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The lobster is the most logical marine animal to use for aquaculture. Its symptoms of stress are easily recognized and, unlike the appearance of oysters and hard shell clams, when the lobster is dead it is quite obvious. The lobster is also able to protect itself from most of its enemies. It is generally a durable animal, and with a minimum of intelligent care will survive unfavorable conditions.

In a paper, "The Story of the Maine Lobster (Homarus americanus)" published in 1949, the concepts and techniques of lobster rearing were described. Several extracted ideas from this report are significantly illustrative of the problems of raising lobsters commercially under modified environmental conditions. For example, hollow brass fixtures in which holes had been drilled to throw jets of water provided the basis for the circulation system in each rearing tank. It is now known that the copper in brass is highly toxic to lobsters and should be avoided to reduce the mortality rate.

Finely ground beef liver was used for food, although toward the end of the experimental evaluation of lobster rearing it was found that ground fresh mussels resulted in a significantly higher larval survival rate.

It was also learned through experimentation that survival could be improved by seasonally heating seawater up to 5.5° C. above ambient. In fact, lobster larvae which hatched prior to about mid-June did not survive to the fourth stage at all unless rearing water was heated. Optimum temperature appeared to the 20-21° C. for survival to fourth stage in about two weeks. Without a heat exchanger or baffles, super-saturation of sea-water with nitrogen and oxygen resulted in virtually 100 percent larval mortality.

Obvious deficiencies in the rearing procedure led to a controlled evaluation of the operation in 1947 and 1948. In this two-year period it cost $33,636.45 to carry on the rearing operation alone, without consideration to the U. S. Fish and Wildlife hatchery operation which supplied first stage larvae to the State for rearing to fourth stage (post-metamorphosis). During the two years, 114,101 (by actual count) lobster larvae were reared to fourth stage, representing 4.4 percent survival. The average rearing cost was 29½¢ each. Since experimental laboratory survival was considerably higher both in Maine and elsewhere, it was estimated that 30 percent survival could be expected with trained personnel and under improved sanitary and management conditions. Four and one-quarter cents each for fourth stage larvae on the basis of 1947-48 values does not seem to be an unreasonable cost estimate.

Survival of fourth stage larvae to the following year under semi-natural conditions of an abandoned lobster pound was estimated by Taylor and Baird to be about 10 percent. With protection from predators, survival can be improved. At the survival rate observed, from egg to approximately 15 months of age, .44 percent, the cost (1947-48 values) would be about $2.95 each. On the basis of experimental results, the cost would be about $42.5¢ each.

Under the conditions of the year-'round trap fishery, natural mortality from the largest sublegal group to the first legal size class appears to range from approximately 25 percent to about 35 percent, although it is likely that much of the loss to this size group is related to the return of sublegal lobsters to the ocean bottom by the fishermen.

If the estimated magnitude of lobster mortality is reasonably accurate, then any man-made efforts which are able to reduce this loss will increase the available supply correspondingly. If increased survival could be projected back into the larval and post-larval stages, it might very substantially increase the natural population. Selective breeding for greater viability and more rapid growth is a long-term procedure which might benefit production of lobsters under both natural and controlled conditions.

The lobster is relatively slow growing, about five years to minimum commercial size, as compared with four years for Northern shrimp and six years for sea scallops, and requires adequate cover for protection against predation. It is assumed that growth rate of the lobster can be considerably increased by providing a longer period of the year in which the lobster will feed. Declines in feeding activity associated with lower seawater temperatures have been dramatically indicated by recent trends in moulting behavior, the index of growth, and in recruitment, relative abundance and catch (Figure 1) representing more than 99.5 percent of the North America lobster supply.

To compensate for the decline in natural abundance and the increase in the market for lobsters, methods will have to be developed to produce lobsters under modified or controlled environmental conditions. Based on temperature records and corresponding lobster landings for the past 60 years or more, it is likely that natural landings in which 90 percent of the available supply is used will range from about 8 to 13 thousand tons in Maine annually, and actual abundance from 8 to 15 thousand tons annually. In view of the market for lobster, this is a relatively modest contribution. Prices paid suggest that the supply could be economically increased severalfold. Data on seawater temperature and lobster abundance indicate that this is the principal area of environmental modification in order to increase the supply. As we are now in a period of relatively low seawater temperature which it has been predicted will continue until the next century, there is obviously need for some means of heating seawater to a more favorable level.

An assumption of naturally supra-optimum seasonal seawater temperature in the record warm early and middle 1950's is supported by evidence of reduced supply and availability during the period.

It is likely that a modest annual increase in temperature, perhaps no more then 1 to 1.5° C. above the all-time Boothbay Harbor average would be adequate to provide optimum growth and yield conditions. It is also likely that seasonal application of this increment (for example, spring or fall) would be more effective than even distribution throughout the year.

Since knowledge essential to the accurate prediction of future lobster abundance does not solve the problem of supply, some other type of solution must be developed. The most promising long-range solution appears to be that of establishing a growing area in which critical environmental factors can be controlled within those limits which would permit the economically feasible production of lobsters on a commercial scale. Yield of the better growing areas of Maine did not exceed 90 pounds per acre per year during the more optimum temperature years, and the average for Penobscot Bay and adjacent areas was only about 15 pounds per acre per year for a twenty-year average. In order to raise lobsters commercially, the populations must be more concentrated. Concentration in itself poses some problems.

The two principal obstacles to this operation appear to be cannibalism and growth rate. There appear to be three solutions to the problem of cannibalism: segregate individual animals, provide adequate shelter and food so that cannibalism becomes a minor problem or reduce temperature so that lobsters become inactive. This last would not be desirable because of reduced growth rate.

The influence of temperature on lobster behavior: foraging, feeding and moulting becomes important in solving the problem of growth. Growth is directly related to frequency of moult and moult appears to depend upon food intake. In turn, food intake depends to a great extent on seawater temperature. Therefore, it appears probable that growth rate (frequency of moult) can be increased only prolonging the season during which the lobster will feed.

Several solutions to the problem of temperature control are possible:

1. An onshore facility in which seawater drawn from the ocean would be artificially heated and probably recirculated. Recirculation would require filtering because of food and fecal solids, and sterilization because of bacterial contamination. Cost of heat would be the major difficulty in this type of operation.
2. An inshore submerged facility in which lobster living conditions are retained as naturally as possible but tempera-

ture of seawater and other environmental factors are artificially controlled or modified.

3. An offshore, relatively deep-water facility in which the naturally warmer seawater is used to increase lobster activity and prolong the period of feeding.

The experience of the Department and of the Bureau does not suggest that the onshore facility has any merit for the commercial production of lobsters. Study of the feasibility of utilizing an inshore submerged facility is now in progress.

Parallel increases and declines in species abundance and seawater temperature indicate (1) the influence of optimum environmental conditions on supply, and (2) the limited natural supply of lobster and other commercially important marine species. It is equally obvious that the development of cultural techniques to increase species abundance will require methods of controlling seawater temperature at or near optimum levels.

The high cost of heating seawater, experienced by the Department of Sea and Shore Fisheries during the 1939-1948 decade when lobster rearing experiments were conducted in an onshore facility, demonstrated the economic impracticability of such a venture.

Thermal water discharge from electrical generation and other industrial plants offers a supply of heated water to use in modifying discrete marine environments, even within a single general area, in order to provide optimum temperature conditions for a variety of species requiring, collectively, a relatively wide range of optima.

The principal objection at the present time to the use of thermal water discharge is twofold: (1) engineering problems of managing the heated water and using it efficiently in relation to the supply of receiving water, and (2) the poor quality of the heated water at times. The additives toxic to marine life are chlorine, hydrochloric acid, sulphuric acid, sodium hydroxide, and detergents. Condenser tubes and other inplant equipment can also be highly toxic to aquatic life because of the materials used in such equipment. The most lethal is copper, but zinc, aluminum, lead, and stainless steel are also toxic.

Mixing of water stratified by temperature and salinity has been consistently accomplished elsewhere by departmental research personnel using an air compressor and plastic hose in which small holes had been drilled. The purpose of this procedure initially had been to provide better water circulation in lobster holding pounds. Later it was used to eliminate ice cover and to mix oxygen saturated surface water with oxygen depleted bottom water. Temperature differentials between surface and bottom have usually been limited to less than 2.4^{o} C.

This experience suggests the possiblity that compressed air might provide a comparatively inexpensive means, where supplies of thermal water are available, of regulating seawater temperatures for cultural purposes in coastal embayments and other nearly closed, semi-closed, and nearly open circulation systems.

At the present stage of knowledge, the principal problems appear to be those of engineering: how to mix waters of widely differing temperatures and transport them to selected sites within the cove, and how to reduce to tolerable levels for lobster the wide diurnal variations in temperature associated with tidal changes in the amount of dilution water available.

In 1958 the Central Maine Power Company commenced operation of a fossil fuel, steam electric, power station on Cousins Island in Casco Bay. The record of intake water temperatures in ^{o}C. by monthly means is contained in Table 1, which also includes Bureau of Commercial Fisheries' records of corresponding temperatures at Boothbay Harbor. Company data are derived from 24 daily readings, read to the nearest whole degree, and averaged. Monthly means are also averaged to the nearest whole degree.

The capacity of the original pumps at the Wyman Station was 65,000 GPM. The heat increment varies somewhat, but appears to average approximately 15^{o} C. The intake at Cousins Island is at minus 6 meters MSL Sporadically, temperatures have been taken by the Department of Sea and Shore Fisheries' biologists since March 1960 in the cove where thermal waters are discharged.

The area has been sampled from time to time to get an approximate estimate of edible mollusk populations and classification of the sediments of the substrate. Among the principal mollusks are: the hard clam (Mercenaris mercenaria), the soft clam (Mya arenaria), the edible mussel (Mytilus edulis), the razor clam (Ensis directus), and the sea scallop (Placopecten magellanicus). An abrupt change in shell thickness and concentric growth rings of two sea scallops, one living and the other dead, suggest a drastic alteration of the environment. Blue mussel shells also have been morphologically changed; a graduation which is measurable from the immediate vicinity of the outfalls around the perimeter of the cove where the heated surface water circulates. Near the outfalls the width and depth of the shells in relation to length are approximately ten per cent greater than from control sample areas outside the influence of the thermal water. At the head of the cove the proportional difference is decreased to about five percent. Extensive mass mortalities of mussels occur periodically and are associated with higher than average temperature increments. Temperatures in excess of 38° C. have been associated with mussel mortality.

Fishermen have reported a decline in the catch of lobsters in the cove since the operation of the plant. Because the peak catch in Maine occurred in 1957, a year before the plant became operational, it is assumed that this decline is a true decline but one associated with the precipitate 14-year decrease in seawater temperature as measured at Boothbay Harbor.

There may be, however, a toxic metal barrier created by ionization of the condenser tubes which is serving to keep lobsters out of the western half of the cove where the thermal water outfalls are located. The pattern of lobster behavior indicated by the trap catch (Sterl 1966) supports this assumption. Analysis of water samples from the outfall show an approximately 100 percent increase in both copper and zinc over the levels at the intake.

To determine the approximate abundance of lobsters in the cove, Sterl and DeRocher fished the area in 1965, and have summarized their findings in a report by Sterl dated February 1966. Between July 2 and October 19, 1965, 15 traps were used to fish lobsters at Cousins Island. Thirty-seven lobsters were tagged and released after capture; only one was recaptured. It was evident that lobsters entered the cove from Spruce Point and moved about one-half the length of the cove and then moved outside the cove into deeper water.

In conjunction with trapping studies, Dr. Richard Cooper and his Scuba team of the Bureau of Commercial Fisheries worked with departmental biologists on September 21, 1965, to make an underwater survey of the lobster population in the area. Cooper reported only two lobsters. One of these had burrowed under a trap and the other had occupied a discarded automobile tire.

On September 14, 1967, six small boatloads of shore rock were spread over a small area of the eastern portion of this cove. On September 15, two rows, totaling 100, of cement blocks were placed on the bottom (Figure 2). Two lobsters from the rocky area of Spruce Point were transplanted to the rock-cement cover.

In June 1968 approximately 126 cubic yards of quarry rock were placed as cover in the cove.

Observations of the sediments at low tide and by the Scuba personnel indicate that there is only one large outcrop in the cove. The sediments generally are fine sand with some silt, except in the beach area near Spruce Point where there is extensive cobble, course gravel, and small boulder cover. Fly ash, initially collected behind the diked barricade, is allowed to be transported into the cove through the culvert-gate system.

The Department's Scuba team checked at intervals the natural and man-made cover placed in the cove. On September 28 they observed that many of the openings in the cement blocks were being occupied by the edible crab (*Cancer irroratus*). The next time the area was checked (October 17) the crab population was considerably larger. At both times there was no evidence that lobsters had been recruited nor that those transplanted had remained.

Early in June 1968, 25 lobsters were found inhabiting the cover that was provided for them. Counts of the number of lobsters were made by the Department's Scuba team. On the basis of observations made in intertidal areas under natural cover, it is presumed that the total lobster population was several times as great as that reported in Table 2. Periodic checks were made during the remainder of the summer and fall. Lobsters were present through November 6, 1968. No further check was made until January 1969 and at that time no lobsters were observed. It is presumed that the lack of mixing of the heated surface water and the cold bottom water limited the availability of food. Some mixing of surface and bottom waters occurs in the vicinity of thermograph stations III, IV, and VI since the bottom temperature at these sites has been observed over periods of several weeks to be 1^{o} to 3^{o} C. higher than at stations V and VII.

Possibly other factors resulted in the movement of lobsters out of the area during the late fall. It is evident that lobsters occupied the cover for a period in excess of five months. In previous years lobsters foraged through the area but did not remain.

After rock and cement block cover was placed in the cove in September 1967, recruitment of lobsters did not begin until the following spring. Observed occupancy is summarized in Table 2.

The proposed program to turn the Cousins Island cove into a controlled environment lobster growing area will be divided into several several prototype stages. Lobster trapping experiments in 1965 and underwater studies since have demonstrated that lobsters can be recruited into the area if cover is made available. The first stage of the project therefore appears to be one of providing permanent type shelter material consisting of angular rocks (granite, schist or gneiss), cement blocks or the like.

Location of this site appears to be sufficiently distant from the thermal outfall to minimize adverse effects of diurnal-tidal fluctuations in temperature on the lobster population. Concurrently, air lines and a compressor will be used to provide surface-bottom water mixing to reduce temperature differences associated with tide levels.

Various arrangements of shelter materials will be tried. In laboratory tanks lobsters have occupied several layers of cement blocks. It is not known what they will do under more natural conditions. Both mass housing and isolated shelters for the lobsters will be tried. Concurrent engineering studies of the area will be made to determine the most feasible means of stabilizing water temperatures within the cove. Hydraulic, mechanical, electrical and heat-transfer engineers and physical oceanographers among others will be employed or consulted during this stage.

The second stage of the program will consist of:

1. experimental design and construction of equipment for mixing and distributing waters of characteristic temperature differences;

2. design and development of some type of encapsulating shelter for lobsters to provide protection from predation and to reduce further temperature differences;

3. design and construction of underwater laboratory and experiment station adjacent to the lobster study site.

The third stage will be a general expansion and development of the site to saturation levels.

The fourth stage will consist of transfer of the methods and techniques to other appropriate locations including:

a. other thermal plant locations,

b. deeper water sites where temperatures are seasonally more stable and other sources of heat transfer can be exploited.

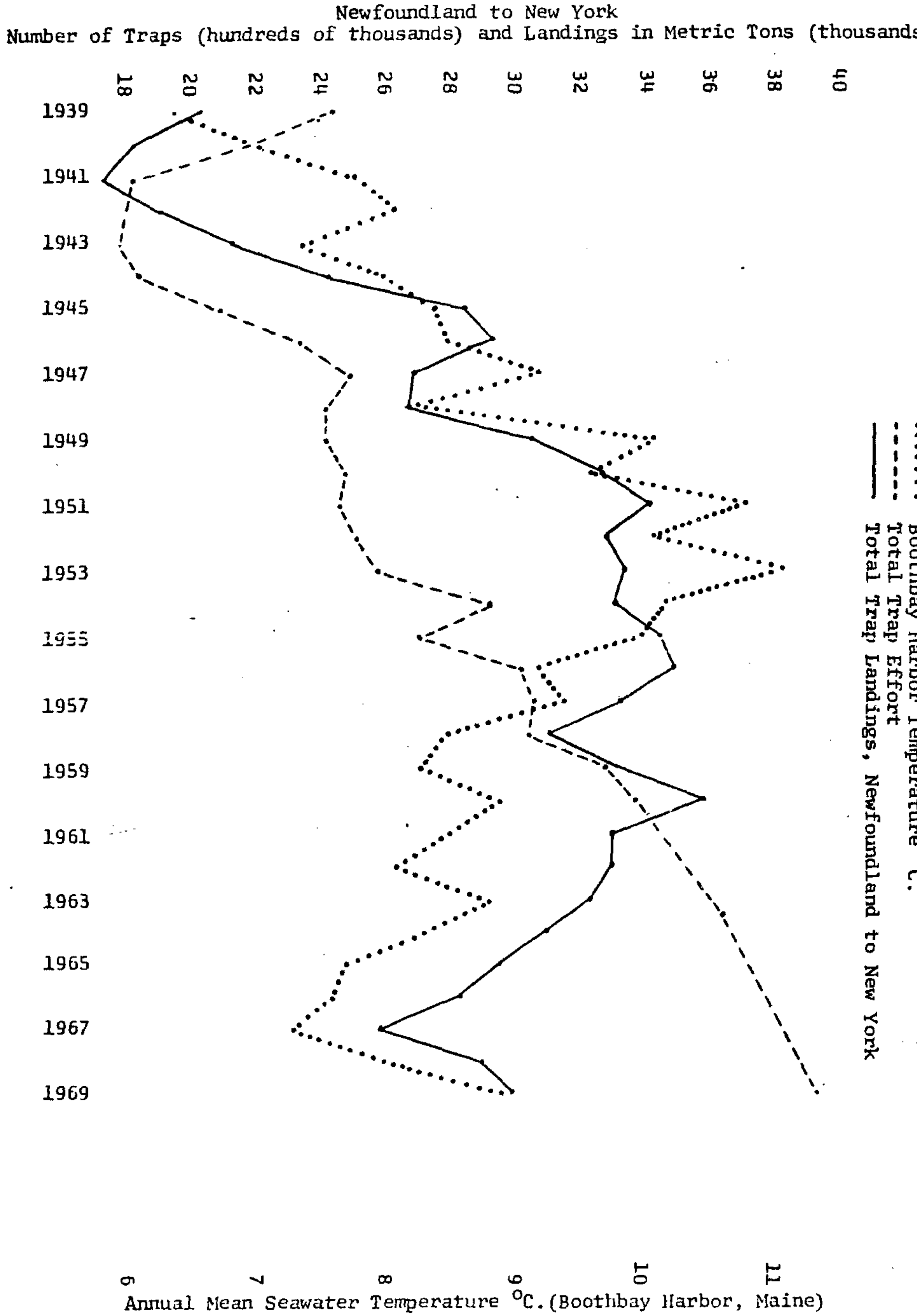
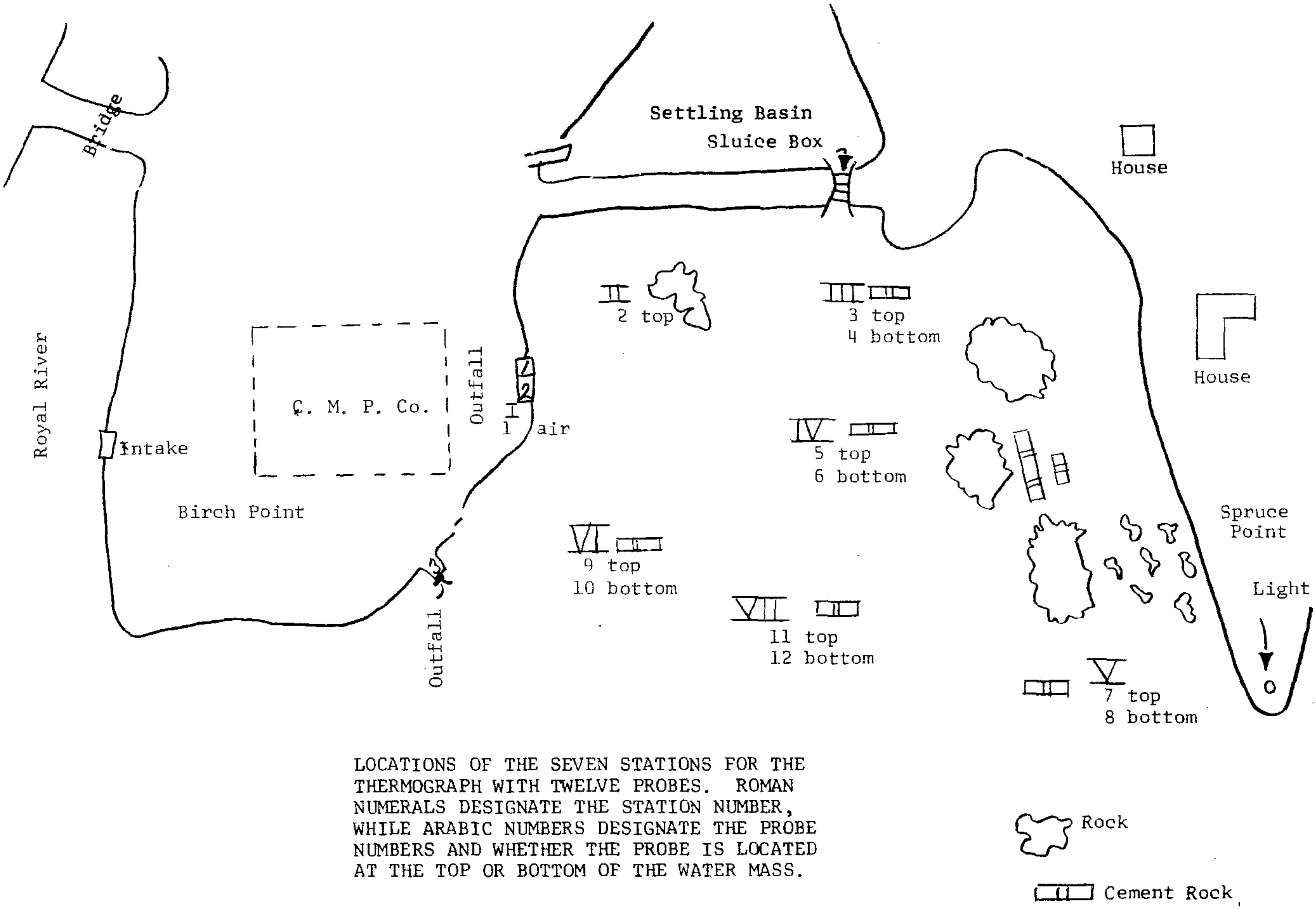

Newfoundland to New York
Number of Traps (hundreds of thousands) and Landings in Metric Tons (thousands)
18
20
22
24
26
28
30
32
34
36
38
40
1939
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
Boothbay Harbor Temperature °C.
Total Trap Effort
Total Trap Landings, Newfoundland to New York
6
7
8
9
10
11
Annual Mean Seawater Temperature °C. (Boothbay Harbor, Maine)

Figure 1

Figure 2



LOCATIONS OF THE SEVEN STATIONS FOR THE THERMOGRAPH WITH TWELVE PROBES. ROMAN NUMERALS DESIGNATE THE STATION NUMBER, WHILE ARABIC NUMBERS DESIGNATE THE PROBE NUMBERS AND WHETHER THE PROBE IS LOCATED AT THE TOP OR BOTTOM OF THE WATER MASS.

Table 1

Month	Sea Surface Temperature °C. Boothbay Harbor Range of Monthly Means 1905-1968	Sea Temperature °C. Cousins Island at 6 Meter Depth Range of Monthly Means 1959-1968
January	-2 to 6	-2 to 2
February	-2 to 6	-2 to 1
March	-1 to 6	-1 to 2
April	1 to 8	3 to 6
May	5 to 11	6 to 10
June	10 to 15	11 to 14
July	14 to 18	15 to 16
August	14 to 18	15 to 18
September	11 to 17	13 to 16
October	8 to 13	10 to 12
November	4 to 11	6 to 9
December	0 to 9	2 to 3

Table 2

Average Number of Lobsters Observed
Summary by Months
September 1967 to October 1970

January	0
February	*
March	0
April	0
May	*
June	25
July	23
August	11
September	9
October	4
November	7
December	*

*No observations made