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Title

Cod and Water Temperature

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COD AND WATER TEMPERATURE

During the investigations on the cod, quite a number of observations have been made on the relation between the cod and the temperature of its surrounding medium.

In order to form a basis for further work in this regard, it is believed that this information should be set forth. The data collected are from two sources, namely, that obtained from commercial and experimental fishing, and that from holding cod in tanks supplied with running sea water which varied in temperature in accordance with the sea conditions.

In Nature

Figure 1 shows the average monthly cod landings at Campobello and adjacent islands over a period of years. The average temperatures * over the same period at bottom in ninety metres at a position, station 5, which is located somewhere about the middle of the fishing grounds is also shown. It is seen that the temperature curve is fairly uniform and regular, indicating that the yearly minimum temperature is reached in March and the maximum in October or late September. The landing curve shows that the fishery is at a very low ebb during the first three months of the year, but in April it picks up definitely, though not greatly, while in May and June the landings reach a very high level, the peak for the year in fact. However, in July it drops greatly, remaining so in August but increasing again in September. From then on to the end of the year they decrease, rapidly in October and slower thereafter until the yearly lowest point is reached in March.

In this figure, it is seen that the lowest level in the fishery corresponds to the minimum water temperature which is about one and a half degrees centigrade. During the two peak months in the fishery, May and June, it is seen that the water temperature increased from about three to six. While the landings were at a low ebb in July and August the temperature increased from six to about eight point five. However, the decided increase in the landings in September corresponds to a still further increase in temperature from eight point five to about nine point five. From then on, generally speaking, both curves drop indicating that, while the temperatures dropped to a level which was apparently suitable for the peak landings of May and June, the landings did not increase as they did in May and June under the same temperature conditions.

When the data are plotted for the individual years in the period under discussion, it is found that during the first part of each year no cod were landed over a period varying in length from one to three months. During these months when the cod were either absent from the fishing grounds or not biting, the temperatures varied from minus point five to plus three point six degrees centigrade. Thus, while on the average this latter temperature seems suitable as in figure 1, still at certain times, no cod are landed even at this apparently suitable temperature.

* Temperature curves for each year were plotted, based on monthly records. The mid-month temperatures were read off each graph and the average for each month determined and plotted in figure 1.

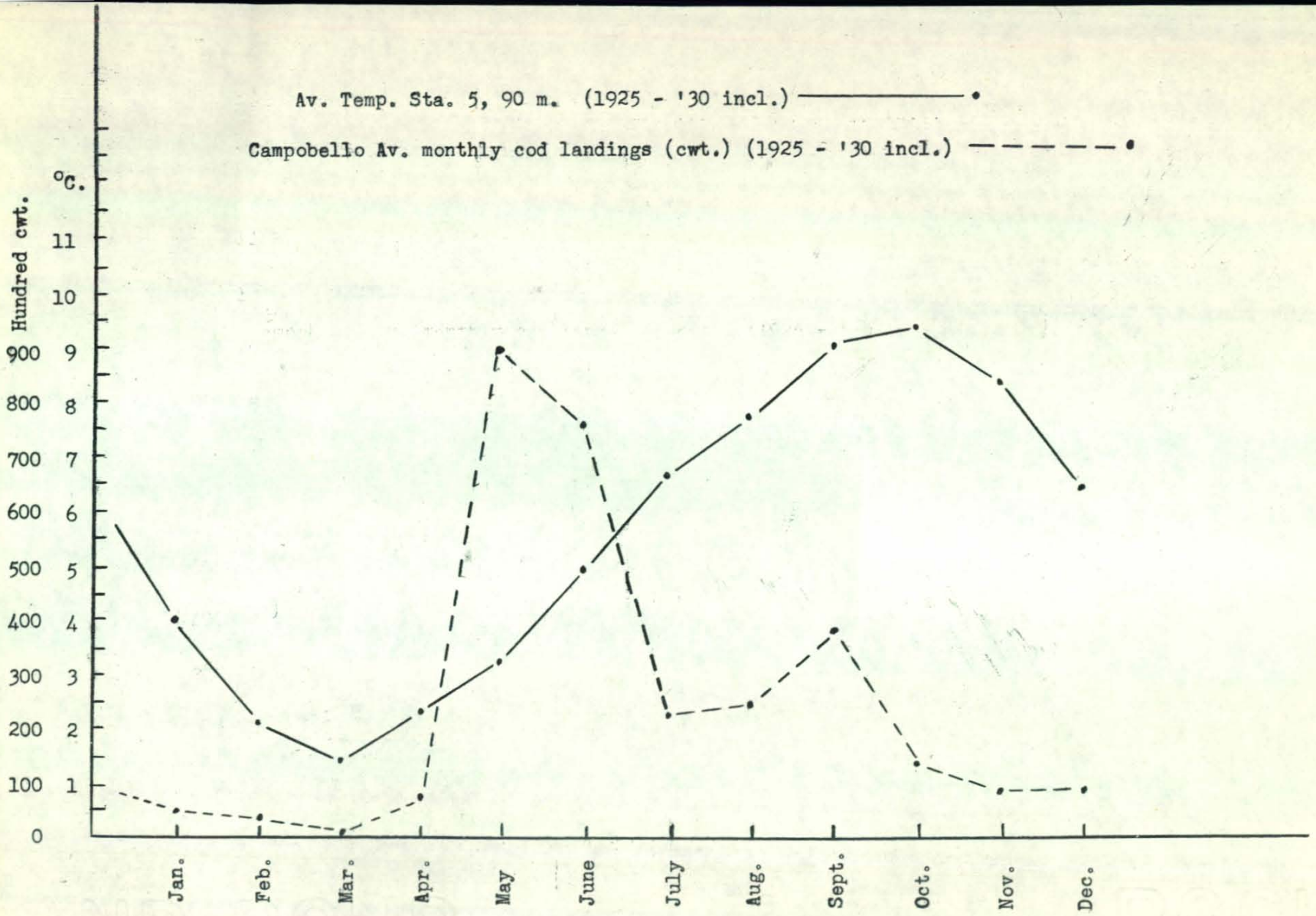


Figure 1. Shows the average temperatures (1925-1930 inclusive) at the ninety metre level, station 5, as well as the average monthly landings of cod at Campobello for the same period.

Examining the temperatures during the first month's fishing succeeding this period of no landings reveals the fact that the temperatures at which the first cod were caught each spring varied from one point nine to four point two. The minimum temperature at which cod were landed is found to be about one point two.

An examination of the temperatures at which the yearly maximum monthly landing was made brings out the interesting fact that these ranged from three and a half up to nine point two degrees centigrade. This last temperature was recorded for a month in which fourteen thousand eighteen hundredweight was landed. This landing is only very slightly below that of the maximum monthly landing made during any month of the whole period under consideration, namely fourteen thousand and fifty-four hundredweight.

Thus it has been found that while the maximum monthly landings usually occur in May or June when the temperature varies from about three point five to six, still it may occur in September at a temperature of nine point two. Then, too, in the spring when the cod seemingly return to the fishing grounds in this vicinity, the temperatures may vary from one point nine to four point two. A similar variation in temperature was found to occur at the time when the cod apparently left the region each winter. The only apparent order in the data seems to be the fact that the yearly peak in the landings usually occurred in May or June, generally the former, and that the landings were, as a rule, very small during December to March inclusive, irrespective of the temperature.

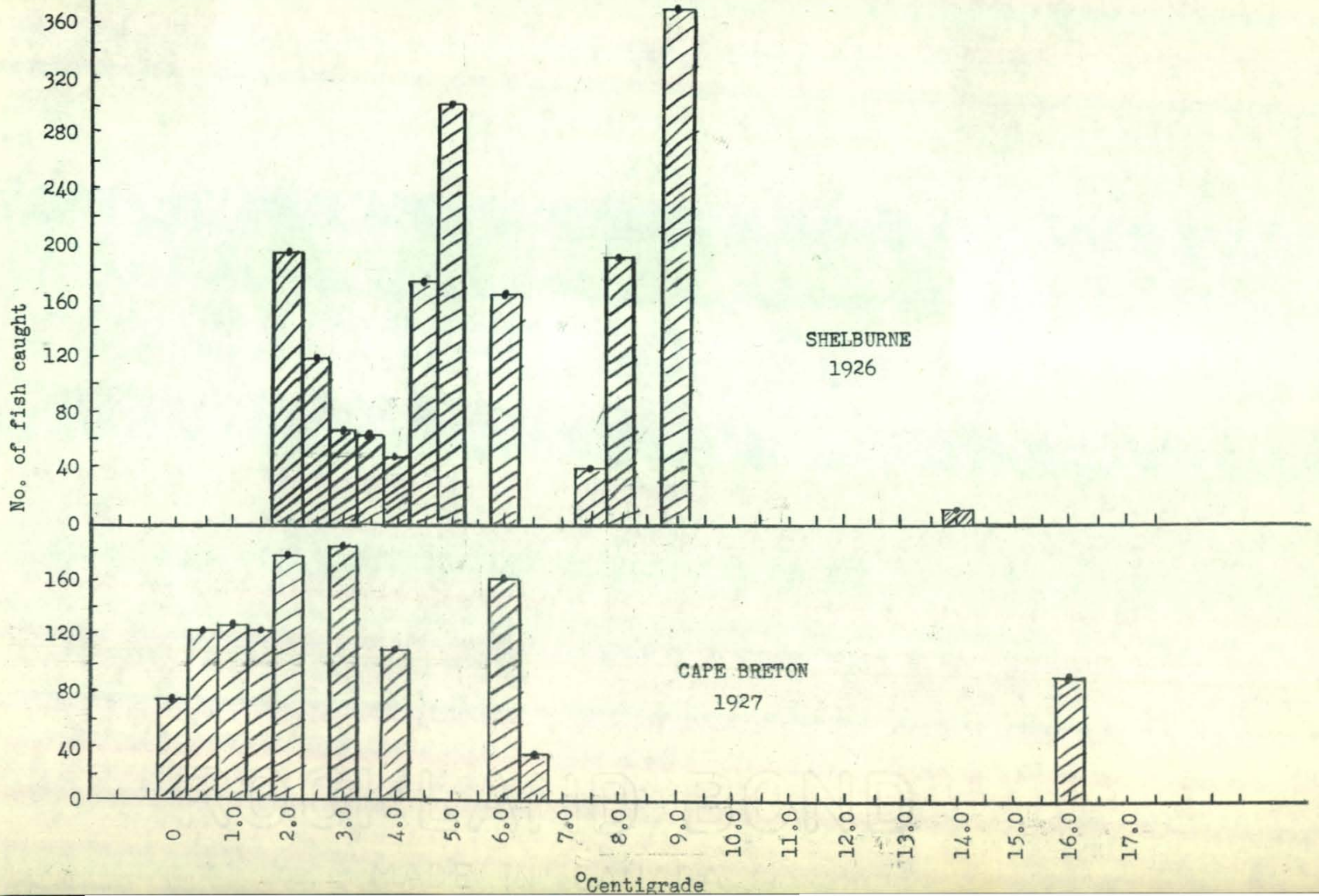
In figure 2, the cod caught for tagging purposes are shown in relation to the temperature at the bottom where the fish were caught. Here, at Cape Breton, it is seen that very good catches were made at temperatures between zero and six. A comparatively poor catch was made at six point five degrees centigrade. From there on up to about sixteen degrees, no operations were carried on but a very good catch was made at fifteen point seven five degrees. The best catch was made in water of three degrees.

At Shelburne, no water of less than two degrees centigrade was fished. From this temperature up to about nine catches of varying sizes were made, some very good and some poor. The best was made at nine point one. Fishing at the high temperature of fourteen degrees centigrade gave a very poor catch in contrast to the good catch made at Cape Breton at an even higher temperature.

The records of two commercial fishermen operating in Halifax harbour from the middle of July to the middle of October 1932 have been obtained, reduced to the same denomination as nearly as possible and plotted in figure 3. At the same time, temperature records at the twenty-five metre level at station Z. 62 have been plotted over the same period in the same figure. * From July to the middle of September, it is seen that the daily catch very slowly declined as the average temperature gradually increased from about three and a half to six degrees centigrade. During the second week of September, a strong south west gale lasting for a number of days drove a lot of warm surface water towards the shore, raising the temperature to about fifteen centigrade as shown in figure 3. This condition of warm water on

* The twenty-five metre level has been chosen since it is within the range of depths fished in Halifax harbour and also because temperature records for this depth about the centre of the harbour are available.

Figure 2. Shows the magnitude of the cod catches made during the tagging operations in 1926 and 1927 in relation to temperature.



the bottom prevailed not only in the harbour but all along the shore out to about the hundred metre contour line. Corresponding with this figure 3 shows a cessation in the catching of cod in the harbour and reports from along the shore indicate that fishing was successful only outside the hundred metre line. Whether the cod actually left the shoal shore waters or just stopped biting is not known. However, as the water cooled off again during the first part of October, figure 3 shows that the fishing returned to its former level or higher.

A somewhat similar occurrence was noted at Shelburne in 1926 where very successful fishing was being carried on during the first part of September in water twenty to thirty metres deep at a temperature of from four point five to five point one. However, at the same time very good fishing was being obtained in forty metres at two degrees. Two weeks previous to this excellent fishing had been obtained in twenty-five metres of water at nine point one degrees centigrade. During the third week of September, gales brought much warmer water to the shore raising the temperature suddenly to fourteen at the twenty to thirty metre level. Correspondingly, the cod catches in this warm water dropped to less than a dozen fish per day for the boat in question. However, as soon as they moved off into water of fifty to sixty metres depth and five to seven degrees in temperature the catch increased to five to seven dozen cod per day. Even this, however, compared unfavourably with the fifteen to twenty-five dozen per day being caught just a few days before in twenty to thirty metres at four to five degrees.

Thus a sudden rise in temperature from about seven to fifteen as at Halifax and five to fourteen, Shelburne, results in a drop to practically nothing in the catch of cod. Previous to the sudden great rise in temperature at Halifax, the smaller fluctuations seem to have no counterpart in the catch except once during the last of July when the curves moved in opposition to each other. Even a gradual, or comparatively so, rise to seven, eight, or nine degrees, as noted for Shelburne early in September, does not result in a negligible catch. Briefly, it seems that small sudden irregularities in temperatures below nine degrees as above may or may not appear to react on the catch while sudden great rises above this do seem to correspond to sudden large drops in the catch of cod.

During the period 1928-33 inclusive, notes by Claude Darrach concerning the cod fishing in Halifax harbour have been kept irregularly. These have been put into a graphic form in figure 4, both in their proper temperature relation and monthly relation. Below about ten degrees, the temperatures used are those recorded at the twenty metre level at station P.537 which is situated among the fishing grounds in the outer part of the harbour where the fishing was done. Above ten degrees, it so happens that the temperatures were accurately recorded on the grounds at the time of fishing.

When plotted according to temperature, it is seen that the catches were made from a temperature of about minus point two five to plus fifteen. Below six there were no catches of practically zero magnitude while above this four out of the twelve records indicate that almost no cod were taken. It is interesting to note that the temperature range is so great and that such good catches were made about zero degrees centigrade as well as between seven and eleven. Those at thirteen and a half and fifteen show decidedly that cod can live at this high temperature. However, at the fifteen degrees the cod only averaged about thirty-eight centimetres in length while at the next lower temperature there were some decidedly larger fish in the catches seen. The fish taken from the eleven degree water averaged sixty-six

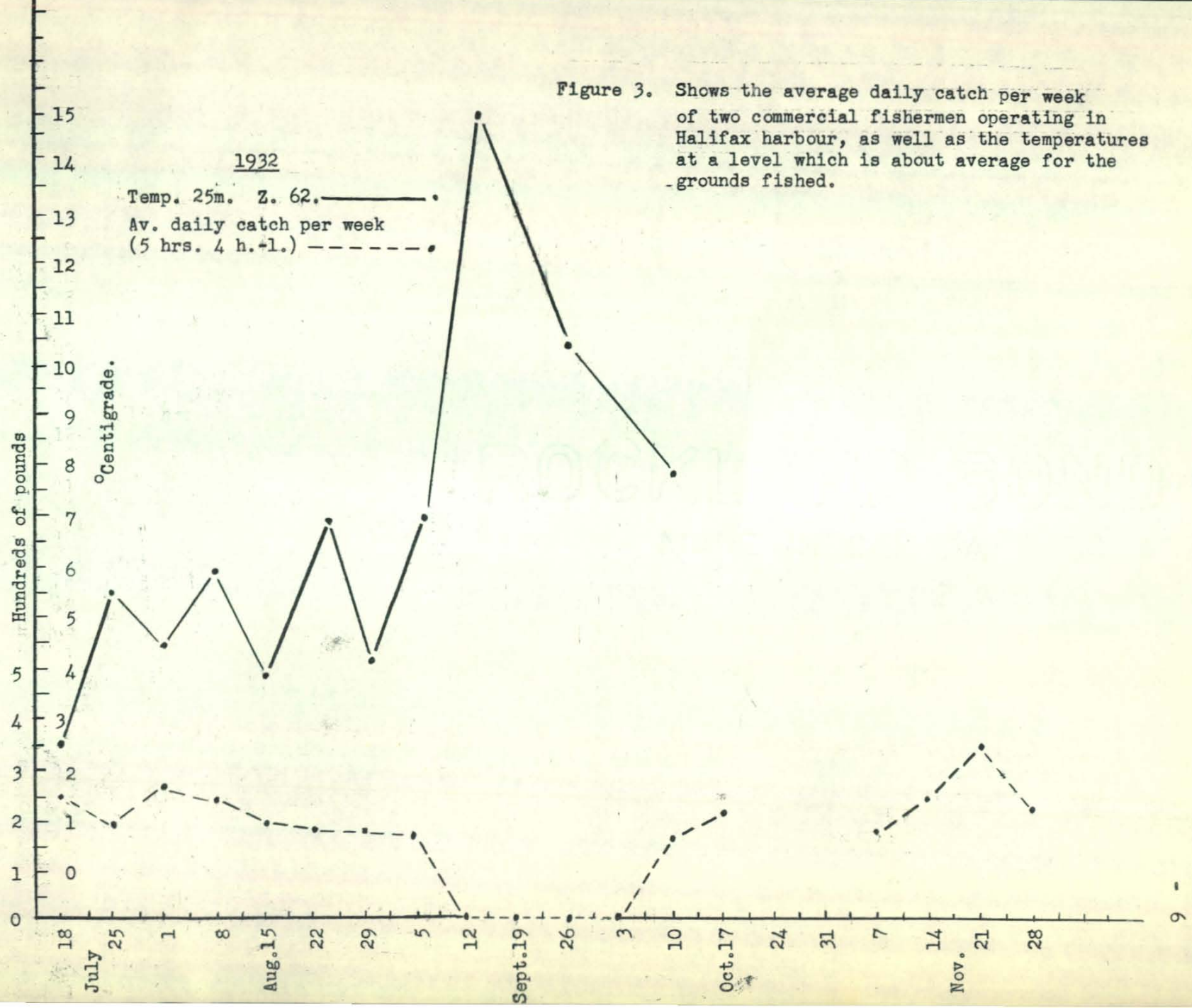


Figure 3. Shows the average daily catch per week of two commercial fishermen operating in Halifax harbour, as well as the temperatures at a level which is about average for the grounds fished.

centimetres in length and in fifteen minutes, thirty cod were taken with a jig from the water of this temperature. Our records which are very few, also show that the percentage of small fish caught goes up generally when fishing in the very cold zero or lower water. The average size for the harbour is greatest in the early summer and fall. It is very interesting to note that generally speaking the jig is by far the best type of gear for taking cod at the high temperatures, that is of a marketable size for baited hooks are more effective in taking smaller fish than larger ones at these high temperatures. It has also been found that by far the greater number of the larger cod taken in such warm water have empty stomachs.

Considering the catches according to months, it is seen that the catches are more irregular during the second half of the year than during the first. Along with this the records show practically no trawl sets giving no cod in the catches up to July, while after that until about the end of the year the percentage of blank sets increases month by month. Two factors are thoughtto play a part in this. The first is the comparatively warm water which usually pervades the harbour from about July or August on and the second is the onset of spawning which begins, with some of the cod at least, as early as the last week of September and continues on until December.

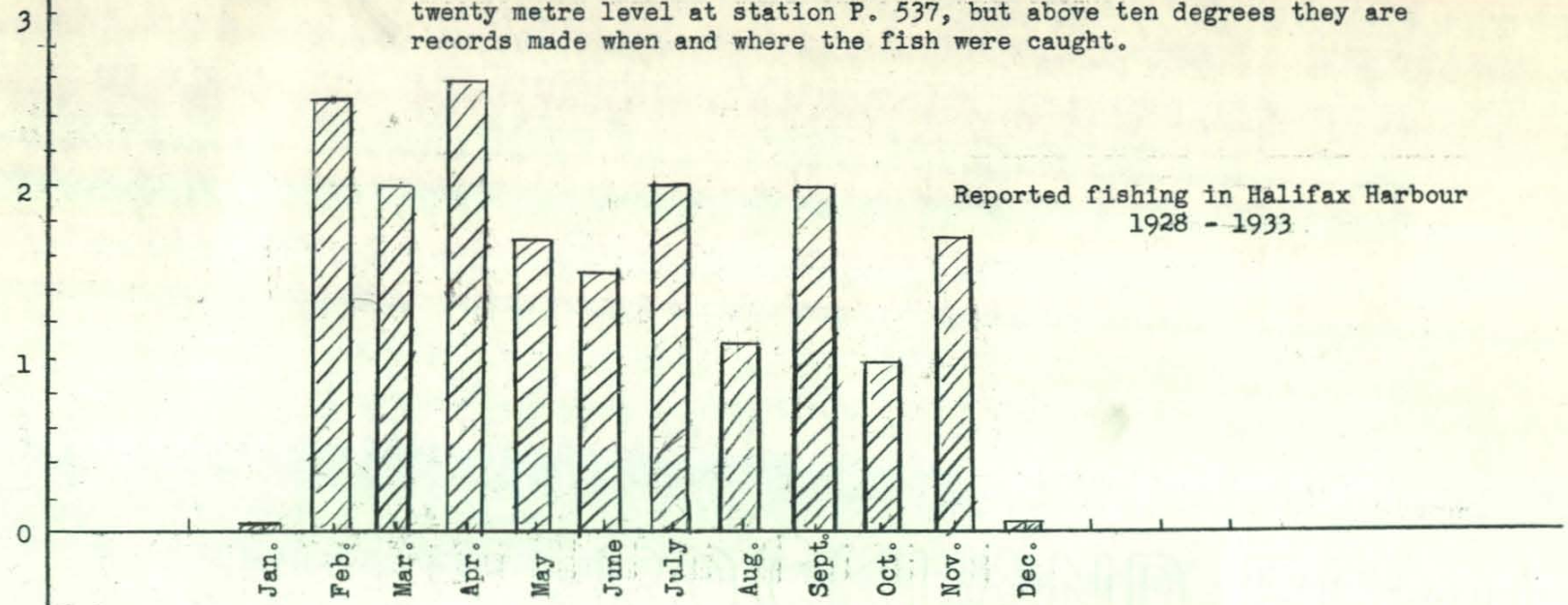
During the summer of 1932, experimental line trawling was done in the Halifax area in water of different temperatures and depths. The actual fishing gear, bait, length of set, etc. was the same in each instance as nearly as possible. The results of this fishing have been arranged in figure 5 according to temperature. Here it is seen that between zero and four degrees centigrade, the catches were much better than above that. Excluding catches of five or less, it is found that roughly speaking the average length of the fish in the catch goes up from point five to five point five degrees centigrade. Unfortunately there were no large definite catches recorded from above this temperature.

In 1933 experimental fishing was again carried on as in 1932, but more stations were established and fished more consistently. Figure 6 shows the catches according to temperature again. Here it is seen that while most of the comparatively good catches were made between one and six degrees centigrade, still, some very fair fishing was obtained in water of ten and twelve degrees centigrade. Above six, the catches were also very much more irregular in size than below it. This figure is based on all the catches during the summer.

Another interesting point appears when the average length of the fish taken at the various temperatures is determined. The cod caught in water between one and three degrees averaged sixty-five centimetres in length, between three and five degrees seventy-six centimetres, between five and seven sixty-five centimetres, between seven and nine fifty centimetres and between nine and twelve forty-nine. The number of fish in the last two groups was very small indeed, but in the first three there were between a hundred and a hundred and fifty cod in each group, obtained by fishing at different times in different places. While the averages at the higher temperatures are not very reliable, still, the whole thing seems to indicate again that a greater percentage of smaller fish are caught, and presumably live, in water which has a comparatively high or low temperature than in water which is more intermediate in temperature.

In fugure 7 the catches along with the temperatures from week to week are shown for three of the fishing stations which were located in three different depths

Figure 4. Gives a graphic representation of the reported fishing in Halifax Harbour 1928 - 1933 inclusive. The temperature records are nearly all from the twenty metre level at station P. 537, but above ten degrees they are records made when and where the fish were caught.



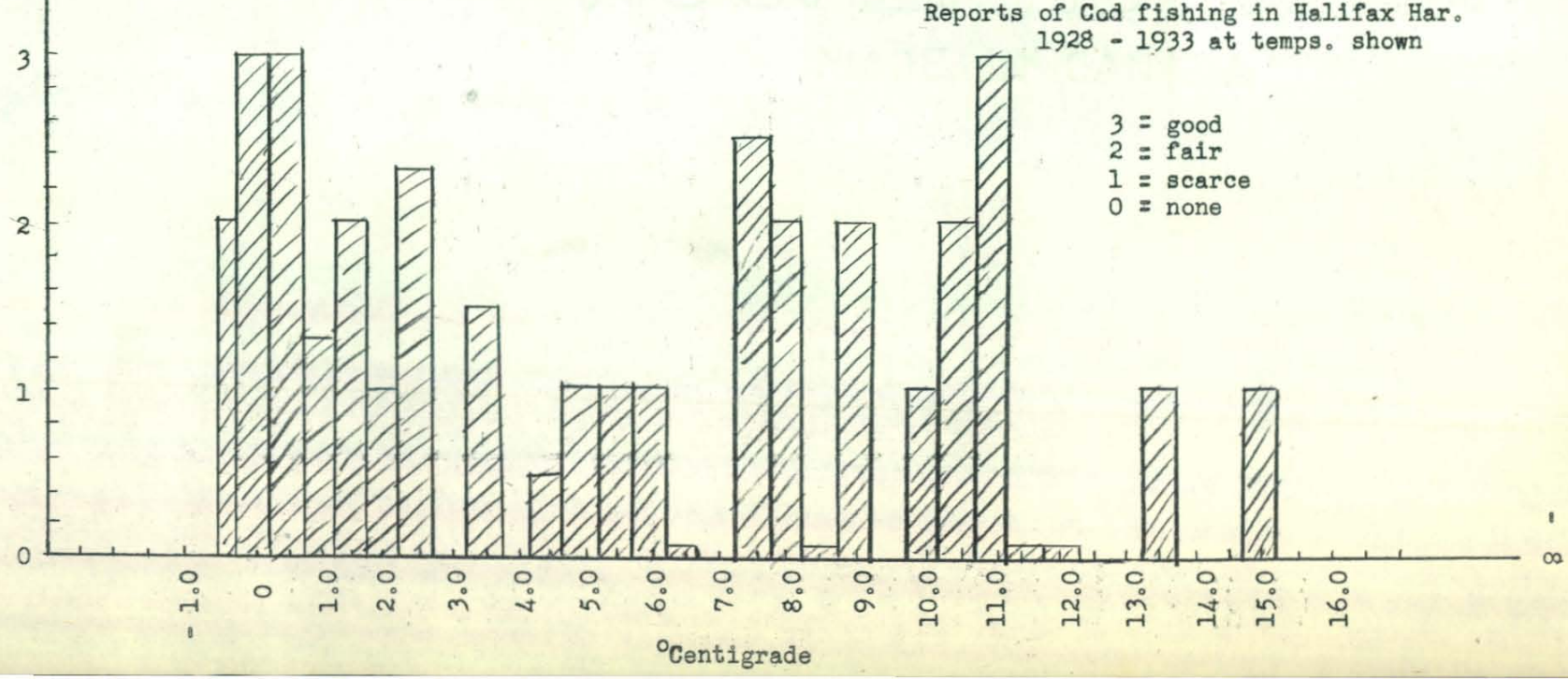


Figure 5. Shows the number of cod caught per 300 hooks on experimental gear as well as some comparable commercial catches in the Halifax area, 1932.

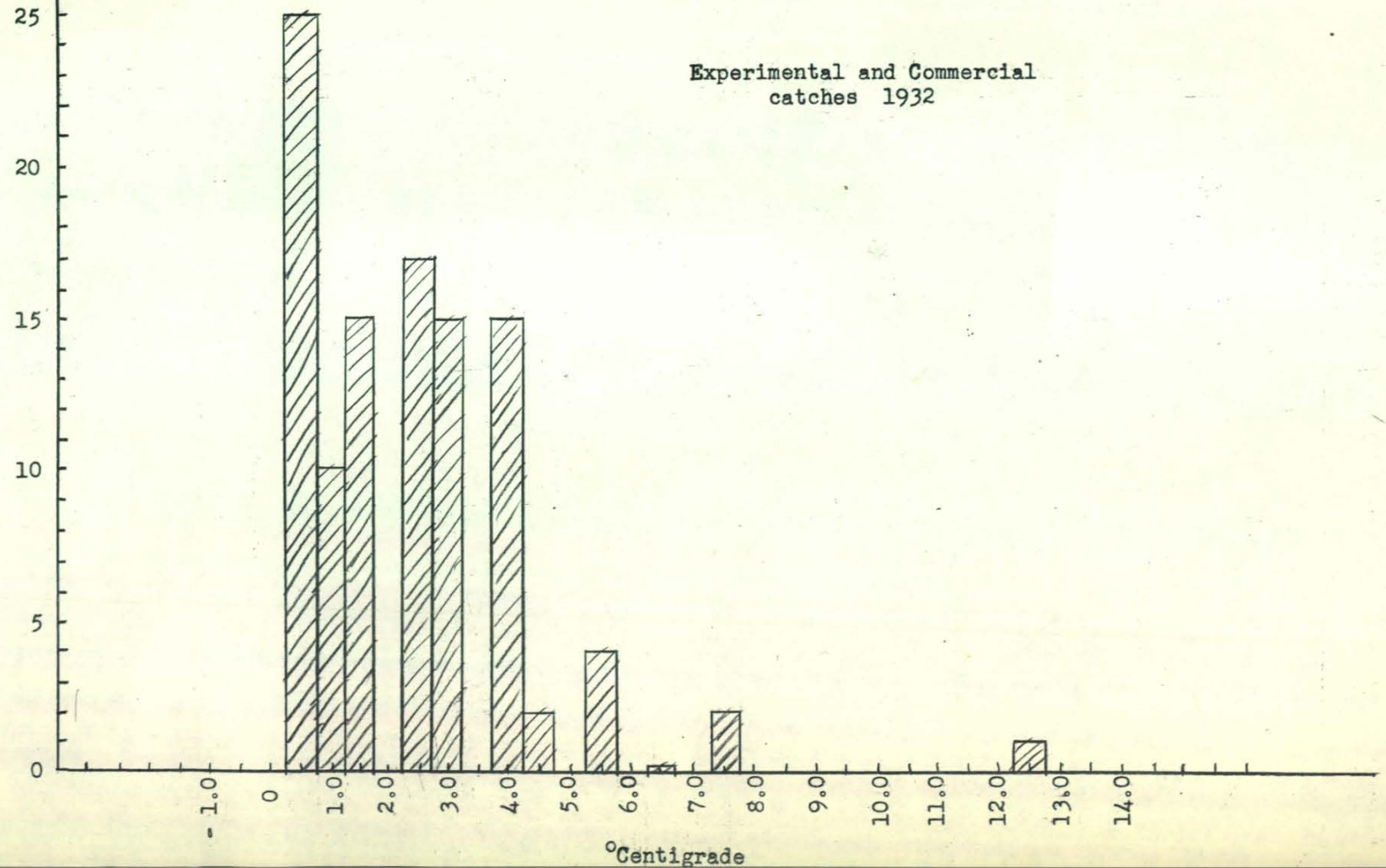
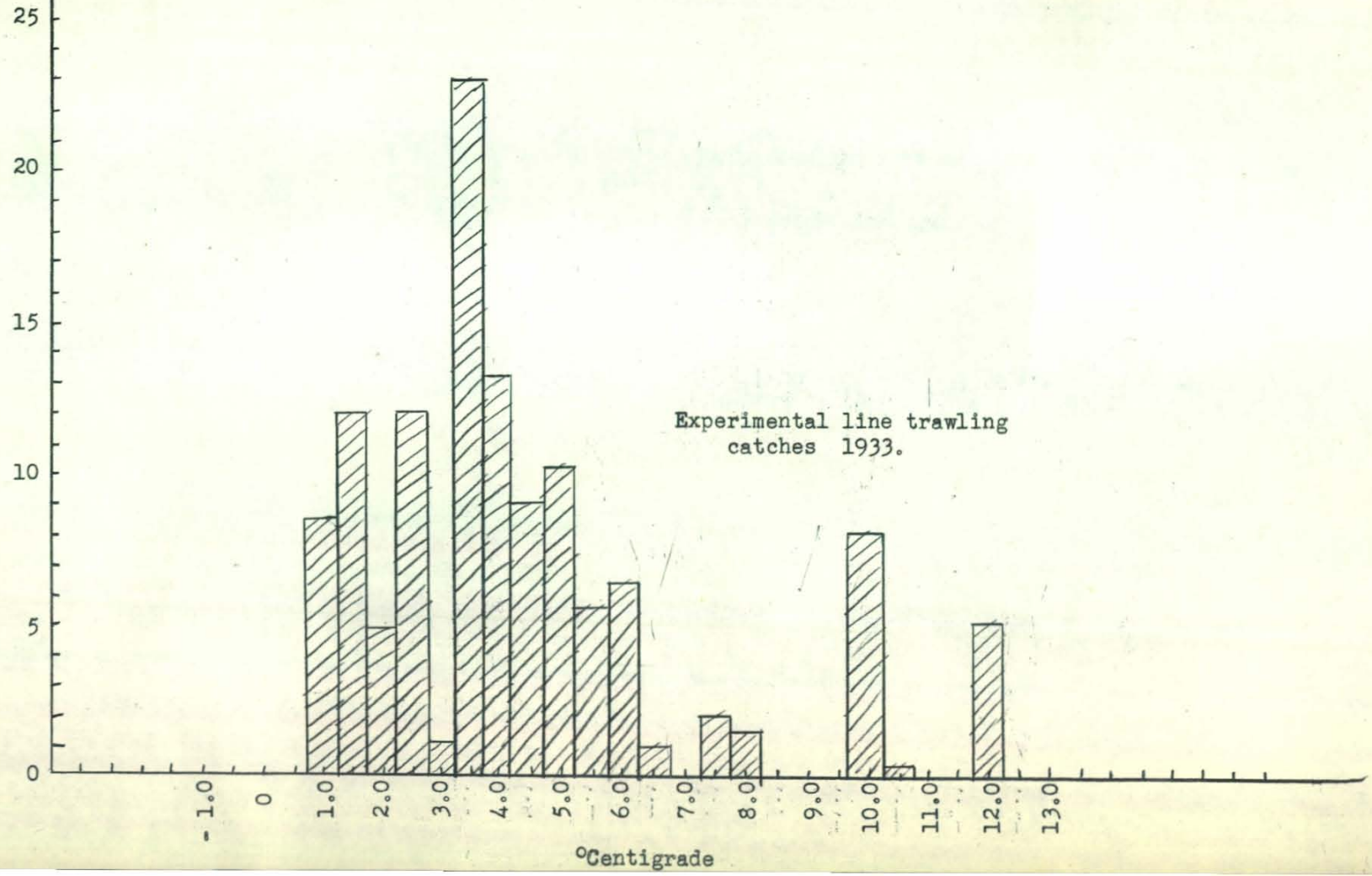


Figure 6. Shows the number of cod caught per 300 hooks on experimental gear in the Halifax area, 1933.



of water. The shoal one had comparatively warm water, the intermediate one cold water and the deep one water of from about four to seven degrees centigrade. Off this coast, there is a comparatively cold intermediate layer of water during the summer. It is seen that generally the catch decreased from the end of May to the middle of August irrespective of the temperature. Thus, since at the end of this period, water ranging in temperature from about two to seven degrees was available within a short distance of shore, it is believed that the water temperature was not the cause of the decrease in cod catch. Throughout the summer the shoal water, station Z 96, ranged from five to twelve degrees centigrade, the intermediate depth, seventy-eight metres, ranged from about one to two point five (one exception in July) while the deep water varied from about four to six. The shoal water thus had varying temperatures on the warmer end of the range, the intermediate layer had a fairly uniform low temperature and the deep water a quite uniform moderate temperature of four to six degrees centigrade.

The fish caught in these three divisions have been found to vary greatly in average length. The average for the summer in the warmer shoal water was fifty-four centimetres, for the cold layer sixty-three and for the moderately warm temperature (four to six) of the deep water seventy-eight centimetres. These averages are based on fifty to seventy-five fish in each case.

Thus it is seen that cod were caught in water ranging from one to twelve degrees centigrade, but given the supposedly suitable temperatures it didn't always mean cod were obtainable, as in August. Along with this it has been found that the larger fish were caught in the so-called moderate temperature range of about three point five to six. However, the depth factor may be responsible for this though very large cod are quite frequently caught in very shoal water. Again, it has been found that cod off Shelburne as they grow older remain progressively farther off-shore when they come in towards shore each summer. However, even in this instance the largest cod came in to water of thirty to fifty metres in depth. By reason of this, it is believed that this uniformly (it varied but little all season) intermediate temperature water had a great deal to do with the largest cod in the Halifax inshore area being found where they were.

Summary

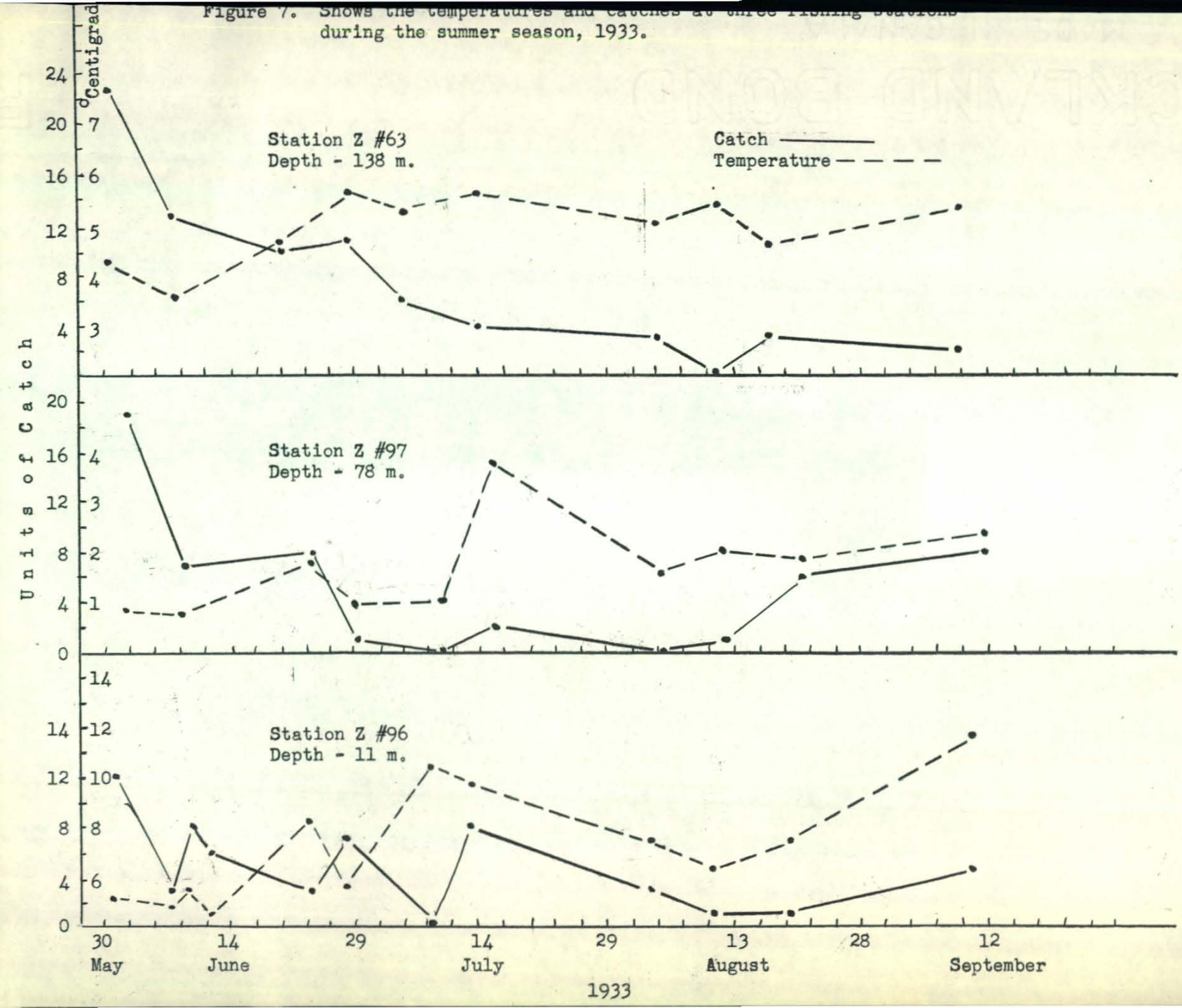
At Campobello the maximum landings come from water of three point five to six degrees centigrade. However, cod were taken from water with as high a temperature as nine in considerable numbers, and with as low a temperature as one degree centigrade. The period of no landings corresponds more with the time of year than the water temperatures.

During the tagging operations at Cape Breton, most of the cod were caught in water of temperature zero to six degrees, but a very good catch was made in approximately sixteen degrees.

About Shelburne, water of two to fourteen degrees was fished with the best individual catch being made in nine degree water. Below this, the catches were varyingly good, but above it they were very poor.

In Halifax harbour 1932, very good fishing was obtained generally as long as the temperatures remained between two point five and nine, but an influx of warm

Figure 7. Shows the temperatures and catches at three fishing stations during the summer season, 1933.



water (about fifteen degrees) suddenly put a stop to successful fishing inside the hundred metre line. Outside of this, -- temperature two to five -- the fishing was fair. A similar incident is also recorded for Shelburne. Thus sudden changes in temperature seem to be more or less disastrous to fishing.

The available records regarding the fishing conditions in Halifax harbour from 1928 - '33 inclusive show that fairly good catches have been made from water of point two five degrees up to eleven degrees in temperature, and some even as high as fifteen degrees. Generally speaking, the fishing becomes more irregular as the year advances and the number of catches without results increases decidedly towards the end of the year, possibly due to both warmer water and the onset of spawning.

Experimental trawling in 1932 showed the better catches to be made between zero and four degrees, while in 1933 the better catches were made in one to six degree water with a fair catch being made in ten and another in twelve degree water. In spite of the three distinct layers of water off Halifax, supplying a wide range of temperature within a small area, the catches decreased in all three from May to the middle of August. It is thus believed that some other influence was the dominating factor or factors.

Our general records show that in Halifax harbour the larger fish are taken in spring or early summer and fall when the temperatures are more intermediate in nature while the percentage of small fish in the catch increases in water of about zero or lower as well when the water is comparatively warm. However, large cod, generally with empty stomachs are often taken in large numbers with a jig in water of over ten degrees. The experimental line trawling of 1932 also showed in a rough way that the average length of the fish caught in point five degree water was much less than those caught in five degree water. In 1933 experimental line trawling in the Halifax area again showed that the average size of the cod taken in the intermediate temperature layer, i. e. deep water three point five to six degrees, was greatest. Those from the colder temperature range were next largest and those from the warmer, the smallest. Temperature is believed to be one of, if not the leading factor in this distribution.

In Tanks

During the past few years, cod of varying sizes have been held in cement tanks, roughly six by three by three feet in size, with running salt water. While none of these fish have been kept a whole year (most of them met so-called violent deaths) still different fish have been kept at different times so that cod have been observed during all the seasons of the year.

One bad feature has been using observations from different fish at different seasons. So far as this work has gone, it has been found that one of the most striking points is the individuality in the fish, for two fish rarely behave alike even under what appear to be similar conditions. Some cod become accustomed to tanks and artificial feeding within a day, while others never eat in the tanks (at least up to four months). Thus even at the very beginning they do not behave alike and the observations would be of so much more value if one fish could be compared with itself first, and others later, over all the seasons of the year.

Feeding

Frozen herring, both the small sardine size as well as the mature herring, has been the food most generally used. Fresh clams and mussels have been used to some extent. These items of food have been cut into pieces suitable for the different sizes of fish. The amount eaten was determined by weighing an excess of food before feeding a certain fish and then the remainder after. All the weights are very rough since they are all wet weights, but the larger differences and trend of curves are considered significant.

Differences occur in fish of different sizes, under different temperature conditions, etc., but generally speaking it has been found that the fish eat most regularly if fed three times per week. Again, our information so far points to no differences being found between feeding early in the morning, throughout the day or late in the evening.

During the spring of 1933 four fish were kept in the tanks from the beginning of March until the beginning of May when they met violent deaths enroute to Halifax. From the middle of March, at which time the lowest water temperature of the winter in the tanks was recorded, the temperature increased from about two point two centigrade to six point seven by the first week of May. In figure 8A the average amounts consumed per feed per week by the three small cod which varied from thirty-three to thirty-eight centimetres in length have been averaged and plotted while the amounts eaten by the one large fish, sixty-one centimetres in length, have been plotted separately.

It is seen that the large fish began to eat when the temperature began to rise. Previous to the middle of March this fish, though placed in the tanks with others the latter part of November, 1932, ate practically nothing, and during this same period the water temperature was rarely above four point five degrees centigrade. However, the smaller fish did eat throughout this period much as seen for March. Unfortunately, no usable records for this November to March period are available. However, they seem to indicate that below two point eight the large fish displayed absolutely no interest in food while the smaller fish continued eating throughout. After the middle of March or towards the end of the month the temperatures definitely began to go up and with this definite upward trend the large fish began to feed. However, this upward trend did not seem to have an effect upon the smaller fish until the warming was well under way, that is up to about three point five degrees.

The drop in the feeding curve of the large fish and the maintaining of the same level of feeding in the small fish late in March instead of rising about the same time that that of the large fish did, is attributed to the fact that these fish were all weighed, measured and scale samples taken on March 21. This was again done on April 21st and its effect may be seen in the drop in the curve on April 24th for the smaller fish. However, they recovered from this handling much more rapidly than the larger fish which was handled more roughly in April than in March due to improper facilities for weighing. There is seen to be a correspondingly greater effect on the feeding of this fish which effect lasted over at least three weeks. Thus handling them causes a change in the feeding and possibly the rate of growth of these cod which is manifested at least in the feeding curves.

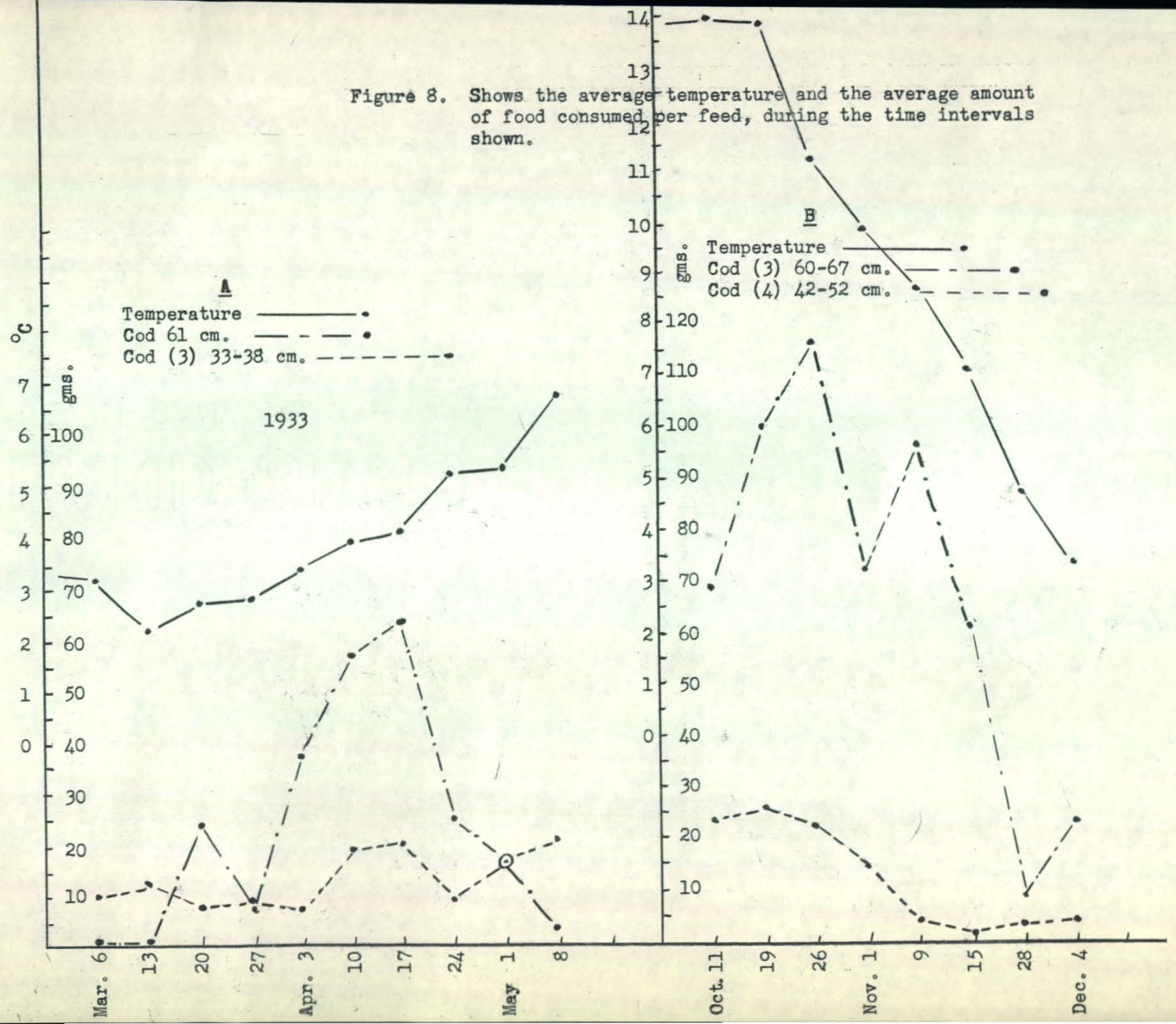


Figure 8. Shows the average temperature and the average amount of food consumed per feed, during the time intervals shown.

In the B section of this figure altogether different fish are considered, but it is seen that the steady drop in temperature is paralleled by a drop in the feeding curve, just as a steady rise in temperature in section A paralleled an increase in feeding. The larger fish were caught about October tenth and for the next two weeks the amount of food increased, but handling on October 28th and November 13th caused definite breaks in the feeding curve. However, after the first two weeks the trend was decidedly downwards. The smaller fish were not handled and their feeding curve drops regularly with some recovery after November 15th when the temperature went below seven degrees centigrade.

Thus these graphs indicate that at least up to eight degrees centigrade both the small and medium size cod increased the amount of food they consumed with the increase in temperature. At temperatures as low as two to three some of the medium size cod ceased feeding while others ate comparatively sparingly. Some of the small fish did the same but most of them continued to feed at this temperature, though some much better than others.

In figures 9 and 10 the feeding curves are shown along with the temperatures at the high end of the temperature range. Probably the most surprising point is the fact that all the cod used, that is, ranging in size from twenty-two to about seventy-five centimetres in length, lived through and continued to eat to some extent at least, temperatures as high as eighteen and a half on an average and a maximum of twenty to twenty-one degrees centigrade on certain occasions. On the average, it is seen that the larger size fish (fifty to seventy-three centimetres) seem to increase the amount of food consumed up to about fourteen degrees, but above this the general trend is downward. On the other hand, the small fish eat very well indeed, up to fifteen and possibly seventeen before the general trend of the feeding curve turns downward.

Another point seen in both figures 9 and 10 is the fact that in general the temperature and feeding curves move in opposition to each other. Usually the feeding curve drops when the temperature curve is seen to rise rapidly and vice versa, while in figure 10 the feeding curve remained at a fairly constant level from the middle of September until the middle of October during which time the temperature remained fairly regular. During August, figure 9B, the curves for the two large fish do not follow this rule very closely. However, the larger fish died very early in September and it is possible that it did not behave properly for some time previously. The cause of death is not known, though excessively high temperatures, lasting for several weeks as seen in the graph, are thought to have played a part since the smaller of the two fish seemed to be uneasy during this period also.

While the oxygen content of the tank water was not determined, it is believed that the water was saturated through the system of conveying it to the tanks.

Thus it is seen that up to a point, a generally rising temperature seems to be accompanied by an increased food consumption. During this period of increase, however, any sudden rise in temperature is usually accompanied by a drop in the food consumed, while a sudden small drop in temperature is accompanied by an increase in the food consumed. A prolonged drop in temperature seems to be followed after a time by a drop in food consumed. A period of uniform temperatures following a sudden rise is usually followed a little later

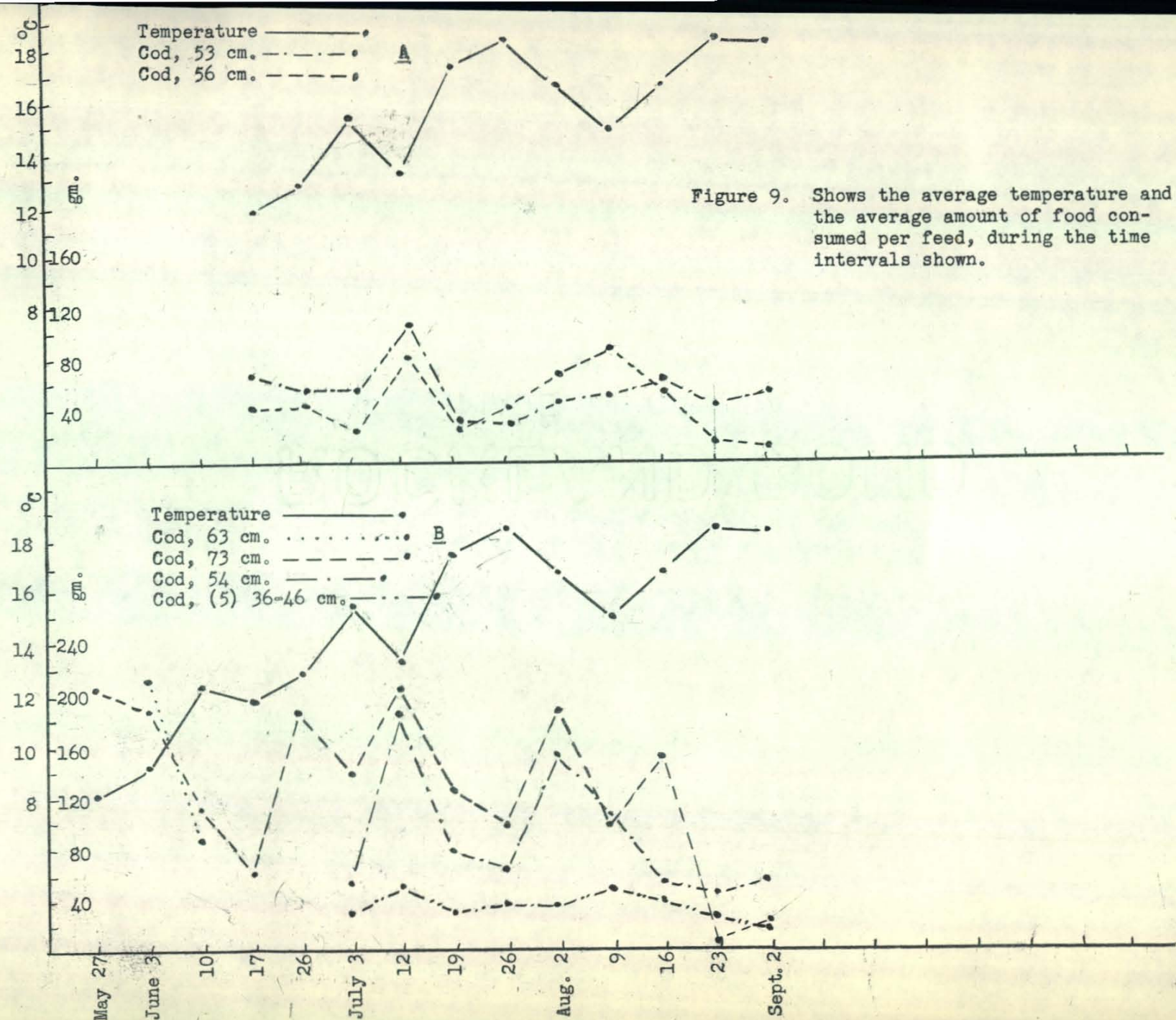
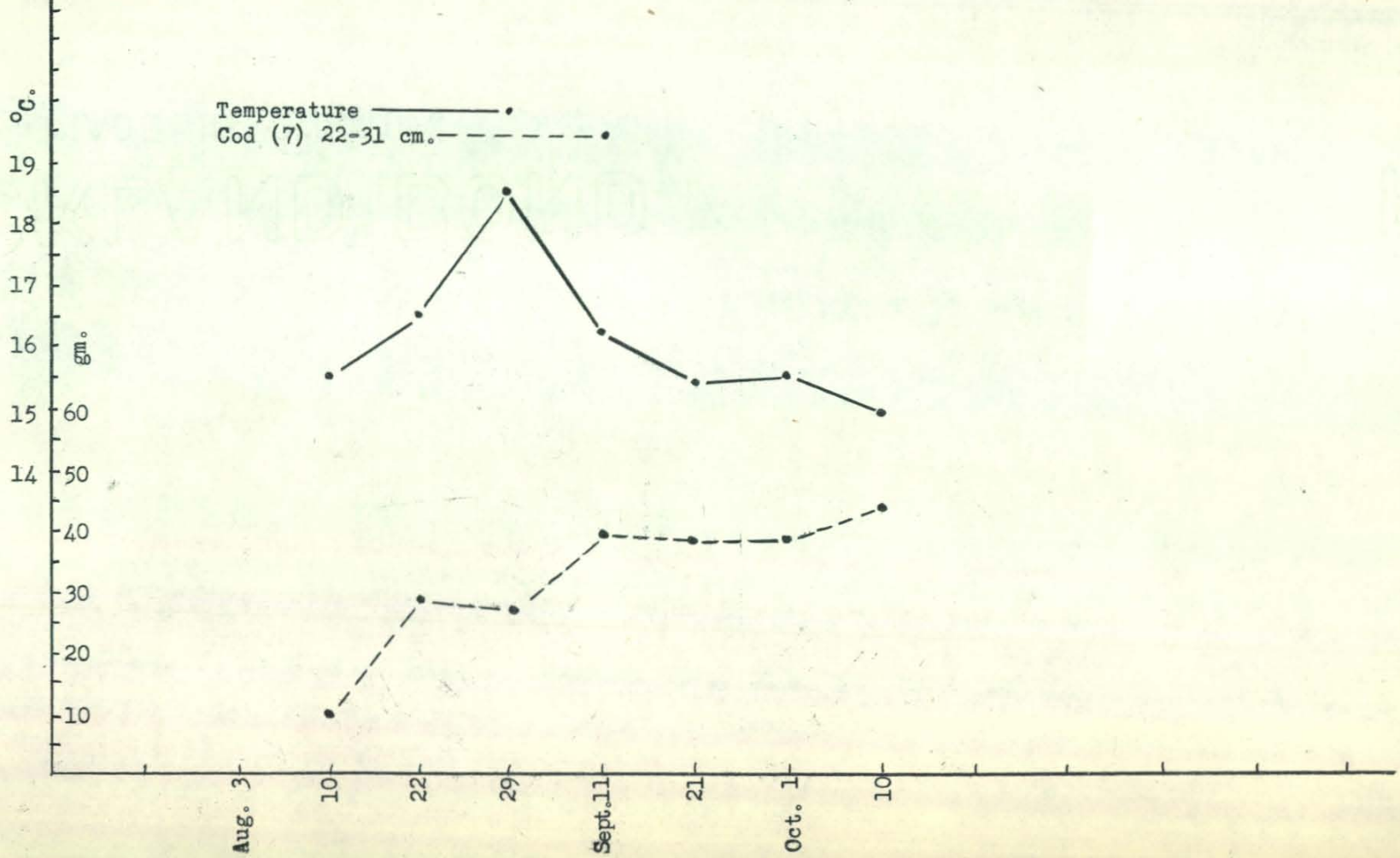


Figure 9. Shows the average temperature and the average amount of food consumed per feed, during the time intervals shown.

Figure 10. Shows the average temperature and the average amount of food consumed per feed, during the time intervals indicated.



by an increase in food consumption while a similar period following a drop in temperature seems to be accompanied by a fairly level part in the food curve.

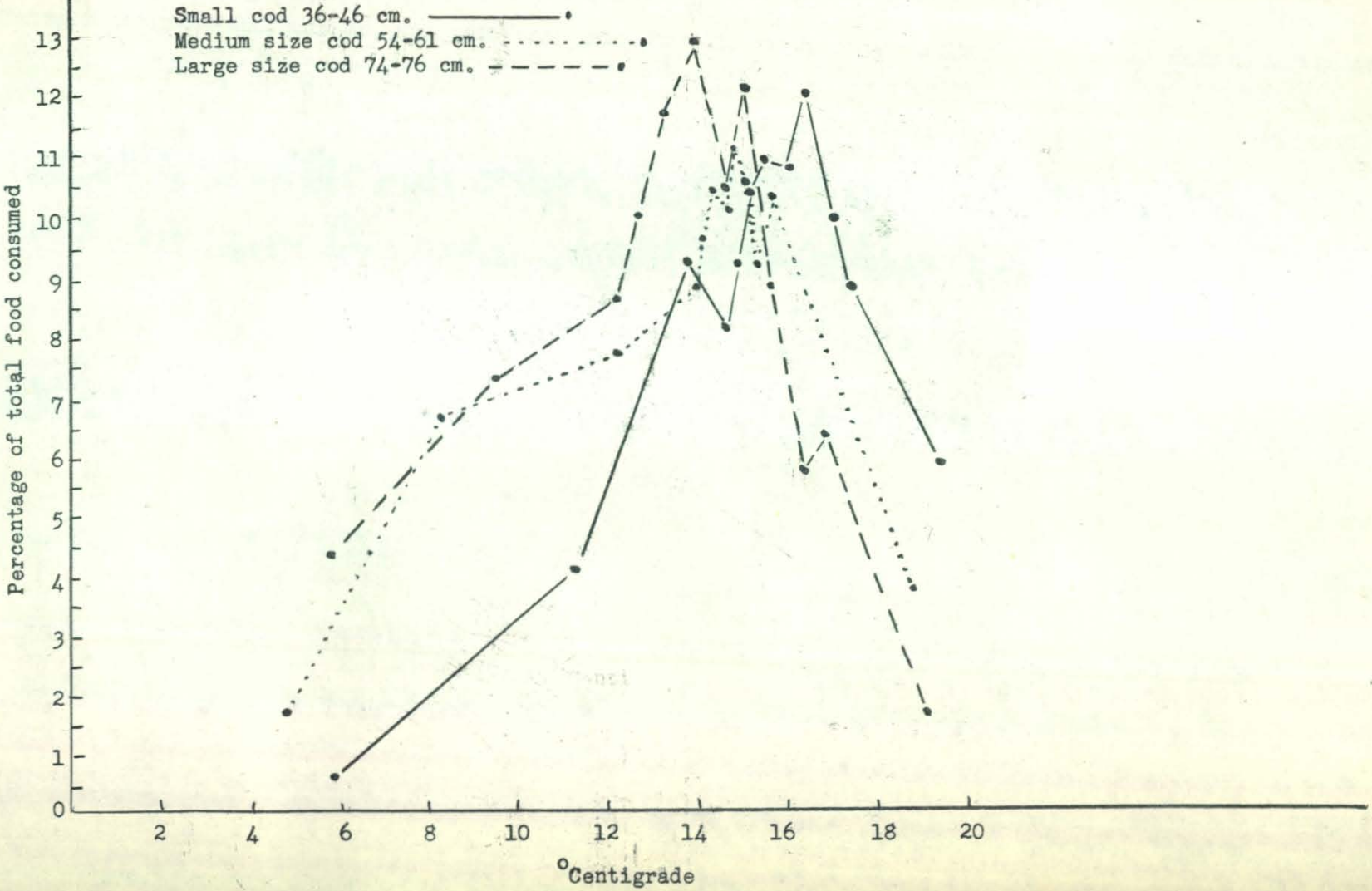
Considering the general trend of these curves, it is seen that up to a certain point the trend of the feeding curve is upward, but above a certain temperature it seems to turn downward. This is not very clearly shown in figures 9 and 10, but figure 11 brings out the main points. Here it is seen that with an increase in the size of the fish the peak part of the curve shifts from right to left, or towards a lower temperature. Arbitrarily taking the eight per cent consumption level, it is seen that the temperature range for consumption greater than this, in the small fish is about thirteen to eighteen degrees centigrade, in the medium fish twelve and a half to sixteen and a half, and in the large fish eleven to fifteen and a half. Thus the temperature range for optimum food consumption as well as the peak shifts towards lower temperatures with increase in the size of the fish.

Considering this figure in respect to upper temperature limits for feeding, it is seen that the smaller fish continue to feed comparatively well at a temperature of nineteen, while the larger fish are seen to consume only a comparatively small amount at a similar temperature. This, together with the death of one large cod at these high temperatures and the seeming uneasiness of the others seems to indicate very strongly that the small cod can not only withstand higher temperatures but also feed at higher temperatures than the larger fish. This high temperature limit as shown in this figure is quite definite since the temperatures varied from moderate to this extreme several times during the season with the same results each time, namely that at nineteen degrees the largest fish did not eat, the medium size ones ate to a slight extent and the small ones ate very well, comparatively even at twenty degrees.

Little significance should be attached to the indications of these curves at the low temperatures, for these low temperatures were only reached a couple of days before the experiment terminated and after a very rapid and drastic fall in the temperature. This rapid and extensive drop in temperature ultimately was followed by a drop in the amount of food consumed and the experiment terminated before equilibrium was restored.

Thus it is seen quite definitely that the small fish feed well, over a higher temperature range than the large ones. In all cases this temperature range at which the optimum feeding occurred, was quite high (approximately eleven to eighteen) to that expected. The larger fish cease feeding altogether between eighteen and nineteen degrees centigrade while the small ones eat comparatively well at twenty. So far, our data are somewhat conflicting in respect to the lower temperature limits at which the different sizes stop feeding, although it is believed that the larger fish cease feeding at a higher temperature than the small ones. This, however, is not supported by some of the graphs shown so far, and in some instances it is even contradicted. However, in most of these cases some other factor or factors are believed to have upset the picture. It has also been shown that sudden small drops in temperature are accompanied by an increase in the amount of food consumed and vice versa. Rapid increases to a high temperature or decreases to a low temperature seem to be accompanied after some days by a decrease in the amount of food consumed.

Figure 11. Comparison of the feeding with temperature in various sizes of cod.



Respiration

In order to obtain further data on the temperatures most suitable for cod, the respiration rate has been determined by using a stop-watch to determine the number of respirations per minute. The counts were made on all sizes of fish throughout as great a temperature range as obtainable to date, and quite regularly one half hour after feeding.

Figure 12 shows the results of this work graphically after the data have been harmonized by the graphical least square method. In order to avoid complication, the abscissa for each curve was moved up so that the curves did not intersect. However, in doing this, the figures on the ordinate have had to be left off while those on the abscissae were the same each time.

Since the curves were all plotted to the same ordinate scale, it is seen that in the smaller fish the respiration rate increases fairly regularly to a higher temperature without showing a break in the curve, than it does in the larger fish. This first break in the curve of the three small fish occurs at about fifteen point five degrees centigrade, in the fifty-six centimetre fish it occurs at about twelve point two, in the sixty-four centimetre fish at about ten to eleven and in the largest specimen at about eight. These changes in the direction of the curves indicate a physiological change in the fish which is seen to be brought about at a lower high temperature in the large fish than in the small ones. This, together with the fact that some of the largest cod died in water of about twenty degrees while none of the smaller cod did, indicates that the optimum temperature range for large cod is lower than for small cod.

Another interesting point is, that at any given temperature the actual number of respirations per minute is greater in the small cod than the large.

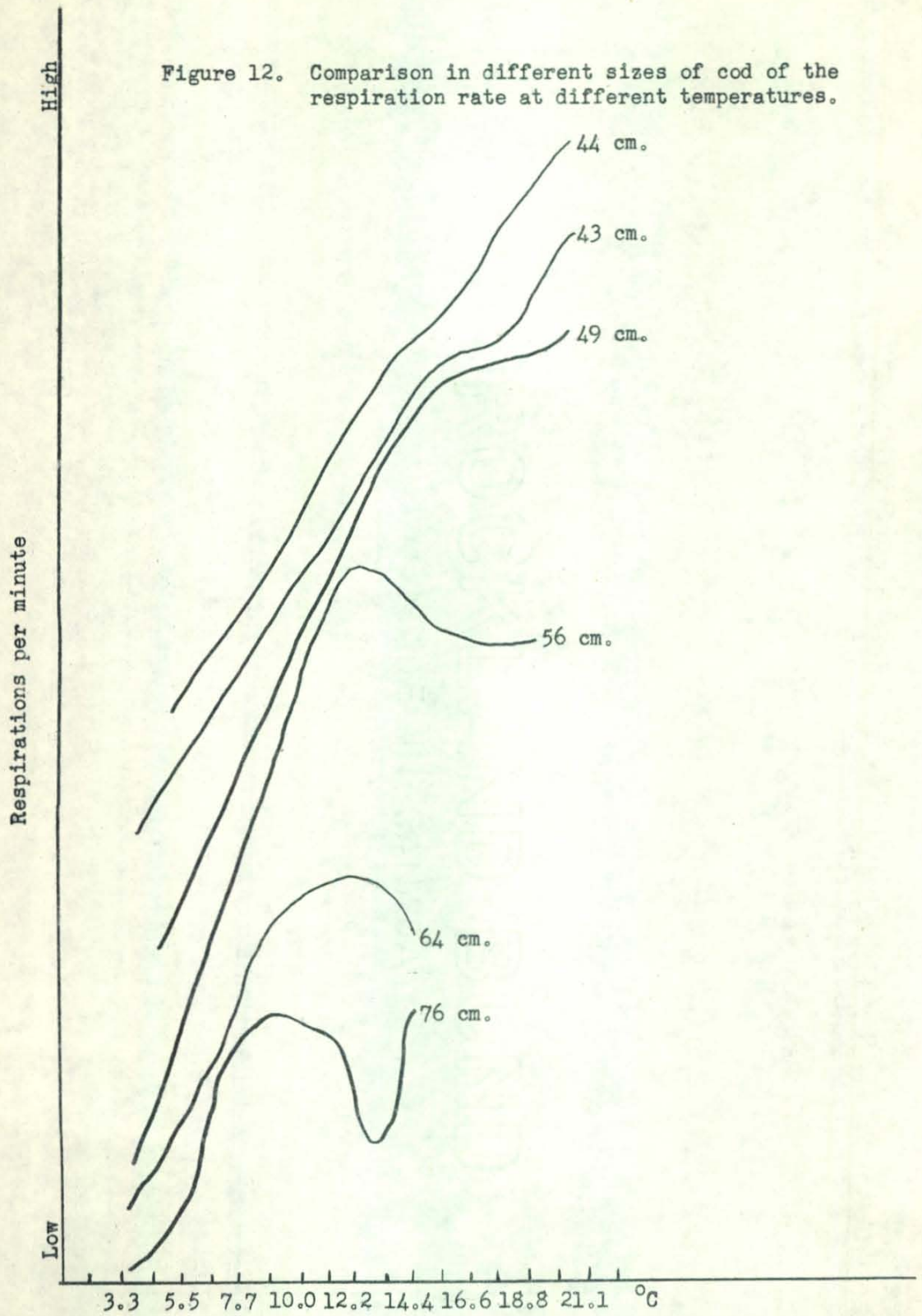
Summary

These cod kept in tanks when fed to capacity eat on the average about three times per week, and so far, feeding at different times of day produces no apparent effect on the amount consumed.

In the winter of 1932 - '33 at St. Andrews, the small cod continued to eat regularly but sparingly in water of two degrees while the one large cod ate practically nothing when the temperature went below three. When the temperature rose from this low level in the spring, all of them increased the amount eaten. In the fall of 1933 at Eastern Passage, both the large and small cod ate less and less as the temperature dropped rapidly from fourteen to three, and some of all sizes ceased feeding altogether. The temperature range for optimum feeding has been found to be from thirteen to eighteen degrees for the small cod and from eight to about fifteen in the largest fish kept. These large fish cease feeding at about nineteen and some even die, while the small cod continued to eat sparingly even at twenty degrees. Any great change in temperature is accompanied or brings about a cessation in the feeding of all sizes, however, a small rapid rise is usually accompanied by a decrease in the feeding and vice versa.

Handling usually causes a change in the feeding rate.

Figure 12. Comparison in different sizes of cod of the respiration rate at different temperatures.



The small fish respire more rapidly than the large ones and the break in their respiration curve occurs at a much higher temperature, i.e., about fifteen to sixteen degrees, while in the largest fish this break indicating some physiological change no doubt occurred at about eight degrees centigrade.

The temperatures at which these breaks occur correspond roughly to the lower temperature limit of the optimum feeding range.

Discussion

Our data show that fairly good catches of cod have been made in water from zero up to fifteen degrees centigrade. As a rule, water of ten to twelve degrees on the bottom seaward from, say, twenty-five metres (fifteen fathoms), -- little cod fishing is ever done in water shoaler than this -- is quite rare. Consequently, the opportunities of making and recording catches from water of such high temperatures are few and far between. Usually the temperatures in which the inshore cod fishing is done range from about two or three up to, say, eight degrees centigrade. When temperatures high than this do occur they usually are brought about suddenly by storms. Subsequently, successful cod fishing in these regions is rarely heard of. However, when these high temperatures of eight to fifteen plus come about gradually good catches of cod are not unheard of as some of our records show.

This state of affairs is checked by the reactions of the cod in the tanks, where the temperature range for optimum feeding was found to be between eight and eighteen depending on the size of fish. However, if these great changes (either up or down) occurred rapidly, feeding ceased, which seems to be exactly what occurs after a gale produces very warm water along shore, for the cod stop taking baited hooks. Whether they leave such regions at these periods or not is uncertain, but it has been shown previously that they can withstand any extremely warm water that we, as yet, have record of occurring naturally.

Thus it is believed that very warm water conditions do not necessarily drive the cod away and if they come about slowly, they may not necessarily affect the fishing. However, such conditions usually come suddenly, with the accompanying cessation in the catches of cod, accounted for just previously by the experience of holding cod in tanks. There is also the possibility of the actual physical violence of the storms driving the cod out to deeper water.

Since the small cod have been shown to withstand and eat at, higher temperatures than the large cod the point brought out previously regarding the smaller average size of the cod captured at higher temperatures is to be expected. The same thing possibly holds true at extremely low temperatures, but our data are not sufficient to justify any very definite statement in this respect as yet.

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