggs usually occurs along the edge of the continental slope and their frequency decreases with increasing distance from the edge of the spawning banks. The distribution that results is composed of a number of highly skewed frequency surfaces with the modes close inshore near the 100-meter line and with the long tails sloping out to sea. From the catches of eggs in the individual net hauls it appears that the halibut eggs do not form a continuous distribution. Their distribution might be compared to that of scattered clouds that vary both in size and in numbers of eggs of which they are formed. With greater egg production this type of distribution might become continuous.

The highly skewed and discontinuous nature of the halibut egg distribution limits the methods that can be used to test the accuracy of sampling. The accuracy of a measurement is usually indicated by the dispersion of the individual observations around a mean measurement. These observations are usually considered to be individual measurements of a single population and all should be grouped about the mean value. However, the halibut egg hauls are independent samples of a widely distributed population comprised of a number of more or less independent units and therefore the σ of their values would be meaningless. Their distribution when plotted as a frequency polygon is "J" shaped with the mode at zero. There is no central value other than zero about which the individual catches could be expected to cluster.

This is only true from a rather narrow viewpoint. Actually they are samples of a population the individual members of which vary in age and pass through quite rapidly, leaving the population either by natural death, predation, transportation or hatching. Recruitment is through spawning. As long as rate of spawning exceeds the rate at which eggs leave the population, the population increases; as soon as the spawning rate falls below the losses, the population decreases. It completes a cycle in one spawning season.

Values obtained from successive hauls in a single locality will measure the variability in the numbers of eggs occurring in that locality within the limits of accuracy of the individual net hauls. If these successive hauls are close together in time and if the drift of eggs due to tidal and other currents during the period of hauling does not change the portion of the population sampled, the variation in such hauls would measure the variations in the efficiency of the net, if the eggs were uniformly distributed; but this is not true. Since during the period of hauling at each station the vessel moves approximately two nautical miles, some variation could be expected from this movement alone since it is impossible to retrace exactly a course once travelled. With these factors in mind, paired hauls made from a number of localities were studied as a measure of the reliability of values determined for any location. This reliability will be affected by errors due to variability in the efficiency of the net and differences in hauling speed as well as by variations in the numbers of eggs drifting past any location at different times.

Six sets of two hauls, and two sets of four hauls were taken successively without changing location. Using all combinations taken in a single series these furnish 18 pairs of comparable catches. The Pearsonian coefficient of correlation, *r*, between the total number of ova taken in the first and succeeding hauls of each pair, corrected for the number of minutes per meter of cable hauled, was found to be +.56 (5% point, .468, Snedecor, Table 13.6) and is interpreted to mean that the hauls tend to be consistent in yielding large or small catches. The mean difference between the paired catches was 6.71 or 50 per cent of the average number of eggs taken in each net.

A better estimate of the magnitude of errors involved in single catches is obtained from the coefficient of variation (Yule and Kendall, 1937, p. 149) for stage 1 eggs at the two stations where four successive hauls were taken in 1943. For these two stations σ_x was 2.69 (hauls 2204-2207) and 3.93 (hauls 2217-2221). These corresponded to mean catches of 4.48 and 5.55 eggs respectively and give coefficients of variation, $\left(\frac{\sigma 100}{\text{mean}}\right) = v$, of 60 per cent and 71 per cent. The variability of the catches in these successive hauls reflects the uneven distribution. The high values for the coefficient of variation may be due largely to the scarcity of eggs.

While the number of pairs of successive tows is small, it is of interest to study the degree of association between the two series by the method described in Snedecor pages 448 to 451. For this purpose each haul of a series was used only once, which reduced the number of combinations of pairs to 10. The numbers of eggs taken in each net shown in Table 3 were converted to logarithms and the variance of the logarithms was then analyzed. It is recognized that there is no particular reason why the first haul of a pair should be larger or smaller or even the same as the second haul. To test the degree of correspondence in variance between the two distributions, the F value was computed as the ratio of the variance of the logarithms of the series of first hauls of each pair to that of the series of second hauls. It was found that

$$F = \frac{.27354}{.18799} = 1.455, \quad F_{(5\%)} \text{ for d.f. } 17,20 = 2.23$$

Therefore, the variances do not differ significantly. The results of the analysis of variance of the logarithms carried out by standard methods are shown at the bottom of Table 3. The mean square within columns is much larger than that between the first and second series. Obviously, differences between individual hauls taken at different stations is so great that it is sufficient to obscure any difference between first and second hauls at any one station, and while these tend to be positively correlated in size they show no consistency in one being larger or smaller than the other.

The mean catch (12.36) of all the successive hauls is typical of the low values obtained in the halibut egg tows. The area of the opening of a one-meter plankton net is 8.4 square feet. During a one-hour haul period, they are towed an average of two nautical miles. Using a conservative estimate of 50 per cent filtering efficiency, each net would strain a column of water at least 6,000 feet long or a total volume of 50,000 cubic feet. These hauls varied as to the number of nets used at one time but an average of 1.7 nets was hauled within the depth range in which the eggs were found. This would correspond to an average of 85,000 cubic feet of water filtered per station.

TABLE 3. CORRECTED CATCHES OF STAGE I HALIBUT OVA IN SUCCESSIVE HAULS

Haul No's.	CATCH		LOGARITHMS	
	Haul No. 1	Haul No. 2	Haul No. 1	Haul No. 2
1233-34	28.0	51.6	1.4472	1.7126
1745-46	27.0	19.3	1.4314	1.2856
1824-25	5.1	6.7	.7076	.8261
1892-93	1.0	1.0	0	0
1894-95	0.0	2.0	0*	.3010
2204-05	4.9	8.1	.6902	.9085
2206-07	2.8	2.1	.4472	.3222
2212-13	48.0	17.3	1.6812	1.2380
2217-18	1.1	8.0	.0414	.9031
2219-21	9.6	3.5	.9823	.5441
Mean	12.75	11.96	.7428	.8041
Range	48	50.6	1.68	1.71

ANALYSIS OF VARIANCE OF LOGARITHMS

Source of Variation	Σ squares	d.f.	Mean square
Between hauls (columns)	.01877	1	.01877
Within columns	6.06134	18	.33674
Total	6.08011	19	

$$F = \frac{.01897}{.33674} = .056 (\text{d.f.} 1,18) \quad 5\% \text{ pt. } 4.41$$

*To avoid changing the numbers of eggs in the hauls by adding 1 to each, the log. of zero is taken as zero in this analysis.

The relative scarcity of halibut eggs on the Cape St. James ground as compared with plaice eggs in the southern part of the North Sea in 1921 (Buchanan-Wollaston, 1926) and mackerel eggs (Sette, 1943) on the Atlantic Coast of the United States in 1932, is emphasized by comparison of the estimates of the number of cubic feet of water per egg for the three locations. The estimate of the concentration of both plaice and mackerel eggs was one egg per 21 cubic feet of water. The halibut egg concentration determined from the 6,425 eggs caught at 442 stations where eggs were taken during the first nine years of operation, and from the estimated 85,000 cubic feet of water filtered per station was calculated to be approximately one egg per 6,600 cubic feet of water. It is evident that the halibut eggs are about 1/300 as abundant and for this reason the problem of obtaining a representative sample is more difficult.

Buchanan-Wollaston (1923) stated that even if pelagic fish eggs were distributed uniformly, the chances are slight of getting the same number per net haul. With the low densities of halibut eggs, the probability of obtaining large percentage differences between successive tows is very great. The hauls were designed to eliminate as far as possible the chances of missing eggs due to variations in vertical distribution but could not overcome the variability due to scarcity of eggs with any practical sampling technique.

It was indicated above that the period of time during which the net hauls used for analysis were taken was confined to a period of six weeks. Some stations were sampled twice and occasionally more times during this period, giving average values upon which the density contour lines were based. Many stations were visited but once and sometimes had to be omitted. The variability of the values obtained for the different stations can be studied from an analysis of the catches obtained at stations which were visited a number of times.

Five stations are available at which four or more hauls were made during the period used for computing the density contours. These are listed in Table 4, with the corresponding mean catches, standard deviations and coefficients of variation, v. The values of v for these series of hauls are as large or larger than those determined for the two series of successive tows (Appendix, p. 35) with the greatest difference shown for the series of hauls at station 7A during January, 1940, where $v = 125$ per cent. This station is located at 51° 53′ N., 131° 05′ W., about 4 miles south of Cape St. James light. The tidal currents are particularly strong here and computation of resultant drift from hydrographic observations indicates the presence of an offshore drift up to 0.5 knots at a depth of 200 meters. The bank slopes steeply here from 100 fathoms to over 1000 fathoms in only a few miles and considerable turbulence is apparent. Conditions at this station are not typical and possibly exhibit the maximum variation in size of egg catches that are to be expected.

The coefficients of variation of the series of hauls taken throughout the month of January or over the period used for computing the density contours, average larger than the same values computed for successive hauls at the same station, but are of comparable magnitudes. The density contours therefore may not represent conditions on the banks at any moment. However, each point on the density contours is determined by interpolation over an interval of four stations, two on either side of the interval containing the contour. The location of the contour in any line of hauls reflects the size of the catches in the four stations concerned. Since each contour is located by points determined in a number of sections, they represent the average abundance of eggs over the areas sampled.

Although no quantitative measure of the accuracy of these contours has yet been devised, they should provide a more dependable series of values than that of the individual hauls, just as an average is a more dependable measure than that of one of its component quantities. The standard error of the contours should vary inversely as the square root of the number of hauls on which they are based.

TABLE 4. THE COEFFICIENT OF VARIATION OF HAULS REPEATED AT THE SAME LOCATION DURING THE MONTH OF JANUARY.

	Mean No. Eggs	σ	$v = 100 \frac{\sigma}{x}$
Station 6A, Jan. 1938 *1528, 1542, 1545, 1547, 1548, 1557, 1573 and 1584	27.225	20.83	76.51
Station 6A, Jan. 1939 *1715, 1745, 1746 and 1748	19.35	12.01	62.07
Station 6A, Jan. 1940 *1824, 1825, 1846, 1850 and 1883	5.18	4.97	96.53
Station 6A, Jan. 1941 *1926, 1935, 1961, 1977	14.95	16.59	112.98
Station 7A, Jan. 1938 *1533, 1541, 1570, 1576 and 1577	18.58	11.51	61.95
Station 7A, Jan. 1940 *1823, 1842, 1851, 1894 and 1895	8.9	11.19	125.73

*Net hauls used in making the computations.

Indication of the dependability of the contour surfaces is found in the consistent picture they present of the egg population each year. In general the same center of abundance can be identified from year to year and within certain limits they are similarly located.

METHOD OF ANALYSIS OF THE DATA

H. J. Buchanan-Wallaston's (1923 and 1926) method of estimating egg abundance by drawing contours of egg catches was used because it uses all of the data and yields results most nearly comparable from year to year. There are several disadvantages to the use of this method. One is the amount of time and effort required to compute the locations of the contours and to draw them. The time and energy expended in calculating the contours was cut to a minimum by using the graphic methods of computation. Another disadvantage is the lack of a measure of error of the weighted areas within the contours. This error is a function of variations in results of the individual hauls taken at the different net stations. Since many stations were usually visited only once, no measure of the errors of the areas can be obtained. In addition interpolation between stations assumes that the distribution of eggs is continuous and is similar to that of a correlation surface. There is good reason to believe that in an area of violent tidal mixing as well as strong wind and density currents, such as around Cape St. James, the distribution of eggs would be very irregular.

A further handicap affecting uniformity of contours is the fact that the circular method of drawing contours results in a wider sweep of the inner contours representing areas of greater density due to the more acute angles formed by lines connecting successive interpolated points. Each contour was drawn independently of all others, in accordance with set rules, as described by Buchanan-Wollaston. When they were transferred to the final distribution chart, it was sometimes found necessary to modify them. If the outermost contour swept into waters less than 100 meters deep (where it was known that halibut eggs were not found) then the egg contours were modified to follow the 100-meter depth contour. Then, if the modified outermost contour was crossed by an inner contour, the inner contour was changed to conform with the outer one.

The principal advantage of the Buchanan-Wollaston method is uniformity of results and the use of all observations made within the prescribed limits. With sufficient care in the use of interpolation methods and manner of plotting contours, the same results can be obtained from the same basic data within relatively small limits.

Computation of total numbers of eggs, represented by Figures 6-16, was carried out with the use of a mechanical integrator. The areas between successive contours were measured by the machine, and then weighted by the average of the numbers represented by the two boundary lines. Addition of all the weighted areas which were in terms of square inches of area times average number of eggs gave the relative weighted number of eggs represented by each chart and are shown in Column 1, Table 2.

The ideal result of a comprehensive system of sampling such as has been carried out in the present program would be that a particular locality or series of localities could be found which, if sampled adequately, would yield the same results as are obtained from the entire universe. Irregularities in the weather and associated variations in the nature of the ocean currents over the banks as well as variability of the numbers of eggs taken at any station so far, have made it advisable to continue the complete system of sampling. Because of differences in the distribution of the eggs from year to year, and in the actual coverage of the area with stations, it was impossible to use the average catch of eggs per haul as a measure of the abundance of ova. However, two other methods in addition to the contour method were tried in order to obtain an estimate of the total number of eggs produced each year. One method involved a year by year comparison of the catches made at comparable stations after the catches had been corrected for time of hauling at different depths (p. 14). The stations were matched according to location and then according to the day of the year, using only hauls taken within 20 calendar days of each other. This resulted in a set of pairs of hauls for each pair of years. The set used for any one year was the set with the greatest number of pairs involving that year. The total number of eggs taken in these pairs then formed comparable measures of the abundance of eggs in the two years in question. The figures for all years were then linked to the catches in one base year (1941, the year with the greatest number of sets of pairs) by simple proportions, and the results were put on the same scale as for the contours by converting to the figure determined by the Buchanan-Wollaston method for the base year and multiplying by the figure obtained from the comparable catches. The results are shown in Column 2, Table 2.

Another attempt at simplifying the method of treatment of the egg catches was to use all the corrected egg catches taken at 12 stations located around Cape St. James. The same 12 stations being used each year, these stations showed the greatest average catch of eggs for all years combined and were sampled most consistently in all years. In Figure 2 these stations can be identified as A and B in Sections 5, 6, 7, 9 and 10 and Ex 1 and Ex 2. The simple weighted average corrected catch of stage 1 eggs at these 12 stations was used as a measure of abundance and is shown in Column 3, Table 2.

The variations in egg catches tend to be minimized when the greatest number of stations is used in arriving at a total figure for any one year. The contour method seems to make better use of all material and in years when sampling is thorough it is probably the most effective manner of representing the data. However, it is believed that for a system of abbreviated sampling the average obtained from the twelve representative stations if carefully executed would provide an adequate basis for rough comparisons between years.

VARIABILITY OF EGG POPULATIONS

In addition to the problems associated with sampling and the accuracy of individual net hauls there are many other factors which effect the accuracy of estimates of spawning intensity by altering the actual size of the population being sampled. In order to measure the effect of any one of these elements, some measure of the influence of the others must be obtained.

Three of the principal sources of variation in number of eggs produced or present on a spawning bank are listed below. Each of these may be broken down into a large number of interrelated factors, many of which cannot be evaluated but all of which should be considered in attacking the problem. These variables are:

1. Variation in numbers of eggs produced due to changes in the size of the spawning population.
2. Variations in amount of spawn produced by the individual fish due to the effect of hydrographic changes and changes in other conditions.
3. Variations in numbers of eggs occurring on the banks due to fluctuations in:
   (a) Length of spawning season and variation in spawning intensity within the season.
   (b) Rate of spawning and development.
   (c) Rate of mortality.
   (d) Drift in and out of area or variations in distribution due to drift.

In the case of the halibut work, the first variable is the one to be measured, relatively if not absolutely. The second variable is difficult to measure since it would depend upon whether or not the number of eggs spawned by the individual female during any one season is predetermined before the season starts, or is dependent upon the length of time conditions are favorable for the maturation of the ova or upon the conditions of the fish before and during the spawning period. These factors are difficult to measure and for the present it is necessary to try by indirect methods such as correlation with other measures of abundance of the fish themselves to overcome the handicap of lack of knowledge of this factor. The only available evidence which indicates that the number of eggs spawned by the individual female is not predetermined was produced by Hjort (1914) in quoting from the work of B. Helland-Hansen and F. Nansen. The latter showed that for the years 1901 to 1904 inclusive, the mean temperature of intermediate Atlantic water in the Lofoten section was inversely related to the quantity of cod roe (liters per 100 fish) obtained during the Lofoten fisheries. From this evidence, the amount of roe was presumed to be dependent upon temperature and thus upon the fluctuations in the ocean currents. If the average size of the cod egg remains relatively constant from year to year this would infer that the egg production would be less in years of high temperature. To our knowledge no other evidence has yet been produced to indicate the effect, if any, that changes in temperature may have upon the fecundity. The data used by Hjort (1914) to prove variation in numbers of eggs produced by individual fish are meagre and proof of such variations is still lacking. Correlations drawn between fecundity and size as well as age indicate that within limits of the data involved neither the individual variations nor cyclical variations in fecundity are sufficient to obscure the relationship between the first three factors. It is possible that the effects of temperature upon rate of spawning or fecundity may be quite different. Temperatures both above and below the optimum may be inhibitory. Accurate quantitative results would require investigation of these points but it is not probable that errors introduced by ignoring these effects would alter the trends of abundance of eggs significantly in the present data.

The third group of variables which effect the total number of eggs on the banks—in most respects without regard for the total number spawned—can be measured. Proper evaluation of all these factors is necessary before the total spawning intensity can be calculated. Evaluation of their relationship to changes in abundance due to population changes and to the problems of sampling is fundamental to successful solution of the problem of measuring the production of eggs, or any other similar pelagic population.

RATE OF DEVELOPMENT OF THE OVA

As soon as the eggs are spawned and are fertilized, they begin to develop at a rate which depends principally upon the water temperature. Throughout their period of development, they are subject to a natural mortality which, for convenience, may be considered constant for all stages and throughout the spawning season. We may divide this period into stages of development, each of which would represent an equal amount of time if the temperature were constant throughout the area and period of development. The amount of time represented by each stage would then vary according to the rate of development, that is, inversely as the temperature. The total population present on the banks at any one moment will therefore contain eggs in all stages of development (except at the beginning and end of the season) but the number of days' spawnings represented by these various stages will vary inversely as the temperature or rate of development. The same relative changes in numbers of eggs present on the banks, which are correlated with varying rates of development, occur no matter how small a section of the embryonic growth period is considered. Keeping in mind these features of egg population, examination of temperature observations taken in past years near Cape St. James indicates the importance of treating this population as dynamic rather than static.

Distribution of temperatures with depth taken off Anthony Island at latitude 52° 00′ N., longitude 131° 14′ W., at four times in the same year (January 18-February 9, 1938) is shown in Figure 17, left. Distribution of temperatures at the same stations in six years, 1937 to 1942, is shown in Figure 17, right. These observations were made (January 31 - February 11) shortly after the height of the spawning season.

Examination of Figure 17, right, and Table 5 shows that in the six years for which observations are available, the range of temperatures at depths where halibut eggs were caught was from 4.7°C. to 9.7°C. The time to hatching for halibut ova at these temperatures can be estimated from the observations of Johansen and Krogh, and Rollefson. Johansen and Krogh (1914) observed that the product of the number of degrees centigrade above biological zero at which eggs develop and the time in days from fertilization to hatching is a

TABLE 5. MEAN TEMPERATURES AT 0 TO 1500 METERS OF CABLE OUT FOR THE YEARS 1934-1935 TO 1942-1943, AND 1945-1946 AT THE CAPE ST. JAMES HYDROGRAPHIC STATIONS.

Wire Out	1934–1935	1935–1936	1936–1937	1937–1938	1938–1939	1939–1940	1940–1941	1941–1942	1942–1943	1945–1946	Total No. of Observations
9.16	8.87	8.95	7.04	7.24	112	0	7.87	8.41	6.15	7.87	7.62
25	7.89	8.43	6.27	8.07	8.21	9.17	8.90	9.04	—	—	88
50	7.96	8.43	6.36	7.96	7.71	9.23	8.96	9.10	6.98	7.15	115
100	7.39	8.30	6.54	7.83	7.48	9.18	9.10	9.09	7.76	7.08	113
150	7.16	7.83	6.16	8.17	6.78	9.03	—	9.27	7.38	6.76	30
200	6.18	7.14	5.68	6.76	6.52	7.62	7.27	8.05	5.74	6.30	78
250	6.07	6.44	5.46	—	6.12	—	7.08	7.19	—	—	28
300	5.64	6.04	5.22	6.03	6.02	6.31	5.81	6.30	5.57	5.51	56
400	5.33	5.46	4.99	5.44	5.38	5.56	5.30	5.32	(5.02)*	(5.03)*	44
500	4.60	4.87	4.78	—	4.89	4.73	4.45	—	4.51	4.57	31
750	—	—	—	—	—	—	—	—	—	4.02	3
800	3.90	3.92	—	3.89	3.90	3.78	—	—	—	—	26
1000	—	3.52	—	—	—	—	3.46	3.26	—	—	11
1500	—	2.58	—	—	—	—	—	—	—	—	3
Mean of the mean temperatures at 100, 200, 300 and 400 meters of cable out.											
	6.14	6.74	5.61	6.52	6.35	7.17	6.87	7.19	6.02	5.98	

NOTE: No observations in 1944-1945 because of failure of water bottles to function properly.
*Interpolated.

constant for any one species. For the Atlantic halibut, Rollefson (1934) observed that this period was 18 days at 6°C. Hence the number of days from fertilization to hatching using 0°C. as the biological zero would be 23 days at 4.7°C. and 11 days at 9.7°C.

Using the relationship shown by Johansen and Krogh and the rate of development of halibut eggs as published by Rollefsen (1934) with various combinations of mortality rates from 30 per cent to 70 per cent between spawning and hatching and with the intensity of spawning distributed as a normal curve of error about January 19 with $\sigma_x = 15$ days, the possible errors introduced by temperature induced variations in rate of development into the estimates of total abundance of eggs were calculated. Over the range of average temperatures noted, the errors involved were found to be insufficient to change the trends established from the original data.

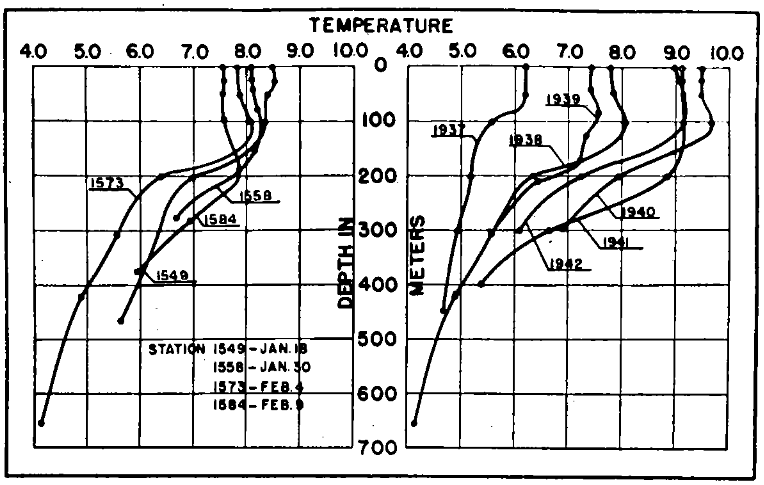

FIGURE 17. Temperatures at Station 6A, 52° 00′ N., 131° 14′ W. Left, 1938; right, 1937-1942

RATE OF MORTALITY OF HALIBUT EGGS

An approximation to the rate of survival during embryologic development can be made by use of the formula $S' = Se^{-rt}$ where S is the original number of eggs, S' the number surviving after time t, and r is the rate of loss. For the first nine years of net hauls at Cape St. James the yearly mean number of stage 1 eggs* was 595; of stage 2, 184. Assuming stage 1 and 2 divide the period of embryologic development into two equal time intervals, then 595 and 184 would be the number of eggs at the end of .25 and .75 of the total

*The mean number of all halibut eggs per year was used for this purpose because the number of stage 2 eggs was insufficient to enable the drawing of contours and also because it was considered that the best results could be obtained by using all net hauls including those taken after the peak of spawning when greater relative numbers of stage 2 eggs were found.

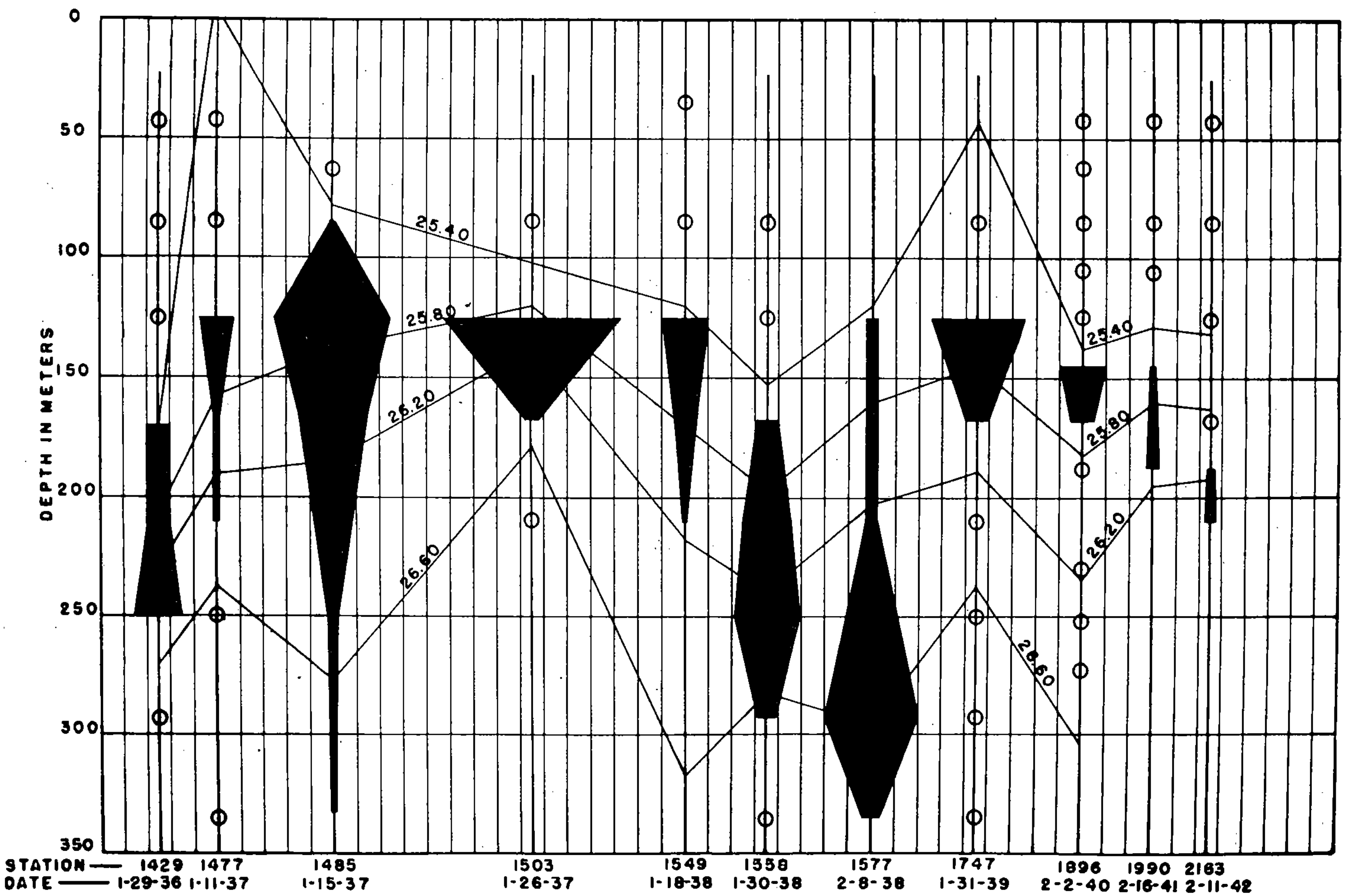

FIGURE 18. Catch of halibut eggs in closing hauls, associated with depth of haul and water density. Circles indicate hauls without egg catches. One unit on the abscissa equals 20 eggs.

period of development respectively. By substitution $184 = 595e^{-.5r}$ or $r = 2.347$. By extrapolation the number of eggs at spawning, S, would be 1070, ($595 = Se^{-(2.347)(.25)}$). The number surviving to hatching $= 1070e^{-2.347}$ or 102. This indicates that approximately 10 per cent of the eggs survive from spawning to hatching. The average temperature of the water at levels where eggs were caught over the different years was 6.38°C. The mortality rate could be expected to be greater at temperatures much higher or lower than that observed.

RELATION OF DEPTH DISTRIBUTION OF OVA TO WATER DENSITY

The relation between abundance of halibut eggs, the specific gravity *in situ*, and depths as determined from data gathered from a combination of closing hauls and hydrographic stations is shown in Figure 18. Practically all eggs were found between densities of 25.40 to 26.60 with the mean density of all eggs of 25.94 (i.e. 1.02594). The coefficient of correlation between the number of ova for a one-hour closing haul and the value of the deviation of σ_t from the mean of σ_t in which eggs were found was calculated as —.452 (5% pt. = .404, 1% pt. = .515, for 22 degrees of freedom, Table 13.5, Snedecor). The value of beta for number of eggs and deviation of σ_t from its mean, taking into consideration the deviation of depth of capture from its mean, was found to be —.550 (Snedecor's $t = 2.52$, 5% pt. = 2.080, 1% pt. = 2.831 for 21 degrees of freedom, Table 3.8). On the contrary, the correlation of number of eggs with deviation of depth from its means was —.067 with a beta coefficient of +.201 with the 5% point for r as above, and for $t = .92$. As would be expected the correlations indicated that the vertical distribution of the eggs was more closely associated with density than with depth.

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