Practical Biology of the Olympia Oyster in Puget Sound

Vance Tarter

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Dedicated to

LOYD ROYAL

without his permission

TO WHOM IT MAY CONCERN:

It is the reasoned conclusion of the author that the paper, "Practical Biology of the Olympia Oyster in Puget Sound", should be published in its entirety because of the following considerations:

1) The paper summarizes the work of ten years by the entire staff of the State Shellfish Laboratory and it cannot be expected that so large an amount of work can be treated adequately in small compass.

2) The writing has been wholly compacted with no "padding" whatever and is designed to appeal both to practical oystermen and to biologists.

3) The figures are all essential to (a) locate geographical points, (b) give oystermen an immediate, visual portrayal of the performance of their bays, and (c) demonstrate the correlations arrived at.

4) The second section and all the tables constitute the essential scientific proof and argument supporting the conclusions advanced. Without them the statements offered would become mere opinions.

5) The Laboratory has followed a policy of few but substantial publications rather than frequent and minor notes and observations.

6) This is such a publication, for, as stated above, it brings together the work of ten years and presents the finest method of predicting oyster sets that has been developed in any part of the world, procedures which will in time be applicable to other oysters in other areas.

Hence it may be asserted that every part of the paper is essential and valuable, and that only its publication in entirety will complete the public return on the funds expended in pursuit of the Olympia oyster project.

Cordially yours,

Vance Tartar

Vance Tartar

Practical Biology of the Olympia Oyster,
Ostrea lurida, in Puget Sound
(Notes on present Introduction)

Condense acknowledgements & place in back or condense & leave in front after Introduction.

Omit reference, ¶ to writer in paragraph 2 of page 1.

~~Post~~ omit ¶ 2, p 3, ~~after ¶ 1, p. 1.~~

Reduce discussions of earlier workers.

Order of ¶'s indicated by number in right margin.

PRACTICAL BIOLOGY OF THE OLYMPIA OYSTER, *Ostrea lurida*, IN PUGET SOUND

VANCE TARTAR

STATE SHELLFISH LABORATORY

Gig Harbor, Washington

INTRODUCTION

This paper is a result of our wanting to know more about coastal fisheries in order that we may increase the productivity of the seas for human needs. In the bays of lower Puget Sound the Olympia oyster is the subject of the principal fishery. For many decades the State Department of Fisheries has promoted investigations concerning the problems of the Olympia oyster grower and since 1942 has issued a weekly series of Puget Sound Oyster Bulletins during the spring and summer months in order to supply oystermen promptly with information concerning the time and prospects of a catch of seed oysters and other matters of importance to them. These bulletins constitute the running account of which this paper is the summing-up.

Largely because he was connected with the Olympia oyster investigation for the longest period of years, it has fallen to the lot of the writer to tie these studies together in the present report of work in progress. As such he takes responsibility for the conclusions and speculations drawn therefrom; but it is not forgotten that we worked as a team and that the wealth of data herein summarized and interpreted could only have been the product of many contientious hands and heads supported by able and sagacious supervisors during the years involved.

Dr. A. H. Banner and his assistant Mr. Charles E. Woelke contributed the data for the years 1942 and 1943. Many interesting and significant special studies were conceived and executed by Mr. Roger Tollefson and are so designated in the text. Mr. John B. Glud was for several years head of the laboratory and responded nobly beyond the call of duty to assure the success and continuity of this work. During the years of his concern with ~~supervision of~~ the project Mr. David C. McMillin contributed much toward the gathering of data and increasing the precision of oyster set predictions. The able and enthusiastic assistance of Mr. Harold Wicksten, Mr. Charles Woelke and Mr. Frank Henry is gratefully acknowledged.

We owe a special debt to Mr. Donald L. McKernan who made the objectives of this study his own and in 1944 set up the Olympia oyster investigation in essentially its present form. Much of the completeness of our data was due to his tireless energy and unflagging zeal. McKernan also saw through to completion the first experiments on the effects upon oysters of minimal concentrations of sulfite waste liquor from wood-pulp mills, the results of which have already been published (McKernan, Tartar, and Tollefson, 1942).

Finally, the present account of the practical biology of the Olympia oyster appears under the auspices of Mr. Cedric E. Lindsay, Supervisor of Shellfish Researches of the State Department of Fisheries, who himself collected valuable data on the Olympia oyster at the Gig Harbor laboratory besides generously placing all information at our disposal and fostering and supporting the project with abundant helpfulness in every way.

The State Department of Fisheries and the U. S. Fish and Wildlife Service have on many occasions cooperated in Olympia oyster studies, and during several years of our investigation the Service provided a boat for our use.

To the oystermen themselves we express our gratitude for their indulgence and their help and encouragement. Only if our work has resulted in useful contributions to their fishery will it have justified itself.

The plan of this paper will be to present a continuous and compacted account of our findings on the Olympia oyster and the conclusions tentative or otherwise which can be deduced from them. In bold-faced type within this account are given page references to later portions of the publication wherein tables of data and further discussion and substantiation of the points of the main story are to be found. This will relieve the reader of groping around among tedious ~~charts and~~ tabulations and, we trust, contribute something to remedy the situation whereby in their scientific papers oyster biologists often argue with each other while the practical oysterman can only stand by and hope that some useful morsels of information may chance to shake out of the discussion.

The great predecessor of this paper was the study of the Olympia oyster by Dr. A. E. Hopkins during the period of 1931 through 1935, published in 1937. Hopkins' paper may be consulted for references to earlier researches and observations on <u>Ostrea lurida</u>. Although we have taken exception to several of Hopkins' suggestions we realize that they were put forth provisionally, as befits the scientist, and require emendation largely because he did not have time in his extensive and under-staffed investigations to make quantitative studies on the larval stage of the oyster and because he did not employ over-all seasonal cultch. And we appreciate also how much we are indebted to this biologist for his pioneer work on lower Puget Sound. To Hopkins the industry owes the demonstration of the importance of angle of cultch surface for efficiency of spatting and the possibility of floating cultch, with all the vast practical gains that have followed therefrom.

Important contributions of more distant source stem from Dr. H. F. Prytherch's introduction of the cemented cardboard egg-case filler cultch (1924?) which is the best that we know for Olympia oysters; and his observations on the actual process of setting of Eastern oyster larvae in the laboratory are of importance and great potentiality in visualizing the relevant factors in spatfall. Cole and Knight Jones (1939) also contributed to our knowledge of the setting of oyster larvae in vitro.

We are indebted to Dr. P. Korringa for a recent, comprehensive, logically comparative and intelligently critical review of the oyster literature of eight languages. His publication (1940) has as its central theme a thorough study of the reproductive cycle of the European flat oyster in Holland from which he and his co-workers are able to predict time and intensity of oyster setting on short notice and to locate the most favorable areas for cultching. Conditions in the Oostershelde are however quite different from those in the Olympia oyster bays of lower Puget Sound. In this work we miss an investigation of over-winter mortality in relation to time of setting and a quantitative study of surviving spatfall (seasonal catch) which is most relevant to the actual, practical recruitment of seed oysters from year to year.

For the benefit of distant readers who may not be familiar with the Olympia oyster, a few orienting remarks are made in passing. *Ostrea lurida* is the oyster native to the northwest coast of North America and is similar to *O. edulis* of the northwest coast of Europe, being a small, larviparous oyster subject to intensive cultivation as a high-valued food item. Once abundant in all our deep bays from San Francisco to British Columbia, its distribution has now been markedly curtailed by depletion of natural beds and competition of the introduced Japanese species, *O. gigas*, with the result that now the only really extensive area of native oyster culture is in the bays of southern Puget Sound near the city of Olympia. These long inlets (**Fig. 1**) radiating out like the fingers of a hand are ideal locations for oysters since their upper reaches flatten into wide tidelands and each bay is sufficiently attenuated so that it confines and retains its own spawn. ~~It results that~~ each bay is to a large extent an independent oystering unit and has been treated as such in the present work.

The area of oyster land has been greatly increased by the building of dikes which have the twofold purpose of retaining 6 or more inches of water over the oysters at low tide in order to protect them from freezing and over-heating, and to extend the area of usable tideland by providing appropriate gravel substrate in places where only soft mud was encountered before. In many places the dike wall facing the incoming tidal current is made lower than that of the remaining sides with the result that the dike is filled after low tide seepage ~~only~~ by water flowing in one direction. In such "current dikes" the directed inflow efficiently cleans oysters and cultch and washes away the silt.

At the proper time cultch in the form usually of clean oyster shells or cemented egg-case fillers is placed in the dikes and seed is caught. Here the dikes may be said to have the additional function of keeping the cultch submerged, for exposure is inimical to permanent attachment of the seed oysters. After the spatting season the seed are scattered and allowed to grow until 4 or 5 years old when they are large enough for marketing. One or more periods of take-up and culling may intervene between these terminal operations.

The publications of Galtsoff (1929) and of Hopkins (1937) may be consulted for discussions of procedures of the Olympia oyster industry.

Marketing of oysters and care of the beds involve well-established operations wherein improvement depends largely on the industry and cost-accounting of the grower; and simple methods for the control of oyster pests have not been forthcoming due to the extreme difficulty of this type of problem. For the growth and fattening of oysters we are still largely at the mercy of the provender of the seas. Hence the most immediately effective point at which one can aid the fishery is by helping in every way possible to assure a continued abundant supply of seed oysters through attention to the reproductive cycle of the oyster.

The Olympia oyster begins spawning usually some time during the month of May. Sexually mature after one year, the oyster spawns first as a male and later as a female, alternating thereafter even within a given year (Coe, 1931, ~~a, b,~~ 1932); and the developing eggs are retained within the mantle cavity for about 10 days until the larvae are shelled. Liberated larvae spend a pelagic life of around 30 days and then metamorphose into oysters on attaching to suitable surfaces. The reproductive cycle through the spring and summer season may therefore be followed by contact at these points: (1) time, number and proportion of spawning oysters, (2) abundance and size of pelagic larvae, (3) time and rate of spatfall, and, (4) magnitude of effective surviving set for each year and each bay.

Season after season we obtained frequent spawning and plankton samples and put out weekly, bi-weekly and seasonal test cultch in as many as 5 separate breeding populations of oysters. Within this coverage we tried of course to have our data be as accurate and as representative as possible. A description of the methods employed together with an assessment of their accuracy and representative character are given in detail on ~~elsewhere in this paper~~ (P. 52). The result was that we now have a quantitative picture, usually quite complete, of the reproductive season in each bay for each year during ~~the past~~ nine consecutive years. Since these representations are the substance of our field observations, we turn to them now for a view of what occurs bay-wise during the reproductive cycle of our Olympia oyster.

THE BAY-YEARS

I prefer a title like
Explanation of Figures — to —.
and condense each explanation as much as possible.

Put REVIEW OF REPRODUCTIVE SEASONS, BY BAYS & BY YEARS at beginning of this section & leave off this specific title.

Detail about ~~[illegible]~~ relative rank of the various bays as given on p. 12 seems out of place here.

THE BAY - YEARS

We want first of all to say what needs to be said about how the bay-year graphs were set up, referring to a typical example like Figure 14. The graphs show successive waves of spawning leading to blooms of oyster larvae eventuating in waves of spatfall. The temporal sequence of spawning, larvae production and setting are evident from the uniform date line at the top of the graph, while at the bottom are shown the periods of spring tides with the predicted maximum tidal run-out indicated by height of the black pyramids.

or actual?

A telescoping scale is employed for the abundance of larvae and magnitude of spatfall, the points where the scale "breaks" being clearly indicated by horizontal lines. This compromise arrangement is to be fully kept in mind in studying the graphs because increments within the telescoped bands are greatly minimized in relation to increases within lower portions of the curves. The use of broken - line histograms would have been more legitimate; but data points have been joined to form curves and no broken lines are used in passing from one scale to another in order to eliminate confusion, to compact all the data for one bay-year in a single figure, and to enable oystermen to make immediate, visual comparisons of the performance of the bays from year to year. Furthermore, the telescoping scale permits all graphs to be of identical scale and emphasizes minimal, critical values of spawning, larvae abundance, and spatting intensity essential to a successful catch of seed oysters. Excesses above these thresholds may be generally discounted for practical purposes as contributing little to an already saturated cultch (see P. 41).

The only exception to this uniformity of presentation is that the spatfall of 1942 and 1943 is expressed in different terms since an entirely different type of test cultch was used during these years.

It is to be emphasized that the graphs do not necessarily represent what actually occured in the bays, but rather are to be viewed as the best approximations to these real events which we were able to obtain with the time and means at our disposal.

SPAWNING

Points on the spawning curves represent percentages of mature female-functioning oysters found to be "incubating" larvae, on successive days in one patch of oysters in each bay which was thought to be representative of the whole bay. Intensity of spawning ~~at a given time~~ rises more or less rapidly to a peak and then falls off. Steepness of the curve may depend upon the prevailing temperature of the water at the time of spawning.

Since the larvae are retained by the parent for about 9 1/2 days it can be assumed that at 10-day intervals throughout the curve the spawners encountered will contain none of those found previously and that after the peak of spawning the individuals not gravid will contain both those which have not yet spawned and those which have already completed spawning. Hence cumulative percentages at 10-day intervals will give a measure of the total proportion of the sampled oysters which have spawned as females. This value may vary from 35% to 121%, the higher figure demonstrating that individuals which spawned as males may later spawn as females during the same season. But the spawning curve is chiefly of importance in indicating the time of commencement of the reproductive cycle. Being a matter of percentage, its magnitude has little to do with the actual abundance of larvae produced since this depends on other factors as well, such as the size of the broods, early survival of larvae, and, chiefly, the number of mature oysters in the bay. When the aggregate percentage of female spawners was unusually high during the first wave of spawning (83% and 80% for Oyster and Mud Bays, respectively, in 1945) the abundance of larvae produced was phenominal; but at lower values no significant correlation appears between the aggregate percentage and size of the larval mass. Hence we have not charted these cumulative percentages but plotted only the week-to-week proportion of gravid oysters.

LARVAE

Points on the larvae curves represent maximum numbers of pelagic, swimming larvae found on any one day by filtering 20 gallons of bay water. The reasons for using the maximum number will be discussed more fully later (P. 61), but for the present it suffices to say that maximum counts are the best substitute for such a valid average density of larvae as could be obtained only in more time than was at our disposal.

Secondary spawning curves are also reflected in second peaks of larval abundance.

Since a wave of spawning occurs over a 20 to 30-day period, a variety of sizes of larvae is present at most times. In addition to counting the number of larvae per 20 gallon water sample, we noted the percentage of those which were near setting, or roughly 270 to 330 microns in diameter (see also P. 67). The percentages from all samples measured on a given bay-day were averaged and multiplied by the maximum count to give the ~~number~~ density of large larvae near setting. These values are plotted within the over-all larvae curves and show the ~~actual~~ number of larvae contributing to the set at a given time.

SETTING

Points on the setting curve represent the number of spat caught on 100 Pacific oyster (O. gigas) shell faces per day averaged during a period of from 3 to 7 days, a value which we call in our bulletins the Setting Index. Test cultch was made by stringing a dozen flat Pacific oyster shell "lids" on a wire with face downward and in a horizontal position. Hence the setting surface was maximal, being the underside of a horizontal shell surface (Hopkins, 1937). The strings were placed in one or two areas considered to be typical in each bay.

Care was taken to choose cultch shells which were clean and of uniform size. The area of the face (smooth) side of 100 such shells was carefully measured and found to average 11.6 square inches per shell. The Setting Index is thus the number of oyster spat attaching to 1160 square inches or slightly over 8 square feet of clean shell surface per day. Parallel catching tests with shell and cemented fillers showed that the catch per day per single, ordinary, upright egg-case filler is roughly 45% of the Setting Index ~~of Pacific oyster shell strings~~ in the same location.

Again, the secondary spawning and larvae peaks are reflected in late-summer spatfall. As will be shown however, this later set is generally subject to heavy mortality.and so is of only slight significance for the final recruitment of seed oysters at the end of the season.

SEASONAL CATCH

During the setting seasons test cultch was put out periodically with the weekly or biweekly strings but left until the end of the season when the accumulated live spat was counted. The number of <u>large</u> spat from the first wave of setting was usually distinguished, these being the seed which have a good start toward maturity and will most likely survive over the winter. In general, strings put out just before the first setting peak accumulated the most large spat. The strings are "hung" from the date-line ~~of~~ in the graphs at the times they were placed out in the bay, and the figures given with each are the average number of surviving large spats per Pacific oyster shell.

REVIEW OF REPRODUCTIVE SEASONS, BY BAYS AND BY YEARS

Comparable, graphical presentation of the reproductive events by bay-years enables one to compare them by inspection, whereby general features emerge and more precise distinctions can later be made. The first point one notices is that there is great difference in performance from bay to bay and from year to year, our quantitative data amply confirming the general impression and experience of oystermen.

Oyster Bay is the largest center of production and shows consistently the most vigorous surge of reproduction, with generally the highest seasonal catches of seed oysters. North Bay may be ranked second, with consistently good catches ~~and~~ usually characterized by a brief and precipitious peak of spatfall, possibly because there is only one active Olympia oyster farm in the area so that the spawning and development of the larvae is more nearly that of a homogeneous population. Mud Bay comes third, having substantial sets but with the special characteristic that in some years spatfall fails entirely. An explanation for such failures will be offered later. South Bay has had in the years of our study only poor sets, and this we attribute to the combination of a small spawning population of mature oysters in ~~a bay~~ an inlet of such relatively short length that tidal action may often sweep out of the bay a high percentage of such larvae as are produced. And finally Oakland Bay which, before cultching operations were carried on generally in all bays, was the very center of Olympia oyster seed production, is now out of the running due probably to industrial pollution as well as other factors.

Not only is there difference in spatting potentials of the bays, but the whole reproductive cycle is shifted in time of occurrence from year to year by as much as a month. In Oyster Bay, which may be taken as the bellwether of the bays, inception of spawning may vary all the way from the beginning to the end of May. It may even start at the end of April, as in the warm spring of 1934 according to the data of Hopkins (1937). This of course is due to the relative warmth or coldness of the early season, a topic which will be thoroughly considered. ~~in a moment.~~

PREDICTION OF TIME OF SPATFALL

Since the timing of the reproductive season varies so greatly from year to year and even from bay to bay it is of the utmost importance in obtaining a good catch of seed oysters to know within a few days when the first wave of spatfall will begin in order that clean cultch may be ready for the larvae to set upon. If cultch is put out too early it will generally become rapidly fouled with marine growths, since it remains submerged within the dikes, and therefore lose much of its catching efficiency. Hopkins found (1937, pp. 479-488) that even under favorable circumstance cultch lost one-third of its efficiency in 9 days.

The reason why fouled and slimy cultch is unfavorable for the setting of spat is probably to be deduced from the observations of Prytherch (1934) and of Cole and Knight Jones (1959) who found that setting oyster larvae secrets a drop of material from its byssus gland onto the cultch surface and then actively places its shell onto the glue-like material. It is therefore likely that this cementing material will not adhere to a fouled surface with sufficient tenacity to hold the shell of the newly-set larva.

It is equally important that the cultch not be put out too late. The experience of oystermen has been that the initial spatfall of the season is the best and that spat caught later in the season have a poorer chance of survival and so contribute little to the season's yield of seed oysters. This point is amply confirmed by studies discussed elsewhere (P. 87). Then, too, when there is but one wave of spatfall, tardy cultching naturally could miss the spat entirely.

The importance of the proper timing of cultching operations is clearly demonstrated by the seasonal cultch shown in the bay-year graphs. These test strings show how much set, which has a good start in growth and can be expected to survive the winter, (XXXXXXXXXXXX) was accumulated by cultch put out at various times throughout the spatting season.

Hence a careful examination of this data is of great interest in determining the optimum time of cultching with reference to the cycle of spatfall. A review of seasonal catch by dates of cultching is given elsewhere (P 91). Suffice it to state here that maximum catches of potential seed oysters are obtained only on cultch put out at the beginning of spatfall when it is rising toward the first setting peak. Cultch placed out a week or longer before this time usually catches poorly, and cultching shortly after the first setting peak or later also results at least in sub-~~normal~~ optimal catches and often in complete failure.

The problem then was to determine how to predict with accuracy when the first wave of spatfall of the season would begin in any bay during any year and to be able to make this forecast sufficiently in advance to permit scheduling the preparation and placing of cultching materials~~, and placing them on the beds in time for the maximum catch~~. At first we did this by following the abundance and growth of the planktonic larvae and predicting on relatively short notice, as is done elsewhere, both the time and intensity of the set to be expected. The accumulation, over many years, of information on the timing of the reproductive cycle has now made it possible to correlate this variable with climatic conditions and to arrive at an accurate method employing only easily obtained air temperatures, for predicting at the end of April, as far as two months in advance, the date on which setting will begin and cultch should be in place in any bay ~~and in~~ during any year.

The logic and development of this prediction method is presented in a separate supplementary section (P. 93). Here only the substance of the method will be set forth.

First of all, we know of course that the colder the year the later the reproductive cycle commences and vice versa. This is understandable in view of the fact that temperature undoubtedly determines the rate of development of oyster spawn. Humanly we judge the relative coldness or warmth of a season by the air temperatures, but it is of course water temperatures which affect the oyster itself. However, if it should be the case that water temperatures closely follow and are determined rather directly and rapidly by prevailing air temperatures, then we can also infer bay temperatures from ordinary weather records. This has proved to be in fact the case.

The next step is that one wishes to convert if possible the <u>general</u> relationship between warmth of season and timing of the reproductive cycle into a precise and quantitative correlation so that for any degree of warmth of season one can tell by exactly how much the reproductive events will be advanced or retarded. To accomplish this end, quantitative expressions for the degree of warmth or coolness of the early months of the year and for the time that spatting begins are required. For the first, the algebraic sum (sum of the "pluses" minus the sum of the "minuses") of the deviations from normal of the monthly average air temperatures recorded at the nearest weather station, Priest Point Park, Olympia, for January through April was used as an index of the spring Thermal Trend of the season. To designate the optimum cultching dates, one used the number of days after April 30th on which the significant rise toward the first setting peak of the season began.

At this point the Thermal Trend was determined for all the years from 1942 through 1950 and plotted graphically, for each bay, against the number of days after April 30th on which spatting began, the two values for each season determining the points on the graph. For North Bay, data of the weather station at Grapeview were used since the village lies very near this oystering area. We owe our thanks to Mr. Charles F. Norrie of Priest Point Park and Mr. W. O. Eckert of Grapeview for the conscientious completeness of their records.

When Thermal Trend and time of beginning spatfall were paired off together graphically in this manner, it was found that the points of the graphs fall pretty well along an imaginary straight line. Nothing gives the scientist more satisfaction than such an eventuality because it means that a direct, simple, quantitative relationship is shown to exist between the two variables which determine the points of the graph, in this case Thermal Trend and spatting time. It further opens up the possibility that one can discard hunches and designate with certainty to within a few days when the set will occur during any year for which the early spring Thermal Trend is known, for a formula can be derived from each bay-graph which will enable one easily to calculate when the set will fall from the known Thermal Trend of the season.

Before such formulae can be used with confidence they have to be checked. This amounts to answering the question, Will the points of future years also fall near the imaginary straight line connecting the data of past years? Only time can tell, of course, but the method was announced in the Puget Sound Oyster Bulletin of May 24, 1951 and was applied with notable success to predicting dates of beginning spatfall during that year. Another course, is, however, open to us in checking the method, namely, applying it to seasons before our own investigations began. Thus we can use the formulae to "predict" from the weather records of 1931 to 1941 when the set in Oyster Bay and Mud Bay "should" have begun, and these determinations can then be checked against the independent observations, obtained by different methods than our own, of Dr. Hopkins and Mr. W.J. Waldrip during these years.

The fact was that such "retroactive predictions" worked very well indeed and were amply confirmed by subsequent reference to the records of these observers. ~~[illegible] for Oyster Bay and Mud Bay we have added their~~

Figures 39 through 42 represent the relationship between Thermal Trend and spatting time in the four bays of our study. The set in South Bay has been so attenuated that precise correlations are not yet possible. For Oakland Bay we have too scant data since this area fell out as a commercial oystering center during our investigations.

(Insert Figures 39 through 42)

In all the above graphs the diagonal line represents the "best line" between the points of the graph, i.e., the line on which the points tend to fall or the line which is closest to the most number of points. Since in each case the formula is derived from this line, all predictions of setting time will fall on this line. Hence the deviations of the actual times of beginning spatfall (the year-points) from the line represent the accuracy of the forecast and is given in connection with the formulae below.

The following formulae derived in the manner noted above will, on the basis of past experience, predict the proper time for cultching with the accuracy noted:

For Oyster Bay: $D = 1.04\ (53.5 - X)$ gives the expected date of beginning spatfall to plus or minus 3 days.

For Mud Bay: $D = 1.16\ (53 - X)$ gives the date to plus or minus 4 days.

For <u>North</u> <u>Bay</u>: D = 1.1 (52 - x) accurate to plus or minus 4 days.

For <u>South</u> <u>Bay</u>: D = 0.97 (67 - x) gives the date to plus or minus 5 1/2 days.

In the above equations, for "D" read "the number of days after April 30th on which the first significant spatfall may be expected to begin" and for "x" read "the value of the Thermal Trend or the algebraic sum of the deviations from normal of monthly average air temperatures, January through April", using Grapeview station for North Bay and Olympia (Priest Point Park) for all other bays.

An example will illustrate the use of the formulae. Suppose it is May first, 1950 and we want to time cultching operations in Oyster Bay. Inquiring from the Weather Bureau station at Priest Point Park we find that the deviations from normal of the average mean air temperatures for that year so far are:

Jan.	Feb.	Mar.	Apr.
-10.5	-1.8	-3.9	-3.2

The algebraic sum of these figures gives a spring Thermal Trend index of -19.4. Substituting for x in the formula we have:

$$D = 1.04\ (53.5 - (-19.4)\ )$$
$$= 1.04\ (53.5 + 19.4)$$
$$= 1.04 \times 72.9 \quad = 75.816 \quad = 76 \text{ days.}$$

Hence we put out our cultch 76 days after April 30th or on July 15th. Turning to the graphical presentation of events during this season of 1950 in Oyster Bay (Fig. 35) we see that with reference to the actual spatfall picture the cultch was put out two days before the setting peak and half way between the two strings of highest seasonal catch!

It will be apparent that we must have a separate formula for every bay because each bay has a different rate of response to air temperatures depending on its topography so that, for instance, Mud Bay is undoubtedly slower in warming up in the spring than is Oyster Bay (see P. 109). In arriving at the prediction formulae air temperatures have been used instead of the actual bay-water temperatures to which the oysters are subjected. Hence there is little doubt that the accuracy of the formulae could be improved if water rather than air temperatures were used in determining the Thermal Trend of the early spring months. But we are saved the great expense of such surveys during each spring in all the bays if the air temperature records of the U. S. Weather Bureau used in the formulae prove adequate to the practical purpose of assuring maximal seasonal catches. That they will is shown by the fact that if cultch is put out according to the predicted date it will in one direction be at most 5 days "too early" and will not in that period have time to become fouled significantly; and in the other direction be at most 5 days "too late" but will still catch a near-maximal and probably a saturated catch since the formulae are designed to designate the time of the beginning of the initial wave of spatfall. ~~which usually extends over several weeks.~~ And most years ~~of the time~~ the actual date of beginning spatfall may be expected to fall closer to the predicted time than these extremes.

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PREDICTION OF SPAWNING TIME

Since it is possible to foretell the proper date for optimal cultching through a relationship between the reproductive cycle and spring air temperatures which for its regularity must be regarded as truly remarkable, one has little need of predicting time of spawning. Such information however may be of considerable value, apart from cultching, in forecasting when oysters will become "spawny" and less suitable for marketing so that marketing schedules can be arranged accordingly.

Hence in the same manner as for setting dates can be derived the following formulae for determining the date of beginning spawning in any bay ~~in~~ during any year:

For Oyster Bay: $Dsp = -3.4\ (x - 4.8)$ gives the date of beginning significant spawning to plus or minus 7 days.

For Mud Bay: $Dsp = -2.63\ (x - 5.8)$ gives the time to plus or minus 7 days.

For North Bay: $Dsp = -2.63\ (x - 7.0)$ gives the date to plus or minus 4 days, and

For South Bay: $Dsp = -3.3\ (x - 8.5)$ gives an approximate date, of accuracy undetermined because of insufficient years of data.

In these formulae for "Dsp" read "the number of days after April 30th that first significant spawning begins, and for "x" substitute the algebraic sum of the deviations from normal of average mean air temperatures at Grapeview station for January through April, with monthly deviation values of -4 and less and +5 and greater omitted from the calculation.

If "Dsp" turns out to be negative, then spawning will already have commenced in April, as was the case in 1934 according to Hopkins' records. Hence for unusually warm years one should at the end of March calculate the Thermal Trend for the months of January through March. If this value is already + 4 or greater, spawning may be expected to begin in the major bays sometime before May first.

Oddly enough the spawning predictions have proved far more difficult to arrive at than the setting formulae; How this was done is presented in detail elsewhere (Pp. 105-142).

The formulae so derived will therefore allow one to predict the beginning of spawning quite precisely in North Bay and within a fortnight in the other bays. As with the setting predictions, we can say that most of the time the actual date of beginning spawning will fall well within the extremes of accuracy noted.

PREDICTIONS OF INTENSITY OF SET

If and only if a bay has so low a spatting potential that it cannot be relied upon to produce saturated catches on properly timed cultch do we require to predict the intensity of spatfall to be expected so that oystermen may judge whether cultching operations are likely to be profitable.

On this score one can see from the graphs of the bay-years that the relationships between total abundance of larvae, abundance of large larvae, maximum spatting intensity and over-all seasonal catch are very flexible according to our data. This looseness is due in part to the need for greater accuracy in the determination of the always small proportion of large, near-setting sized larvae (see P. 55), in part to our apparent failure always to obtain representative larvae samples by usual methods in North Bay (see P. 85), and in part to other possible factors of salinity and tidal range at time of spatting as will be discussed in connection with setting failures in Mud Bay.

The whole problem of larvae size and abundance is treated in a separate section (P. 67). Here we present only general conclusions which are, in view of the looseness and flexibility shown, about three parts science and one part art. They are:

1) The area under the larvae curves (total production of larvae) is roughly equal to the area under the setting curves (total set, regardless of Setting Index) when presented on the coordinates used in the bay-year graphs. This means that one can graph the larvae abundance as it develops and therefrom gather an idea of the extent of spatfall to be expected. North Bay offers exceptions because, as already noted, we apparently have not always succeeded in finding a valid indication of the true larvae abundance, while Mud Bay experiences anomalous spatting failures as will be discussed shortly.

2) A total larvae abundance of at least 1000 larvae per 20 gallons of bay water is a necessary basis for a satisfactory set.

3) Roughly 100 large, near-setting size larvae per 20 gallons are required for a significant spatfall.

It has been indicated that there are few times in our bays when the extent of spatfall is on the verge between profitable and unprofitable set, but the above practical rules may be useful as a guide when and if one wishes each year to check the reliability of the predicted dates for beginning spatfall by going into the field a week beforehand and taking plankton larvae samples. Since these predictions relate only to the time of setting and not to its magnitude, such a checking would effectively expose a possible spat failure before cultch is put out if such a circumstance should sometime appear.

SETTING FAILURE IN MUD BAY

Up to this point we have reviewed the reproductive cycle of the oyster bays, set forth methods for predicting time of beginning spatfall and of spawning, and noted how an estimate of the magnitude of set can be gained from the larvae picture shortly before setting begins. All this works very well for those bays (Oyster Bay and North Bay) in which good sets appear with gratifying regularity. In those bays which have not sufficient spawning stock to produce an adequate abundance of oyster larvae (Oakland Bay and South Bay) there is no profitable set to predict and the only course is to build up those stocks with seed oysters from the other areas. But there is one glaring anomaly in the whole picture which is most disturbing and this is that although Mud Bay has the stock and produces year after year an adequate abundance of larvae there are years in which spatfall itself is nearly a total failure.

During the years covered by this report, setting failure in Mud Bay occurred only twice, in 1944 and in 1946 when the Setting Index never exceeded 42 and 14, respectively. To this number we may now add the season of 1951 (Setting Index not over 75), and Hopkins found poor sets in Mud Bay during 1934 and 1935. Consequently, although "off-years" have long been familiar to oystermen cultching in this bay, we have only a very few years of spat failure covered by quantitative investigations of spawning, larvae growth and abundance, and rates of spatting on test cultch; and therefore our ~~we simply have inadequate~~ information is simply inadequate to solve the problem of Mud Bay failures at this time. The practical issue of whether or not to put cultch out in this bay is each year so pressing in view of the precarious nature of the set that we must employ any indications we have which are at least better than blind guessing. Still another reason urges one to speculate as best he can within the sparce data available, namely, that such conjectures may very well guide future field studies toward a satisfactory solution of the problem. It is very doubtful that we can do anything about these spatting failures except to predict their occurance accurately, but that in itself would be of very great value in preventing the waste of cultch and the unprofitable pursuit of cultching operations during "off-years".

We have accordingly allowed ourselves some extensive speculations on the Mud Bay situation which are given in detail elsewhere (Pp. 114 et seq.). They indicate that spatting failures in Mud Bay may be due to two causes, operating either separately or together, namely, abnormal salinity of the bay water or the occurance of neap tides at the time the larvae are ready to set. On the other hand we have abandoned the idea that the larvae may be washed out of this bay by a run of spring tides since a plankton study during a cycle of tides has shown conclusively that this is not the case (see P. 82).

The suggestion that setting failures in Mud Bay may be due to abnormal bay-water salinity is derived from the fact that such failures are fairly well correlated with abnormal rainfall for December through June as recorded at Priest Point Park, Olympia. If one procedes, as with air temperatures in relation to setting time, to correlate monthly deviations from normal in rainfall with spat failure, the following rules emerge.

One may expect collapses of the set in Mud Bay in those years when--

1) winter rainfall (December through March) is exceedingly low, the deviations from normal summing to -9 inches or lower, as in 1944, or

2) precipitation during the "larvae months" of April through June is abnormally low (-3 inches and lower) even though that of the ~~xxx~~ early months was high (i.e., the converse of (1)), as in 1934, 1935, and

1951; or

3) average precipitation during April through June is abnormally high, <u>without</u> there having been a compensating abnormally low rainfall during the months of December through March, (as in 1946).

These are the best tentative rules which can be deduced from the meager information at our disposal. They are the result of the rather complicated speculations already refered to. Apparently in years of abnormal rainfall Mud Bay salinity is most sharply affected with the result that the larvae fail to survive to setting size which is the direct cause of the failure of set. This was indicated by the failure to find more than a few large larvae in the plankton during the seasons of 1944 and 1946 in Mud Bay.

During the season of 1951 there was apparently an adequate abundance of large near-setting size larvae and yet the spatfall was still a failure. Hence one may hazard either that the large larvae died off just on the eve of setting due to condition (2) above or else that some other factor operated to destroy what appeared to be a potentially good spatfall. Mr. Cedric Lindsay suggested that the type of tides obtaining at the time of set may have influenced the result. Accordingly this possibility was explored within the data available. Reviewing the years of our own study as well as those of Hopkins it is found that poor sets in Mud Bay have on occasion been associated with the appearance of a run of neap tides at the time the larvae were ready to set (see P. 124). It is possible therefore that low high-tides do not carry the setting larvae well up-bay to the location of commercial cultch, our test cultch and the test cultch of Hopkins. If spat failure in these cases is simply due to the tides not bringing enough setting larvae to the cultch, then the set should still be good at locations farther down-bay. Observations of 1951 have failed to confirm this (the spatting on natural cultch in all areas seemed about the same) but distributed test cultch in future years may give a more decisive answer. In the meantime we may add as a caution a further rule to those given above, namely, that miscarriage of set may occur in Mud Bay when --

4) a run of neap tides begins at or within a few days of the predicted time when spatting is expected to commence, as in 1934 (compare Hopkins, 1937, figures 31 and 26) and in 1951. By neap tides we mean here specifically that both high tides of the day do not attain a level of +12.5 feet or higher (Seattle tides plus 3.6 feet, i.e. corrected to Burns Point).

It is very interesting that the season of 1949 yielded an "in-between" set in which the Setting Index never exceeded about 600 and that during this year the ~~January~~ December through March rainfall deviated very close to -9 inches while the set seems in mid-flight to have run into a period of neap tides which may have cut it off. Hence that season seems to have been a border-line case both from the standpoint of rainfall and range of tides.

The practical rules here given are therefore offered as the best guidance we can devise from the few instances of spat failure in Mud Bay of which we have corresponding quantitative records. It is hoped that they may yet permit reliable anticipation of setting defaults and lead eventually, either through confirmation or refutation, to a more certain understanding of the causes of these failures in Mud Bay.

MOVEMENT OF OYSTER LARVAE BY TIDAL CURRENTS

Oyster larvae are able to swim but weakly and so are classed as truly pelagic forms which must drift at the mercy of the tides. Hence there is an orderly change in distribution of the larvae in the bay during the ebb and flooding of the tide, and this is of considerable importance from many angles as will presently be shown.

The fact is that in mid-summer when oyster larvae are abundant one could take a 20 gallon plankton sample in a given bay and get a count of anywhere from zero to several thousand larvae. This shows that the larvae are not distributed uniformly in the water as if in chemical solution but have a definite and restricted distribution in the bay with regard to stage of tide. We were therefore interested in the tidal movement of larvae originally from the standpoint of finding the larvae in the bay and obtaining representative plankton samples. When we found great differences in density of larvae at different stations in a bay it became apparent to Mr. D. L. McKernan that we would need to make adequate surveys of the distribution of the larvae in a bay throughout a tide. To date various groups from our Laboratory have made 7 such surveys the results of which are detailed in a separate section (P. 73).

The concept which has emerged is that of a Larvae Mass, perhaps more or less elipsoidal in shape, or having a high density of larvae in the center and shading off to no larvae at the periphery. This mass then moves up and down the bay with the tides. Hence the general picture we have gathered may be diagramed as follows:

(~~picture~~ INSERT
(Fig. 43 [illegible])

The original purpose of these studies was fulfilled, for the surveys show that in obtaining a picture of the abundance of a planktonic form like the oyster larvae one is not sampling the bay water as if running a chemical determination, but sampling the Larvae Mass. Knowing the movement of this mass one can find it at any stage of the tide, or better, can sample when it is toward the head of the bay at mid-flood to high tide.

Another conclusion from the tidal-cycle surveys is that the oyster larvae are not washed out of our principal inlets even though the duration of the swimming stage of the larvae is about a month and the tidal range may exceed 18 feet during the summer . This fact seems quite remarkable. It is explained in part at least by the great length of these bays which is therefore seen to be very important in retaining the spawn.

It is also clear from the concept of the Larvae Mass and its tidal movement that other conditions being equal that area in the bay will catch the most seed over which the Larvae Mass passes the greatest number of hours of the day. This explains both the variation recorded in Hopkins' study of hourly catching rates ~~(seexPxxxxxxx)~~ and the possible significance for spat failure of neap tides occurring at the time of spatfall in Mud Bay (P. 124). Needless to say ~~it~~ the concept of Larvae Mass also gives the reason why down-bay and far up-bay areas are not good cultching grounds. On the other hand, what have by long experience been determined to be good spatting areas are indicated by these plankton--tidal-cycle studies to be the locations nearest to the Larvae Mass. This is to say that if one were setting up oyster culture in a bay he could spot the most likely grounds for best seed catches through a study of the "moment of oscillation" of the Larva Mass, and such investigations might even in certain instances improve the location of traditional cultching areas.

CULTCHING EXPERIMENTS AND OBSERVATIONS

Not only must the cultch be placed in the water at the proper time and location and put out only when a profitable set can be expected; it must also be so chosen and employed as to utilize its maximum efficiency in catching spat. In this section are gathered certain studies relevant to this problem.

VERTICAL SETTING STUDIES

During 1946 Mr. Roger Tollefson put out long strings of Pacific oyster shell on cultch floats at Burns Point in Oyster Bay in order to determine whether rate of spatfall varies with depth of water. Only top valve, "lid-shells" were used, to increase the uniformity of the cultch throughout its length. One string was left in the water for only a week during which the rate of spatfall at Dike 5 station was about 12 spat per smooth shell face for the 6 day period. Eight other strings of 4 to 9 foot length were put out at different dates during the setting season and brought in to the laboratory only after the end of the spatting season. Spat was counted on both sides of every third shell of these strings and averaged by half-foot intervals. The results are given for the one week string and for the seasonal strings as follows:

TABLE 1 : VERTICAL DISTRIBUTION OF SPATFALL ON FLOATING CULTCH STRINGS DURING ONE WEEK

Date into water: July 17, 1946
Date out of water: July 23, 1946

Depth in feet	Average spat per shell	Spat counts of every 3rd shell
0-1/2	13.4	1
		12
		17
		8
		29
1	19.0	16
		26
		11
		27
		15
1 1/2	15.2	20
		16
		16
		8
		16
2	9.6	9
		28
		0
		7
		4
2 1/2	6.0	3
		4
		0
		8
		15
3	14.0	9
		17
		8
		16
		20
3 1/2	15.4	22
		9
		3
		21
		22
4	22.7	11
		12
		61
		36
		12
		4

TABLE 2: VERTICAL DISTRIBUTION OF SPATFALL ON FLOATING

SEASONAL CULTCH STRINGS

Date into water	June 27	July 9	July 17	July 23	Aug. 1	Aug. 14	Aug. 20
Depth in feet			Average spat per shell				
0-1/2	191	70	10	5	3	16	3
1/2 - 1	155	74	22	9	5	19	4
1 - 1 1/2	166	79	8	4	4	31	4
1 1/2 - 2	203	90	9	10	2	41	12
2 - 2 1/2	182	53	8	12	4	51	10
2 1/2 - 3	185	54	6	10	12	75	13
3 - 3 1/2	169	52	14	12	13	77	3
3 1/2 - 4	157	58	6	10	20	45	
4 - 4 1/2	no shell	no shell			15	26	
4 1/2 - 5	"	56					
5 - 5 1/2	180	70					
5 1/2 - 6	200	76					
6 - 6 1/2	152	49					
6 1/2 - 7	141	61					
7 - 7 1/2	164	64					
7 1/2 - 8	174	53					
8 - 8 1/2	165	60					
8 1/2 - 9	113	53					
9 - 9 1/2		41.					

Although the number of test strings is small it is clearly indicated that intensity of spatfall does not vary significantly with depth of water, at least from zero to 9 1/2 feet and hence probably also not at greater depths. We therefore agree with Korringa's opinion that, other things being equal (like larvae abundance and current velocity), vertical distribution of set is uniform and larva show no "preference" for certain depths of water in spatting. It was shown in some preliminary tests of this notion during 1945 that the uniform picture in floated seasonal strings may be complicated by secondary factors, as when conditions are very favorable to the growth of fouling organisms which (like algae) attach and grow especially on the uppermost shells of the cultch strings.

We did not find as Hopkins did (1937, p. 493) that a significant setting maximum occurs around 1 to 2 foot depth, but his methods differed somewhat from ours in that he used suspended bags of shell. His results are used by Hopkins to explain good seed catches on high tidal grounds; but since we could not check his results, and for other reasons as well, we conclude that good seed grounds are such mainly because of their location with reference to the Larvae Mass and therefore the abundance of larvae available for set but not on account of their level on the beach. This conclusion was not available to Hopkins because he did not make quantitative studies of the planktonic larvae.

But Hopkins made a very sagacious use of his findings in suggesting the use of floating cultch to catch seed oysters. This, like his modification of cultching methods in accordance with his study of the influence of angle of cultch surface on intensity of spatfall, proved to be of vast practical importance to the Olympia oyster fishery.

FLOATING CULTCH

Not only did the idea of floating cultch enable oystermen who have poor seed grounds to replenish their stocks easily and without interfering with the catch of other oystermen, but when the Japanese oyster drill became abundant in Oyster Bay this method enabled one to catch seed free from drills and their depredations. Moreover such cultch is extremely efficient because it can be placed with reference to the Larvae Mass so as to "fish" continuously throughout most of the tidal cycle. We counted as high as 12,000 spat per cemented egg-case filler which had been out a month when the Setting Index was only 300 - 400.

Our observations on floating cultch probably do little more than confirm what oystermen have learned from practice and the exercise of their own good judgement. Nevertheless we mention them in passing, as follows:

1. Extent of spatfall depends on the amount of setting larvae brought to the cultch surface. Hence every practicable means and precaution should be employed to orient the collectors so that a good current of water passes through them and penetrates to the interior of the mass of cultch material. Tollefson found that there was three times as much catch at the edges as in the center of the cultch.

2. The cultch should be removed and planted as soon as it becomes saturated with seed oysters, otherwise a considerable mortality and arrestment of growth of the spat will generally occur due to the fouling of the cultch with algae and other organisms, including the mud-tube amphipod which may be responsible for "key-hole mortalities". (see P. 46) It also follows that the cultch should be put out only when the Setting Index is high (several hundred) so that the cultch will not have to remain long to pick up a good set.

3. If transport of the cultch to the beds does not result in high mortality of the spat, the setting efficiency of floating cultch is so great that it should permit successive refitting of the bins with two or

more saturated catches of spat during the first wave of spatfall if the spatting rate is at all considerable.

4. Taking (1) and (3) together, it might be more profitable to refill smaller bins in small floats than to attempt to get all the set desired in one filling of a large float. in which crushing and collapsing of stacked fillers may occur.

BEDDED CULTCH

Although we have tested the efficiency of many types of possible cultching surfaces we have found none superior to the cemented cardboard egg-case fillers. Also it may be mentioned that Korringa (1940, p. 230 - 231) finds that the addition of fairly coarse and very coarse grain sand to the cement coating mixture augments the spatfall only slightly due to the increased surface ("hills and valleys") resulting, and concludes that it is the microscopical and not the macroscopical roughness which counts. Hence the lime-cement-sand surface now in use is the best we know. In areas where the tide currents are unusually strong (eg. Holland) the mixture is applied to heavy tiles and the spat chipped off, while in quieter waters like the bays of lower Puget Sound cardboard is used to advantage because of its self-disintegration.

In connection with his study of the effect of angle of surface on catching efficiency of cultch, Hopkins found that egg-case filler collectors caught about three times as many spat when held on edge than when laid flat on the beds with all surfaces oriented vertically. Hence he invented a "flat" type of modified collector which would stay on edge when so placed. Some oystermen however have attempted to compromise and to save themselves both the manufacture of special collectors and cost of keeping ordinary fillers up-ended by "shingling" the regular cemented filler in the dikes. This means that the fillers rest in rows, the far edge of one row upon the near edge of the next, all collectors therefore lying at an angle of about 30°. More cultch can be put in a dike this way, but the efficiency of the individual collector is still only one third what it could be if it were standing on edge.

This conclusion was derived from a test by Mr. Roger Tollefson on a number of ordinary type collectors. Half were cut in two (hence low and always submerged in the dike at low tide) and held vertically together, the bank of collectors being supported by pegs driven into the ground; and half were "shingled" at about a 30° angle, overlapping each other by about half their width. After a set had been obtained, 20 random partitions for each set-up were examined and spat counts made. (By a "partition" is here meant one side of one side of the four-sided enclosure intended to hold an egg----having an area of 4.15 square inches. A single collector is the equivalent of 90 such sections, ie. 747 square inches.)

The results are presented by uniting the 20 random samples of each type of orientation of collector as if they composed one ordinary collector. When a collector is dropped from the vertical (on edge) position to a 30° angle, the vertical sides of course remain vertical while the horizontal partitions become slanted to an angle of 60°. Vertical partitions were therefore distinguished from horizontal or angled partitions in spat count. Several 12-shell strings of Pacific and other strings of Olympia oyster shells were hung out vertically in the dikes during the same period of time to determine comparable set on them.

(Insert table # 3)

TABLE 3 : COMPARATIVE SPATFALL ON DIFFERENT ARRANGEMENTS OF CEMENTED EGG-CASE FILLER COLLECTORS

	UPRIGHT COLLECTOR		SLANTED COLLECTOR	
	TOTAL SPAT	AVERAGE SPAT PER SQUARE INCH	TOTAL SPAT	AVERAGE SPAT PER SQUARE INCH
Horizontal Partitions				
Upper surface	0	0.00	0	0.00
Under surface	305	7.35	98	2.36
Total	305	3.67	98	1.18
Vertical Partitions (both surfaces)	149	1.80	70	0.84
Entire Collector	2043		756	
Comparable spatfall on collectors		2.7		1.0
Comparable spatfall on Pacific oyster shells (smooth, under-surface only)		2.0		
Comparable spatfall on Olympia oyster shells (smooth, under-surface only)		2.5		

The results (Table 3) allow one to come to the following conclusions:

1. Under horizontal surfaces of upright collectors are more efficient spat-catchers than under horizontal surfaces of oyster shell in strings.

2. Angled collectors catch only about one third as much spat as Hopkins-type or upright collectors.

3. Vertical partitions in upright collectors catch twice as many spat as the comparable partitions, also vertical, in slanted cultch. This difference can only be explained on the basis that with slanted collectors the current does not flow through the collectors but over them. Dead current spaces therefore arise and the delivery of mature larvae from tidal waters to the cultch surface is impeded, thereby resulting in lower catch in slanted collectors even on the similar, vertical surfaces.

The quantitative data given should enable oyster growers to calculate whether costs of staking, etc., to maintain banks of erect collectors will be offset by the trebling of spat catch per collector.

The superiority of "open and exposed" horizontal partitions over shells in strings or of "shingled" collectors amply confirms a general principle for the guidance of cultching procedure which has already been stated by Korringa (1940). This is that so far as catching of spat is concerned good cultch fulfills two requirements: (1) it does not create dead water spaces but allows for the flow of larvae-bearing tidal currents passed and through it and therefore for the delivery of available larvae to the surface of the cultch, and (2) the very local, microscopic conditions of the cultch surface favor the complicated maneuvers of the larvae during the setting process, i.e., their crawling and their anchoring their shells by secretions from the byssus gland, either by roughness and cleanness of the surface which may aid the foot to hold on or by local eddies, etc., which will protect the larvae from being swept on by the tidal currents. (The description of this setting process, in *O. virginica* but probably applicable to *O. lurida*, we owe to Prytherch (1934).

It will be seen that these two conditions are somewhat antithetical, that is, one has to have currents to bring the larvae to the cultch surface but on touching it they must be protected against being swept along further. There seems little doubt that cultch could be improved somewhat if materials and methods combining these antithetical factors could be devised. Such an approach, starting from general principles, should prove far more fruitful than merely testing various materials at random.

One ~~should~~ may also remind that cultch should be such as to maintain at least a good portion of its surfaces at the optimum angle for setting and that it should be heavy enough not to be disturbed by storms and tidal currents and yet of such a nature that the accumulated spat can eventually be scattered and evenly distributed over the oyster bed.

SATURATION OF CULTCH

The idea to be dealt with here is simply that after a cultch surface has caught sufficient spat during the summer so that it can be expected to be covered with large, surviving spat on the following spring, any greater density of spat is of no further practical benefit and may even result in undesirable crowding of the seed oysters. We have to leave it to practical oystermen to determine what minimum catch they require to make their cultching operations profitable, but we can gather some notion of maximum possible catch obtainable from an analysis of the seasonal test cultch.

Hence if we compare large, surviving spat on seasonal cultch with maximum Setting Index attained we find the following:

	OYSTER BAY		MUD BAY		NORTH BAY	
YEAR	MAXIMUM SEASONAL CATCH OF LARGE SPAT	FIRST PEAK S. I. MAXIMUM	MAXIMUM SEASONAL CATCH OF LARGE SPAT	FIRST PEAK S. I. MAXIMUM	MAXIMUM SEASONAL CATCH OF LARGE SPAT	FIRST PEAK S. I. MAXIMUM
1944	85	2300	5.2	42	39	6500
1945	107	7500	70	3500	* 43	9000
1946	135	2600	0.8	14	73	1300
1950	125	4000	167	2800	118	4000

* Note--altho conversion of larvae into setting was high---setting did not "stick" well.

These data clearly show (1) that the surviving set is of course no-where near the total amount of spat that originally set and (2) that, whatever the Setting Index, one cannot expect many more than 100 spat per shell in surviving catch, a figure roughly comparable to 3,000 spat per ordinary cement coated egg-case filler. It follows that there is no point in ~~to inquiring how to predict or~~ attempting to assure exceedingly high rates of spatfall since these are of no practical consequence in the recruitment of seed oysters; a moderate spatfall saturates a cultch which is appropriately timed and placed and this is all that is required. And it is likewise evident that although low spatting rates result in low seasonal catch, high setting indices do not assure large catches. In fact it appears from the test cultch of 1945 in Mud Bay and of 1944 and 1945 in North Bay shown in the tabulation above that exaggerated peaks of spatfall may even diminish the overall catch due perhaps to over-crowding of such seed on the cultch.

OYSTER PESTS

The mass of oyster larvae which appears in the summer months is undoubtedly decimated by many natural enemies. On four occasions we have found larvae ingested within the cell of Noctiluca, the large dinoflagellate responsible for one type of "red-tide". The sea-walnut, Pleurobrachia, also frequently abundant may likewise take its toll. We know of no instance, however, in which a spatfailure could be attributed solely to larvae being destroyed by their enemies. Hence we shall attempt here to catalogue only the enemies and pests of the mature oysters and spat.

A) Japanese Oyster Drill.

The most serious oyster pest in the bays of lower Puget Sound is the Japanese oyster drill, Tritonalia japonica, introduced with unclean plantings of Japanese oysters. This predator is the subject of a report by Chapman and Banner (1949) who verified its destructiveness and advised that since the drill has no free swimming stage in its life-history and does not migrate extensively it should be kept from spreading by restricting transfers of infested oysters and cultch. This has been done, and Japanese drills are confined, as of 1950, to the original areas of infestation, namely, Oyster Bay and Oakland Bay. There is no doubt that these drills can do damage; this is especially noticeable when they start on egg-case-fillers of spat and clean off a good set by the end of the summer.

Control measures consist mostly of culling out drills when the oysters are taken off the beds, by hand picking drills where they congregate along the oyster dikes during the spring egg-laying season, and by burning off egg masses exposed on the dike walls at low tide. Weighted planks have been found to attract the drills which apparently like to secret themselves under sunken boards and oyster shell.

It was found in the laboratory that the

one-hour submersion in 50% sea water though the adults are not permanently affected. Undoubtedly the egg case wall is a semi-permeable membrane and admits the dilute solution which then kills the delicate eggs or embryos. In one case where the circumstances appeared favorable, an attempt was made to use this finding by flooding an oyster dike with fresh water at low tide to kill eggs. Apparently in this instance sufficient dilution could not be obtained.

Various types of poisons have been tested for their toxicity to drills but none have so far proved practicable. The problem is far more subtle and difficult than is the case of most agricultural pests where insect and plant are wholly dissimilar organisms, while the drill and the oyster are both mollusks and changing tidal waters limit the possibilities of applying toxic substances. Let it be noted that if oystermen had heeded the warning and advice of Galtsoff in his 1929 report they would not now have to call on other biologists to solve their drill problem. The discovery of a profitable method for eradicating oyster drills remains an intriguing problem yet unsolved in any oystering area in the world. Naturally its solution would prove a tremendous boon to the industry.

B) Eastern Drill.

Uroselpinx cinerea was introduced into Oyster Bay presumably with plantings of east-coast oysters many years ago. The pest has never attained great abundance here and its depredations are entirely eclipsed by those of the Japanese drill. Fortunately, too, the native drill, Thais lamellosa is not a serious oyster pest, prefering to attack mussels, although Hopkins (1937) states that it may in places drill a great many spat. The food preference of all these drills is discussed in the paper by Chapman and Banner already refered to.

C) Moon snail and mud shrimps.

Very rarely we found Olympia oyster shells with the typical "counter-sunk" drill hole of Polinices, Where abundant it is not by drilling, however, that the moon snail damages oysters but by burying them as it plows through the bottom of the oyster bed in search of clams. If this occurs the snails must be picked off the beds and destroyed.

In a similar manner the mud shrimps Calianassa and Upogebia may prove destructive by bringing up sand from their burrows and dumping it on the oysters. The situation was once particularly acute in North Bay and was solved by boarding over the entire dike, gravel being put on top the boards as a substratum for the oysters. Such a barrier prevents the shrimp from burrowing and will not rot or be eaten by teredos or wood-boring isopods when "suffocated" in this manner under gravel and mud.

D) The Black Clawed Crab.

During the early fall of 1946 there occurred in Oyster Bay a high mortality of young native oysters which could not be attributed to known causes. The destruction was found in one oyster dike on the north shore and has not been reported elsewhere, though of course a potential menace is indicated. The dike in question had been planted with cemented egg-case fillers which caught an excellent set of young oysters, but by the end of the setting season a 30% mortality of these spat resulted. In every case the upper valve of the shell had been removed so that the destruction could not have been due to oyster drills or other shell borers. Unusually abundant in this dike, however, were specimens of the "black-clawed crab", Lophopanopaeus bellus, one of the small, less common shore crabs of the region. Frequently the crabs were found concealed within the sections of the fillers used as cultch.

Accordingly both crabs and cultch samples were removed to the laboratory and placed in a clean aquarium with running sea water where they remained together for a period of three weeks. In that time the mortality increased from 30% to 45% and the bottom of the aquarium became strewn with shell fragments and complete upper valves of the spat. It is clear the Lophopanopaeus bellus was self-incriminated as a destroyer of young oysters.

The crab is identifiable as a beast of size and habitat similar to the common shore crab but bearing proportionately larger pincers. The two tips ("claws") of a single pincer are both of a darker hue than the remainder of the "hand", and this difference in coloration forms a sharp line of demarkation across the base of the claws. Accurate identification of the crab is important since the common shore crab is not only harmless but even beneficial. This prevalent opinion was confirmed by a series of tests in our laboratory. For each test equal samples of Pacific oyster shell cultch were placed in separate aquaria with running water. The shells carried a good set of native oyster spat of from several weeks to several months in age. Into only one of the aquaria were introduced many specimens of both species of common shore crab (Hemigrapsus nudus and H. oregonensis). After a period of 4 to 6 weeks the mortality of spat was determined for the aquarium with crabs and for its partner without. Not only did the crabs fail to kill the spat but spat survival was even slightly higher in the aquarium with crabs. Hence the shore crabs apparently even assisted the spat by keeping the cultch clean and reducing mortality due to silting and fouling.

E) "Key-hole mortality"

During the summer of 1945 floating cultch from Burns Point in Oyster Bay was examined and a small portion of the spat found to be dead and with a slit-like hole in the upper valve of the shell which we therefore called "key-hole mortality". The spat were free of drills since the cultch was floating and the opening was not circular and therefore could not have been caused by drills. The only clue we have to the predator is that the cultch was also heavily coated at the time with small amphipods which build and live in mud-tubes. Is it possible that these crustacea could have scratched holes in the small spat with the sharp claws of their forelegs?

F) Cups.

Slipper-shells or cups, Crepidula fornicata, were introduced during early attempts to grow Eastern oysters in Puget Sound. Now they are abundant in Mud Bay and Oyster Bay constituting in some cases half the "crop" on oyster beds. This alien pest does very well in the native oyster dikes. Chapman and Banner (1949) found no correlation between oyster mortality and abundance of cups, but it seems likely that the cups compete with the oysters for plankton food and in any case the pest adds greatly to operating costs in the industry. The present policy is to cull out the cups and throw them up high on the beach to die. We have suggested that increased costs could be offset in part by developing the food possibilities of cups. Tests made at our request by Dr. E. W. Harvey of the Seafoods Laboratory of Oregon State College at Astoria showed that:---

> "Deep-fat frying yields a most satisfactory foodstuff.
>
> "Crepidula can be used successfully in the following preparations (in order of preference):--chowder, stew and cocktail.
>
> "Canning is not satisfactory.......needing more experimental work."

We found the flavor of the fried cups to be somewhat between that of clam and oyster, though the meats were rather dark and slightly mealy.

G) Shell worm.

This is an annelid worm, Polydora ciliata, which burrows in the matrix of the oyster shell, protruding a head bearing two long tentacles at the lip of the shell and apparently capturing plankton food from the in-current set up by the oyster, the food being carried by cilia on the tentacles down to the worm's mouth. Tunnels in the shell, visible from the interior of the shell, and the long tentacles around the lip of the undisturbed oyster are therefore diagnostic of infestation. The pest finds a secure home in the oyster's shell and possibly robs it of some of its food. Obvious detriment to the oyster, however, takes the form of erosion of the shell which results in the oyster partitioning off a part of the shell interior crowding the oyster and creating a space where dirt can accumulate. During some seasons the worms may become abundant enough to become conspicuous through these consequences, but no major damage has yet resulted.

H) Paresitic copepod, Meytilicola orientalis.

This pest is a bright-red parasite which lodges within the posterior alimentary track of the oysters as a rule though it may, when abundant, invade other tissues as well. Dr. Odlaug (1946) found that 5.5 per cent of Olympia oysters in lower Puget Sound were then infected and that a reduction in the "fattness" of the oyster meats was associated with its presence. Uninfected oysters had meats which filled an average of 41.8% of the interior shell space while the comparable figure for infected oysters was 35.5%. The over-all effect of this pest is therefore minor.

I) Bryozoa

In South Bay especially setting and growth of bryozoa colonies may reduce the efficiency of the cultch. This may come about in two ways: either the bryozoa set first and oyster spat have not been observed to set on the encrusting moss-animals (probably spat are picked off by the avicularia of the bryozoa) or the growing colony coats over and smothers the spat, as has been observed in several instances. Since bryozoa are not found on materials exposed at low tide it may be suggested that allowing the cultch to be exposed during a low tide or two may kill the bryozoa, though one should keep a sharp eye on the spat to be sure they also are not beginning to gape. After the spat get a fair start it seems unlikely that the bryozoa could trouble them further.

Summarizing the pest situation we note that the by far the most dangerous predator is the alien Japanese drill. As has happened on so many ill-fated occasions in this country an imported pest prospers in its new environment far better than in its native habitat. Beyond question we should concentrate our attention first on the control of this pest.

SUMMARY

The remainder of this account will be devoted to the presentation in detail of the analyses, tabulated data, etc., on which were founded the conclusions, interpretations and conjectures so far advanced. Before turning to these technical matters we may summarize what has been accomplished which may be of practical use to Olympia oyster growers.

1) Oystermen now have a graphic and quantitative record of the reproductory performance of their bays during the past 9 years. This record will provide a sort of base-line against which any future improvement or decline may be definitely assessed; and furthermore, since all phases of the reproductive cycle have been treated, the advance or decline can be refered to the specific stages in the life cycle affected.

2) Formulae have been derived for each bay on the basis of which, knowing only the early spring air temperatures recorded at Olympia, one can easily compute and forecast at the end of April in any year and for any bay when spatfall will begin and with an accuracy sufficient to assure maximum, surviving catch of available spat.

3) Similar formulae have been derived by means of which the time of beginning spawning can be predicted about a month in advance thereby permitting the arranging of marketing schedules accordingly.

4) Guidance is provided for predicting on short notice the intensity of spatfall that may be expected from the character of the larvae picture.

5) Quantitative tests show that one must arrange to catch the initial wave of spatfall since the spat caught later in the season has a poorer chance for survival.

6) Two suggestions supplementing each other are offered to explain ··res in Mud Bay, and a tentative method for foretelling such

failures on the basis of rainfall records and tide tables is presented.

7) Several suggestions have been made for the improvement of cultch and cultching operations.

8) A catalogue of oyster pests is given, including two new enemies not previously described.

METHODS

In this ~~place~~ section will be described in detail the methods by which the information presented in this paper was gathered. Such procedures can then be repeated at any time in the future when comparable data are desired. We will also give what information we have regarding whether or ~~not~~ to what extent the sampling in any area was typical of the whole bay. Ideally, of course, one would like to have been able to make extensive surveys of spawning, plankton larvae and setting in all bays and then select stations and methods which proved most representative in each bay. But such a study would need to be made during the peak of each of these phases of the reproductive cycle in order to yield large samples of statistical value; and as it happened it was necessary to get some idea and anticipation of the reproductive performance of the bays at once as well as to visit five bays within the short space of one tide once or twice a week. Within these limits therefore we attempted what we could.

SPAWNING

Since Ostrea lurida is a larviparous oyster, its recent spawning as a female can easily be determined by simply opening the shell and noting the presence of eggs or developing embroys within. One is immediately struck by the presence of thousands of small granules which vary in color from white to gray as they develop shells. Possibly through some early misinterpretation such gravid oysters are called white-sick and gray-sick. That developing, shelled embryos are found shows that fertilization must have taken place and that other individuals must therefore have spawned as males around the same time. O. lurida is protandrous and may spawn both as a male and as a female in one season, though apparently it is not self-fertilizing.

Our spawning data (Tables 4 - 12, Pp. 133-141) therefore represents only the proportion of oysters in the sampled population which have on a certain date recently spawned as females and bear eggs or embryos. We also have distinguished between those which carried young, unshelled embryos (white-sick) and those with shelled (conchiferous, gray-sick) larvae. The only indication we have that distinguishing between the two may be of some usefulness is that low larval abundance and relatively low spatting intensity in North Bay during the season of 1946 was preceeded by the appearance of far lower percentages of gray-sick than white-sick oysters in our samples, much as if the embryos had been aborted or in some way prevented from development to normal, liberated larvae.

For a while we opened 100 oysters from a sample area but it was soon found that the first 50 gave statistically the same values as the 100 and thereafter only 50 were opened as a sample. Always the oysters were kept in a sack out of water until opened in order that the liberation or possible abortion of embryos would not occur. The sample was always taken from a bed of mature oysters.

Time prevented our sampling more than one area of a bay since we had to sample all 5 bays on one low-tide. Hence we selected what appeared to be a representative dike(designated in the spawning tables) with mature, marketable--not seed--oysters and kept with that local population all season. The spawning data therefore give a valid picture of spawning-as-females of the oysters in a given place in the bays. No attempt was made to compare extent of spawning in several locations in a bay on the same day. We were simply constrained to choose the most accessable dike which was most nearly in the center of the oystering area in each bay. That the sample areas selected were in fact fairly representative of the bays as a whole is indicated by the reasonable correspondence between peaks of larvae abundance (to which spawnings of <u>all</u> areas contribute) and antecedent spawning waves in the areas sampled, including the appearance of first and second

But unless some further use of the spawning data can be made, its accuracy and representative character is really immaterial anyway since (1) we note, as did Hopkins, that spawning intensity is not appreciably correlated with larvae abundance, the total number of mature oysters in a bay being of far greater relevance, (2) that with the new type of spatfall predictions herein developed spawning information is not necessary, and (3) that there is no important oyster spawning problem in lower Puget Sound. To have determined the latter was of considerable value in itself in directing our attention to other matters.

PLANKTONIC LARVAE

Hopkins (1937) did not study the abundance of Olympia oyster larvae. Hence he predicted time of setting only on the basis of spawning data. We investigated the larvae for the purpose of short-time predictions of spatting intensity and to learn the extent of larvae production and whether decreases in such could account for poor sets when such occurred. (Tables 13 - 19, Pp. 142 - 148.)

All our plankton samples were quantitative, consisting of the larvae and other plankton forms gathered by pumping or pouring 20 gallons of undisturbed bay water through a net of bolting silk of sufficiently fine mesh to catch the smallest oyster larvae. The catch was then rinsed into a bottle, formalin added and labeled by means of a slip of paper placed within the bottle itself. In the laboratory the bottle was decanted, then agitated and the plankton contents poured out into a counting dish already laid on the stage of a binocular dissecting microscope. Quick dumping of the contents at one side of the rectangular dish resulted in a uniform distribution of the plankton mixture on the bottom of the dish.

This glass bottomed counting dish was marked off symetrically into 64 squares with a diamond point. All the squares crossed by the diagonals of the rectangular dish were subdivided each into three equal parts which facilitated "reading" the count when the larvae were numerous. When the larvae were scarce, all larvae in all squares were counted; when numerous only those lying within or mostly within the squares on the diagonals were counted and the resulting value multiplied by 4 for the total count; and when tremendously abundant, larvae lying in only one diagonal of squares were counted and the result multiplied by 8. Comparison of total counts with counts of the 16 squares on the diagonals x 4 gave, for a sample of 42 total count a difference of 5%, for one of 144 a difference of 3% and for one of 1620 a difference of 3%. Hence the shorter method of counting larvae in only the squares on the diagonals of the counting dish was generally used, without significant sacrifice in accuracy.

After counting, the larvae were measured without disturbing the counting dish. This was done with a calibrated occular micrometer or Whipple disc, the occular being rotated when observing each larva to line up the scale with the longest diameter of the larvae shell parallel to the hinge line. Readings were to an accuracy of at least ± 6 microns. The first 100 larvae encountered on a diagonal were measured without selection. Tests on a sample containing 616 larvae showed that if the first 50, the first 80 and the first 100 larvae are measured, the percentage composition of any one size did not differ by more than 3% in each group. A similar test on a sample containing 38,578 larvae measured by groups of 50, 70, 80, 100, 120 and 150 larvae did not differ in percentage composition of any one size by more than 5%. Hence significant error in determinations of size composition of a sample appears only among the very small or the very large larvae since these comprise the smallest size groups.

One is especially interested in the abundance of large, near-setting sized larvae as the most certain indication of the possible set in the near future and of the intensity thereof to be expected. Therefore it is here suggested that larger samples be measured when it is a question of whether a commercial set will occur or not, as in Mud Bay or South Bay, and when therefore the proportion of large larvae will be very small.

It follows accordingly that the data we give for percentage of large and near-setting larvae and therefore the abundance of the same are susceptable to considerable error and are to be used as rough indications only. An idea of the variation in proportion of large larvae in comparable plankton samples is gained from noting the values for such given in Table 20 . Since several samples were taken in any one bay on a given date, the average percentage of large larvae in all samples was used and these are given in the tabulations of plankton larvae. In this way the error and variation resulting from measuring usually not more than 100 larvae nor less than 50 was in part compensated. In O. edulis, Korringa (1940) encountered a uniform proportion of large larvae at any one time in samples taken at different stages of the tide and at the surface and on the bottom.

When we began our work we established stations up and down a bay ~~(Figure 1)~~ and sampled them in succession within an hour. It soon appeared however that the extreme stations, down-bay, often yielded relatively few larvae, depending on the stage of tide. This fact at once directed our attention to the necessity for running horizontal sections on a bay during a tidal cycle to follow the movements of the larvae with the current. These studies were done and constitute a quite thorough investigation of the variation between plankton samples at different locations in a bay on the same day. They are described in detail in another section (P. 73).

TABLE 20: PLANKTON LARVAE FIELD DATA, OYSTER BAY, 1949

DATE	TOTAL COUNT*	NO. LARGE LARVAE**	PER CENT LARGE LARVAE
May 27	16		
	8		
June 2	416		
8	8032		
	7104		
	7584		
13	12,928		
	5,064		
	11,440		
16	16,256		
	6,256		
20	1,992		
	1,264		
	3,096		
23	8,112		
	8,736		
26	9,074	752	8
	10,864	1,264	12
	7,072	480	7
30	568	120	21
	142	24	17
	3,976	704	18
July 5	13,536	208	2
	8,456	408	5
8	2,288	128	6
	11,856	528	4
11	8,640	144	2
	5,360	16	0
	2,112	64	3
18	960	664	69
	6,960	480	7
21	2,088	400	19
	1,480	480	32
	1,360	328	24
27	2,632	416	16
	1,672	312	19
	856	112	13

* Total number of plankton larvae per 20 gallon sample

**Described as "advanced umbo to setting size".

Plankton sampling (larvae) and dike stations (spawning and setting) for all bays are located in Figures .

We now come to the question of how well repeat samples taken at the same location or depth in rapid succession agree with each other. In Table 21 are given the results of the tests made. The larvae counts given are of course to be compared strictly within one station on one day; apparent discrepancies between the data of successive days at a given station are due to favorable or unfavorable tidal conditions obtaining at the time. General agreement as well as considerable variation will be noted in comparing the duplicate samples, a point which we shall return to in a moment.

Comparisons also were made between samples taken at designated stations and others taken immediately following at a distance of a few hundred yards away. The results are summarized in Table 23, P. 152. Again general agreement but considerable variation will be noted and will receive comment later.

During 1945 we established extra stations ("A" series) at approximately the same distance up the bay as our regular stations but on the opposite side of the bay. The pairs of stations were sampled in close succession with no greater time interval than was necessary to move from one to the other. Table 23 presents the comparative larva counts for paired stations on the same day. The variation in this series is great and therefore very disturbing. Some of it may be accounted for by the fact that the "A" stations were near or over oyster dikes rather than in channels like the partner stations and hence may have shown swarms of larvae just liberated by the oysters locally. In any case high counts were not consistently found for one station but first one and then the other station would show higher numbers of larvae per 20 gallon sample.

In 1945 a series of comparative plankton samples at different depths were taken in order to gain some notion of the vertical distribution of the larvae. It will be seen from Table 24 P. 153 that no consistent rule of distribution obtains. It also appears that one may miss the bulk of the larvae by sampling at the wrong depth. There is not much one can do about this possibility of error since depth samples with pump and hose are most time-consuming. (Korringa, 1940, found no significant difference in abundance of O. edulis larvae at surface and at the bottom.)

For a small number of samples the water was obtained by dropping a length of garden hose over the side of the boat, sucking up the water with an impeller bilge pump and allowing it to run through a plankton net into a 20 gallon barrel until the barrel was filled. Pump samples gave slightly higher larvae counts than duplicate bucketed samples (see Table 25 P. 154). No crushed shells of larvae were found. Hence a pump arrangement is satisfactory for sampling oyster larvae.

We also compared the catch with pumped samples when the boat was moving slowly and when it was stationary. As shown in Table 25 , the samples are quite comparable; hence the boat need not be at rest when samples are taken with hose and pump. (Cf. also Korringa, 1940, p. 40.)

The degree of variation we find in plankton samples taken in a bay at the time when and the locations where maximum larvae may be expected is shown in the data of 1948 as follows:

TABLE 22: LARVAE COUNTS OF INDIVIDUAL PLANKTON SAMPLES

TAKEN DURING 1948

DATE	OYSTER BAY	MUD BAY	NORTH BAY	SOUTH BAY
June 15	1124		160	
			620	
22	1827	112	3216	148
	3824	1224	648	96
28	2088	2020	64	112
	728	4912	112	112
July 1	1160	804	4264	724
	6320	736	1608	60
	3264		512	
5	12,224	6144	5440	1112
	3,872	6116	3432	1168
	12,000			
12		92		32
		120		40
		192		20
15		144		168
		336		328
		2424		12
19	2472	3200		524
		5200		376
				832

In regard to the above one could certainly wish for closer agreement in the samples and yet they are sufficient to the problem of determining the relative larvae productivity of the bays and whether abundance is adequate to provide the basis of a satisfactory set in each bay.

Now we may ask, what kind of picture of oyster larvae distribution in our bays do these tests imply in the aggregate? They suggest a Larvae Mass which moves back and forth in the bay with the tide and which is itself quite "spotty" with regard to density of larvae at any one locus within the mass. We may picture it as follows, having in mind that the "spottiness" is found in the vertical as well as in the horizontal distribution.

(INSERT
(Picture Fig. 44)

There is little doubt that extensive study would reveal more order in distribution both horizontally and in depth in relation to tidal velocities, occurences of channels, etc., but such an investigation is not justified in view of the fact that the situations we have to deal with is simply whether a set is going to be a success or a complete commercial failure not profitable to cultch. Only if we were confronted continually with "borderline cases" wherein the set was year after year on the edge of being worth or not worth the cultching would it be necessary to determine the abundance of larvae with high accuracy. Practically we therefore use our knowledge from the tidal cycle studies of movements of the Larvae Mass to locate approximately the center of the mass in a bay at the stage of tide obtaining at the time of our visit and then cruise about in this general area, taking several samples, trusting that we shall hit one or more "spots" of relatively dense larvae in the surface water. Samples are taken at a depth of about 12 inches to avoid surface debris and possible effects of ~~surface~~ rainwater and of wave action. (Korringa (1940) finds that *O. edulis* larvae do not drop out of the surface layer of the water either in rough weather or in calm).

The maximum count in a set of samples is used as representative of the abundance of plankton in the Larvae Mass. It must be explained why this and not the *average* count is given in the tables and presented in the graphs. There are three reasons. The first is that we must postulate that the larvae abundance is in fact not very "jumpy" but waxes and wanes in rather smooth continuity throughout the season; and the maximum counts ~~yield~~ approximate such a theoretical curve better than do the average counts. Hence we have concluded that the maximum counts more nearly represent the true picture than an invalid average of only a few samples. The second reason is that a given piece of cultch receives the setting oysters from a *moving* body of water and therefore if properly located will draw on the maximum density available. For although we do not know what precicely happens when *Ostrea lurida* larvae begin to set (a worth-while study could be done on near-setting larvae gathered in the field and "set" in the laboratory), we may suppose from the observations of Prytherch on *O. virginica* (1934) that the situation is not like a game of musical chairs in which at a given signal, a larva has to set on anything available. Instead Prytherch finds that the larva seeks and tests the available substratum and if it does not find proper cultch may take off and swim again several times before it finally achieves attachment. Eventually of course the larva will have to set even on mud with consequent suffocation but we think it reasonable to guess that it has some time in which to test out the possibilities.

The larvae curves in the bay-year graphs therefore show maximum counts per 20 gallons obtainable by our methods of sampling. In ~~not~~ only six ~~more than three~~ cases throughout all these graphs were data omitted as being completely out of line with the trend of larvae abundance. It was considered reasonable to discount such anomalous low values (indicated by parentheses in the Tables of larvae abundance) since obviously larvae cannot have nearly disappeared from the bay on one day and reappear close to their prevailing abundance a few days later. ~~obvious discrepancies and if this judgment be questioned, then one is welcome to make his own graphs from the data of the tables, which are complete.~~

We shall not leave this topic without assessing the merits of increasing the accuracy of larvae counts and determination of the larger size groups thereof. It has already been remarked that the spawning samples are now rendered unnecessary because (1) there is no "spawning problem" that could not be solved by increased plantings of spawning stock (as should be done in South Bay, for instance) and (2) time of beginning spatfall can now be determined from the early spring Thermal Trend without reference to time of spawning. The new prediction method presented in this publication also makes it unnecessary to take series of plankton samples in Oyster Bay and North Bays as long as these bays regularly produce a commercial set anyway. Hence one may advise that the time saved be used in <u>intensive</u> larvae surveys when and only when it is a question whether the cultching will be worth the cost or not, as in Mud Bay, and South Bay in certain years. In addition, one plankton sampling in each of the bays a week before the date of predicted beginning set will check the forecast and should make possible an even closer determination of the date for optimal cultching.

If the planktonic larvae samples had been more accurate and less variable----which was impossible to achieve in the time available---- undoubtedly such "jumpiness" as appears in the bay-year graphs would have been largely smoothed out. But this is now water under the bridge.

Let it be noted however, that the abundance of the data gathered itself made possible the simplification in procedures later realized; and furthermore that studies of magnitude of spawning, larvae growth and abundance, and setting intensity establish norms which will permit the location of possible future difficulties, as they have pointed to failure of the larva to survive to setting size as the biological cause of certain spatting failures in Mud Bay. Gaining a definite picture, if not always as precise as could be desired, of the quantitative aspects of the stages in the reproductive cycle in the various bays and the normal variation thereof thus represents an indubitable value, however easily overlooked.

SETTING

An adequate treatment of spatfall requires a quantitative determination of spatting rates at frequent periods throughout the setting season as well as of the over-all effective, surviving catch which will contribute to the perpetuation of a stock of oysters on the beds. (Tables 26-39, Pp. 155-168.)

After 1943 glass plates in weighted holders and chicken-wire bags of Pacific oyster shells were not used. Bags of shell are clumsy to handle, they silt in on the bottom and, since the shells lie at random angles as well as exposed or buried within the bag, the catch per shell is extremely variable and large numbers of shell must be examined for reliable results. If used for seasonal cultch they remain in the bay long enough for disintegration of the wire to occur. Glass plates can be held in the horizontal position for optimum setting but we found that such smooth surfaces catch one half or less spat then cemented cardboard or oyster shells and are difficult and clumsy to "read" for spat-counts.

The test cultch settled on consisted of strings of a dozen market-sized, flat, upper valve or "top" shells of the Pacific oyster, Ostrea gigas. Only clean shells of as uniform size as could be selected on sight (average of 11.6 square inches each in a sample of 100 measured) were punched in the center and strung on heavy galvanized wire with the inner faces of the shells facing downward. The shell-strings were then suspended from frames placed in the oyster dikes so that the shells were horizontal and always covered with water at low tide. Shell strings were taken to and removed from the shell racks at regular intervals throughout the summer and each week during the setting season a fresh string was labeled and hung on a rack to remain until the end of the season. Two overlapping series of weekly strings removed in alternation biweekly were used during some years.

When the test cultch strings were removed from the bay they were hooked on a carrier rack in such a way as to keep the shells from jostling against each other and scrapping off spat. At the laboratory the shells, now dry, were examined one by one on the smooth under surface only and the spat counted under a binocular dissecting microscope. A microscope is essential for distinguishing between mussel or barnacle or bryozoa set and oyster spat. With good illumination the bright, white, inner surface of the shell results in even the smallest spat standing out in an altogether satisfactory manner and one can therefore determine spatfall rates promptly without having to wait and grow the spat to larger size as is necessary with the cemented glass plate test cultch used in Holland. When the spatting was heavy, guide lines were drawn on the shells to facilitate counting the spat.

Two strings of 12 cultch shells each were put out together as "weekly strings" in each bay. Usually all 24 shells were examined and the average spat per shell determined. The number of days the shell was in the water was also considered in calculating the average number of spat per 100 shell faces per day which we call the Setting Index, a measure of the rate of spatfall so formulated as to exclude "unintuitable" decimals.

The cultch string pairs therefore constituted duplicate samples, and that they agreed very closely is a sign of the reliability of the method. Thus in Oyster Bay during 1944, for example, duplicate samples, gave the following values for successive periods throughout the setting season.

1	176	1023	838	1961	978	2107	556	527	378	622	238	1795	50	37	7	9	5
2	195	815	704	1326	764	2570	497	552	350	661	137	1322	59	37	9	6	4

The uniformity of results shown amply answers the [redacted] objection that shell-strings are altogether unsatisfactory because of their irregularity in size and shape.

Since there was time on a given low tide to visit only one cultching station in each of the bays, the question arises whether the spatting at the site chosen was typical of the whole bay. We located our test cultch racks as closely as possible to the center of the area in each bay which is cultched commercially, and arranged that they were not placed near dike walls, spillways or other atypical locations. The same dike stations were kept from year to year with insignificant alteration of position.

In Oyster Bay the test cultch was on the East side of Dike 5 of the Olympia Oyster Company. During the 1946 season four additional dikes at Burns Point (see Fig. 1) were cultched. Setting data at these five different locations is compared in Table 40 .

(INSERT Table 40) (P. 66)

The agreement between these five stations is greater than one would have perhaps expected although it is to be noted that Dike 5 and Burns Point are about the same distance up-bay. Nevertheless this is the heart of the cultching area and Burns Point is adjacent to the sink in which floating cultch is moored. It is therefore indicated that the setting data is representative of the bay and that it is the most accurate

TABLE 40: ~~Seasonal~~ Setting Indices during 1946 at four Burns Point dike stations in Oyster Bay compared with Dike 5 station

Setting Index at Mid-dates

Burns Point Dike	June 29	July 6	July 12-13	July 19-20	July 27	Aug. 4	Aug. 11-12	Aug. 17-18	Aug. 24-25	Sep. 4-5
No. 1	620	1718	703	263	107	529	1750	1440	245	181
No. 2	1164	4004	1718	398	206	637	1955	2745	620	454
No. 3	1070	2202	1092	399	166	602	2098	1507	616	147
No. 4	813	3575	1027	686	221	522	1643	1918	836	204
Average of all 4	917	2875	1135	436	176	572	1861	1901	580	246
Comparable setting at Dike 5	800	2700	600	200	150	400	1000	2000	800	--

of all our groups of data.

Seasonal strings were taken up in the fall and spat counted on both sides of the shells. One could therefore tell how much set accumulated on cultch put into the bay on or near the date the test string itself was set out. The spat were measured and the larger spat from the first peak of spatfall usually separated from the small spat from secondary waves of spatting. A large proportion of the latter were invariably found to be dead and only the large spat are tabulated in the tables of seasonal cultch as being the effective, surviving catch of the season (see P. 87). (Tables 41-46, Pp. 169-174.)

LARVAE SIZE AND ABUNDANCE

It is of course quite simple and possibly instructive to determine the size distribution of Olympia oyster larvae obtained in the plankton samples. In this connection one wants to find the answers to several questions:

1) Is the Larva Mass well-mixed as to size groups, or do certain regions and samples show different proportions of sizes?

2) Is there a stratification of larvae sizes such that, possibly, the larger and presumably heavier larvae tend to layer in a deeper level of the water?

3) Are there definite modes in the range of sizes, and can such size groups be followed through to setting?

4) To what extent can intensity of spatfall be forecast from abundance of growing plankton larvae?

These questions will now be considered to the extent of our *present* information.

1) HORIZONTAL DISTRIBUTION OF LARVAE SIZE GROUPS

One would like to know whether a plankton sample at one-foot depth taken anywhere in the bay on the same day will yield the same proportions of size groups. Again there was not sufficient time for a thorough survey of the problem and we had to compromise on a quick review of certain samples for the practical purpose of testing whether our assumption of uniformity in distribution was entirely erroneous. The samples from a horizontal section of Oyster Bay during a cycle of tides on 8 August 1944 accordingly were looked over by the staff member who customarily measured the oyster larvae in our routine. Of a total of 33 samples, 20 were designated as having a "high" percentage of large larvae, 2 as having a "good percentage", 2 with a "fair" percentage, one as having "very few" large larvae, and 8 were at the periphery of the Larvae Mass and so contained too few total larvae for significant comment regarding size distribution. Hence 80% of the samples which contained considerable numbers of larvae up to 640 per 20 gallons showed an obviously high percentage of mature larvae and 88% were reported as being "high" or "good" percentage of large forms. We therefore conclude that the mixing effect of daily tidal currents is accomplished and that variations in size distribution of larvae from place to place in the bay is a minor consideration.

2) DISTRIBUTION IN DEPTH OF LARVAE SIZE GROUPS

Since studies of the size distributions of larvae with reference to depth of water should be done when the reproductive season is in full swing and there are abundant oyster larvae, we have been unable yet to make adequate investigations on this point because at such a favorable time we have always been too occupied with following the set in addition to sampling the plankton. We shall however report what indications we have even though they are not conclusive, having in mind that they may give us probabilities if not certainties and guide the course of further studies.

On September 5th, 1944, at the end of the season when final traces of larvae in the water were spatting out in the last surge of spatfall, a minor study of size distribution in relation to depth of water was made in Oyster Bay. Water samples were obtained by hose and pump and filtered through a plankton net in the customary manner. This was done at about two hours after low water on a 11.2 foot tide, therefore when the larvae were subjected to considerable flooding tide current. The information obtained was as follows:

(INSERT Table 47)

TABLE 47: SIZE DISTRIBUTION IN RELATION TO DEPTH OF SAMPLE, OYSTER BAY, September 5, 1944

Diameter of larvae in microns	STATION 8 0 ft.	STATION 8 3 ft.	STATION 8 6 ft.	STATION 9 0 ft.	STATION 9 2 ft.	STATION 9 3 ft.	STATION 9 6 ft.	STATION 9 11 ft.*
"small"								
168			4					
192		20						
204		12	12	45**			34**	
216			4					
228			8					
240			20					
"large"								
252						24	34**	24**
264	8		8	4**		12		
288			8					
312			4					
Total larvae per 20 gallons	8	32	68	8	0	36	68	24

* One foot off bottom.

** In these samples the larvae were simply grouped as under or over 240 microns in diameter.

These data when coupled with the facts (1) that we do find large larvae up to setting size in our usual 1-foot plankton samples and (2) that we find good set on floating cultch, show at least that there is no exclusive stratification of larvae sizes. We have therefore acted on the probability that the different size groups of larvae are relatively evenly distributed where they occur.

3) THE POSSIBILITY OF FOLLOWING LARVAE GROUPS THROUGH THEIR PELAGIC LIFE TO SETTING.

On this subject all that needs to be said is that since the spawning period of the Olympia oyster is usually so protracted, larvae of all sizes are found in the plankton throughout the season except at the beginning and at the end. Hence one cannot ~~clearly~~ easily follow the outcome of a single spawning as is possible with the Japanese oyster and Ostrea virginica which have sharp spawning peaks. The extent to which one can is indicated in Figures 66-70.

4) RELATIONSHIP OF ABUNDANCE OF LARVAE IN GENERAL AND OF LARGE LARVAE IN PARTICULAR TO INTENSITY OF SPATFALL.

The graphs of the bay-years herein presented show the curves of the abundance of large larvae and of total larvae per 20 gallon sample of bay water. This is the data we have to go on in predicting intensity of actual setting which is also shown in these graphs. (The excessive proportions of large larvae recorded for 1949, and 1950 may be regarded with some scepticism as possibly a trend in the observer to include smaller and smaller larvae in his "advanced umbo and near-setting size" group.)

Abundance of total larvae and therefore also of large larvae is of course correlated with the number of spawning oysters in a bay. Thus Oyster Bay has the most extensive beds and the greatest abundance of larvae, and Mud Bay, North Bay and South Bay follow in that order. South Bay apparently does not produce enough larvae for a gratifying set. (We omit consideration of Oakland Bay because of the ~~obvious~~ abnormal circumstances in this industrial area). Correspondingly, Oyster Bay leads with the highest average intensity of spatfall. North Bay can however apparently produce surprisingly high Setting Index maxima with a relatively low concentration of larvae (vide 1945 and 1948). Very roughly speaking, in all the other bays <u>the area under the first setting curve is equal to the area under the first curve of larvae abundance</u>, as plotted on the coordinates chosen in the bay-year graphs. This is indeed approximate, but allows one to get some idea of the extent of spatfall to be expected before it occurs. A further point is that larvae which have attained three-fourths of their growth or more toward setting size must reach an abundance of about 100 (or greater) per 20 gallons before substantial setting can begin. The greater the abundance of large larvae above this figure the heavier the set.

DISTRIBUTION OF LARVAE DURING A TIDE

In order to obtain accurate and representative plankton samples it is necessary to know the effect of the movement of the tides on distribution of the pelagic larvae. To this end a number of surveys were made in which one either sampled in one spot continuously, cruised rapidly up and down the bay taking samples during a run of tides; or stationed a man sampling from a boat at each of several locations throughout the length of the bay. The results proved very interesting from several standpoints as previously noted (P. 29) and will now be discussed in detail.

1) Tidal Cycle Plankton Study of Oyster Bay, Station No. 9, Aug. 8, 1944.

On this date our boat was anchored at Station 9 for 13 hours and plankton samples taken at 1 foot depth every 30 minutes. In addition a few samples were taken by skiff at Station 8. All samples were 20 gallons in volume. The field data is given in Table 48 of the Appendix (P.175).

The findings are summarized graphically in Figure 45 . The Oyster larvae curve was smoothed by a moving average of threes. Height of the tide throughout the period is calculated as for Burns Point, which is just across the bay from Station 9. In addition, a curve of tidal current velocities is supplied. This was calculated from U. S. Coast & Geodetic Survey Tide Tables as for Dofflemyer Point at the mouth of Budd Inlet. As such they are only suggestive and do not ~~necessarily~~ represent the actual current velocities at the time up in Oyster Bay, but they are the only data of this type which we have available.

The wide range in plankton larvae abundance possible at this one station throughout a tide is apparent, individual samples ranging from 4 to 772 larvae per 20 gallons.

On the basis of this one study it could not be decided with certainty whether the larvae move up and down the bay or merely come to the surface layer sampled, due to some action of tidal current; for the peaks of abundance at Station 9 correspond both to mid-tide stages and to maxima in current velocity. But since oyster larvae are purely pelagic it is reasonable to suppose that they move up and down the bay with the tide. A further point is that if tidal currents merely brought them to the surface, then the greater current velocity at ebbing should be expected to yield the greater larvae abundance, yet the peak at maximum flooding is far higher. We need not speculate however because further surveys to be described amply demonstrate that the Larvae Mass moves up and down the bay with the tide.

Starting at early morning high tide, then, the Larvae Mass is up-bay from Station 9 (Fig. 47). As the tide ebbs it comes past the station in an initial wave of larvae abundance. At low tide the mass is down-bay. As flood begins the mass then moves back to Station 9 and then beyond.

From this study it is clear that at Station 9 in Oyster Bay the samples should be taken at about 3 1/2 hours before high tide to give a measure of the maximum density of the Larvae Mass.

We now have to explain why, as the Mass moves *down* the bay past Station 9 at ebbing, its density is less than when it returns *up* the bay on the flood. A certain observation may here be relevant, namely, that when *Ostrea lurida* larvae are kept in an aquarium in the laboratory with no current they invariably collect and remain near the surface. Hence they appear to be negatively geotropic, always tending to swim upwards in the water and to keep themselves at the surface by continuous action of the velar cilia. If this is true in the natural habitat, then our Larvae Mass may be viewed as generally tending to lie at or near the surface of the bay.

Aggitation of the water by tidal currents would result in the

mixing

mixing of the surface water with deeper layers, with high current velocities at such a rate that the larvae had not time or were powerless to come to the surface. The hypothesis is therefore offered that the reason the larvae abundance is less at mid-ebb than at mid-flood is that at the former stage of the tide the current velocity with its churning and mixing action is greatest and drives part of the larvae out of the surface layer. The reason the tide current is greater on ebbing than on flooding is of course that the run-out of water confines it more to the center-line of the bay and hence has the same effect as a constriction in a pipe.

It follows that to obtain a measure of the maximum density of the Larvae Mass samples should not only be taken at the time mentioned but also in an area near Station 9 away from channels and having the minimum velocity obtainable at mid-flood tide.

2) Study of Oyster Bay, Station No. 9A July 9, 1945

Station 9A is off Burns Point. The data obtained in the surveys are tabulated in Table 49 P. 176 , and graphically set forth in Figure 46 .

(INSERT Fig. 46.)

The larvae curve again shows a general rise around mid-flood tide. Differences from the cycle previously described are (1) that a residue of larvae are still found at slack low tide and (2) that the peak of maximum abundance is bimodal. Thus within a half hour, from 5:30 to 6:00 PM we obtained a range of 4000 to 6400 larvae.

Now from the contour of the bay at Burns Point as well as from the observation of oystermen we may say that it is probable that there is a back-eddy or "whirlpool" at station 9A which could account for the differences from the results at Station 9 across the bay (see also Table 23 , p. 152).

We conclude first, that the general picture of the movement of a Larvae Mass back and forth past an up-bay sampling station is confirmed, and second, that other factors, presumably of the nature of back-eddies make Station 9A somewhat unsatisfactory for sampling as compared with our regular Station 9.

3) <u>Horizontal Section Down Oyster Bay, July 24, 1945.</u>

On this date we took our boat up and down the bay at a time from mid-ebb to low tide, sampling at the stations designated in Fig. 47 .

(INSERT Fig. 47)

Insert

Fig. 47

The stations ran all the way from the mouth of Oyster Bay to Station 9. Changes in the larvae counts (1 ft. samples, just below the surface) are shown in Figure 48 .

(INSERT Fig. 48)

Each point in the curves indicates one sample. It is clear that the Larvae Mass ebbed down the bay until low slack tide, but went no farther than off the Patterson grounds on this -2.1 foot run-out. Hence at a very low tide the mass of larvae still do not move more than half way down the bay and so are conserved within this body of water. Combining this survey with others, we may say that the Larvae Mass moves back and forth from above Station 9 to just around Deepwater Point.

4) Tidal Cycle, Oyster Bay, Aug. 7, 1945.

Four stations were sampled regularly throughout a tide; Stations 9, 9A off Burns Point, Station 8, and Station 8A ~~off Bowman's grounds~~ about half way between Stations 8 and 9 (Fig. 47). The data are represented in Table 50 P.177 , and, graphically, in Figure 49 .

(INSERT Fig. 49)

Studying Figure 49 from left to right we note the following:

a) At low tide the larvae are not in the region of these stations but are down-bay from them, as shown in the studies above.

b) Maximum larvae counts were again obtained at about 3 hours before high tide.

c) <u>All</u> stations showed maxima at this stage of the tide. For this there is no apparent explanation, but the general unevenness of the Station 9 curve may possibly indicate a curious serpentine swirling of the Larvae Mass on this tide.

d) Mid-bay stations are lowest at high tide and low tide, thus showing the tidal movement of the mass passed them.

e) Highest counts were obtained at just past mid-ebb tide. This is unusual as compared with the other cycles and may be explained on the basis that the low tide to come had a run-out to only 5.9 feet (ie. was a "high" low-tide) so the ebbing tidal current velocity could not have been strong and the larvae were not churned out of the surface layer.

During this cycle Tollefson operated a current meter at Station 9 in order to determine actual velocities of warer movement during the flooding tide. The curve of tidal current velocity is shown ~~in~~ (Figure 49), ~~above,~~ smoothed by a moving average of threes. Note that the maximum current at Station 9 during flooding occurs soon after slack water. It would be interesting to extend such studies to ebbing tides and to check whether rapid currents do in fact mix surface with deeper layers and so dilute the larvae by spreading them vertically.

The results of this survey suggest that a location Like Station 8A ~~off the Bowman grounds~~ may be a more satisfactory sampling station than our usual Station 9, possibly because the location is farther away from channels in which the tide runs swiftly. At the former locus the larvae counts showed a beautifully uniform behavior, while the "jumpyness" of counts at Station

9, if typical, is not conducive to reliable results in ordinary sampling. It is also to be noted that Station 9A at no time gave an adequate indication of the maximum density of the Larvae Mass and so is indicated as unsatisfactory. Modification of sampling procedures accordingly might result in a better picture in the curves of larvae abundance. in the future.

5) Tidal Cycle and Horizontal Section in Oyster Bay, Aug. 23, 1945.

The results of this survey are given in ~~Table and~~ Figure 50 . Stations were the same as shown in Figure 47 , and were sampled at 1 foot depth.

(INSERT Fig. 50

It is fairly well indicated in this survey that the Larvae Mass moves down the bay with ebbing tide, though the picture is somewhat irregular, possibly due to churning effect of the swifter ebb-tide currents. But is is obvious that the mass moves up the bay on the flood, maxima following from one station to another progressively up the bay. Highest count was obtained at Station 9 at 2 hours and 20 minutes before high tide. Again we see that this station should be sampled at near mid-flood to give an adequate measure of the maximum density of the Larvae Mass.

6) Tidal Cycle Study of Oyster Bay, July 1, 1946.

In this study by Glud, Tollefson and Lindsay, we have a fine series of samples during a big tidal run-out in Oyster Bay, extending in location all the way from the mouth of the bay up to its highest reaches above Station 9. The stations are designated in Fig. 51 .

(INSERT Fig. 51)

The data are assembled in Table 51 , P. 178, and set out pictorially in Fig. 52 . Subsurface samples, usually at 6 foot depth, are available for down-bay stations.

(INSERT Fig. 52)

This survey locates the Larvae Mass as moving between Station B and Station I during the course of a tide. At high tide it appears that the center of the mass is at Station C, just above Station 9, while at low tide it has drifted down to between Station H and I, off the Patterson grounds. Maximum larvae count was obtained in samples at Station C, at 1 3/4 hours before high tide and larvae abundance at this location was possibly still increasing at the time samples were discontinued. As before, this flood maximum was higher than any maximum during ebb tide. At Station 9 (D) maximum counts were obtained at 5:37 PM or 3 hours before high tide, as also noted from the other surveys previously discussed.

Although we have no complete series of sub-surface samples for all stations, if the trend of those taken at Stations F and G are indicative, then the larvae of up-bay stations at mid-and high-tide are concentrated near the surface. At down-bay stations at low tide, however, the mass of the larvae is not to be found at the surface but deeper. This finding seems to contradict our hypothesis that during the slack tide currents the larvae are found predominantly at the surface layers of water, for at low-slack tide they are definately not to be found in abundance at the surface down-bay. Yet it is still possible that the mixing effect of the ebb tide current may persist during low-slack water. Only further studies can clear up this point and explain why the larvae are sub-surface at low tide down-bay if this is in fact always the case.

7) Mud Bay Tidal Cycle, July 30, 1950.

On this date Lindsay, McMillin, Wicksten and Sayce surveyed the larvae picture in Mud Bay during a fair tidal run-out and return. A good stock of larvae of straight-hinged to near-setting size was present in the bay at the time. Samples were taken periodically at the stations shown in Fig. 53 , and Table, 52 P. 179 , and Fig. 54 are to be consulted for the findings.

(INSERT Fig. 53
Fig. 54)

The mass of the larvae were found at up-bay stations at high tide and disappeared from there at low tide. Maximum count and a true indication of the abundance of larvae was obtained only at Station A off Ellison's plant on the west or channel side of the bay at full high tide. Hence it is clear on the basis of present surveys that field trips should be planned to sample Oyster Bay at Station 8A 3 hours before high tide and at Mud Bay off Ellison's at high tide.

At low tide the mass of the larvae were found in no surface samples at any of the stations. Considering the Oyster Bay cycle just detailed (Fig. 52), one may guess that in Mud Bay also the larvae are for some reason yet unknown below the surface layer at low tide. A further investigation on this point would be worth while, to determine the location of the Larva Mass throughout the whole excursion of the tide.

Of particular importance is the fact that in this bay as in Oyster Bay, the larvae are retained within the upper extent of the inlet. Since the samples contained a fair portion of near-setting size larvae, this confinement of the mass is seen to apply also to older larvae which have been drifting about for 20 to 30 days. Thus the maximum sample (A-3 at 7:00 PM) had 2% setting size larvae as also did D-1 at 3:05 PM. Therefore we may discard the hypothesis once advanced that set failures in Mud Bay are due to "leakage" of larvae out of the bay on low low-tide run-outs. This suggestion was made on the basis that Mud Bay has a smaller water volume than Oyster Bay, in the proportion roughly of 209 to 337, and so might be expected to flush out more extensively. Now we must look for reasons for the disappearance of the older larvae during "off years" in Mud Bay, possibly in the direction of unfavorable salinity changes as discussed previously (P. 114) which gradually deteriorate the larvae, finally effecting their demise after they are half grown.

8) <u>Tidal Cycle of Bottom Samples, North Bay, June 6, 1944</u>.

North Bay has presented a special problem in that usual procedures sometimes failed to show an abundance of larvae commensurate with the high rate of spatfall which later appeared. We have data on a tidal cycle for this bay taken at from just before a low low-tide to high tide. Unlike the other cycles, this was an early-season survey, taken before the larvae population had yet attained its maximum abundance (see the bay-year graph of Fig. 11). Sampling stations are shown in Fig. 55A . and findings are given in Fig. 55.

(INSERT FIG. 55)

In this bay as in others it is seen that the Larvae Mass moves up the bay at flood tide and presumably drifts to somewhere below Sunburn Point with the ebbing tide. Maximum count was obtained off Victor at about 1 1/2 hours before high tide. and greatest abundance at Station 12 was found an hour before high tide. The Larvae Mass enters North Bay proper from Case Inlet about 4 hours before high tide, and there is not much difference between Victor, Allyn and Station 12 in sampling except that the latter shows consistently higher counts. It is indicated that at high tide the mass of larvae is above the power-line towers in the region of the Sargent oyster grounds.

Now this survey contained only bottom samples, of varying depth depending on the stage of tide. It is unfortunate that we have no comparable surface samples at one foot depth on this date. Counts of North Bay surface samples on dates Before and after June 6th were as follows:

	June 2	June 12
Station 12	348	16, 36 (two samples)
Station 11	164	360
Station 10	568	336

We shall therefore consider 400 larvae per 20-gallon sample as being a reasonable estimate of surface counts on the date of the tidal cycle.

Sampling was poor from the start (1 1/2 hours before low tide) until 2:30 PM (4 hours before high tide) after which the larvae abundance encountered was near the estimated surface sample value. But at their maxima, the bottom samples exceeded by more than twice the probable count at the surface.

In explanation of this important indication from the data available we return again to an interesting laboratory observation namely, that when

O. lurida larvae are placed in an aquarium and a layer of fresh water placed on top the sea-water, the larvae rise to and remain at the interface but do not enter the fresh water layer and are not seriously affected by its presemae. This of course duplicates in miniature the Norwegian oyster "pollen" in which oyster-seed production at low air temperatures is made possible by the thermal insulation of confined ponds with a surface layer of fresh water.

Now in North Bay proper, at the head of Case Inlet, we have a relatively small area into which empty two large streams, one below (Sherwood Creek) and one above (Coulter Creek) the oyster grounds. It is therefore possible that a significant sheet of fresh water may be prevalent in this bay and indeed certain of our chlorinity tests seem to bear this out. If so, then the normal negative geotropism of the larvae may be counteracted by their avoidance of fresher water with the result that they remain most abundant at layers below the surface.

All this is conjecture to be sure, and further studies will be needed to clarify the larvae picture in North Bay. But a practical result has been gained, namely, the prescription that for adequate sampling in this bay the stations should be visited at about one hour before high tide and sub-surface samples taken.

The concept of a moving Larvae Mass which resulted from the tidal cycle surveys has been our guide in plankton studies. At first it was thought that one might apply a correction-factor by which larvae counts at a given location at any stage of tide might be converted to the "maximum available larvae", but we soon saw that this could not be done without very complete series of plankton-tidal cycle studies so that we pursued another alternative. We have been careful to sample when and where the pelagic larvae would be found in maximum abundance. It remains only to discuss why we have employed maximum larvae counts rather than averages as the ~~proper~~ best measure of the effective larval population.

If the larvae were spottily distributed throughout the bay and if they set all at once, at the firing of a gun so to speak, then and only then would average larval counts be the best measure of magnitude of spatfall to be expected. Neither of these assumptions are fulfilled. Instead, the larvae form a whole mass which moves together, is densest centrally and fades out at the periphery; while setting draws on this reserve of potential oysters over a pretracted period of spatfall. Theoretically the population of the entire mass could be determined but this is not practicable in the time available on field trips. Hence if one is restricted to taking a few samples on any day there are only 2 end-points attainable: zero count at the periphery of the Larvae Mass or maximum counts near its center. It is clear that one has to choose the latter and that maximum samples are the best indices of the potential setting population available in a bay. In practice several samples are always taken and the maximum taken as the index of the larvae population on a given date. Larval curves in the bay-year graphs are all based on maximum larvae counts obtained.

IMPORTANCE OF THE EARLY SET AND INSIGNIFICANCE OF THE LATER

The Setting Index or rate of spatfall on fresh cultch from week to week is one thing and the spat accumulated throughout the season on cultch put out on a certain date is another. Still another consideration, and of course the most important one from the practical viewpoint, is how much of the accumulated spat survives through the summer and winter and therefore effectively adds to the recruitment of new seed oysters.

It is apparently the experience of the oystermen that the first wave of setting in the season is the "good" one" and that failure to catch this set cannot be made up during secondary or later surges of spatfall. This conclusion is amply confirmed and quantitatively evaluated by our studies in Oyster Bay.

Let us begin by refering to our data on seasonal cultch strings put out in Dike 5, Oyster Bay, on successive dates in the summer of 1946. All strings were brought into the Laboratory in the fall and large and xxx small spat noted and tabulated as follows:

Date Cultch string put into bay	No. Live spat per shell when string removed	
	Large: 8mm diam. & over	Small: Under 8 mm diameter
June 18	135	63
25	115	62
July 2	93	85
9	0	158
15	3	209
23	0	210
30	0	243
Aug. 6	0	242
13	0	210
20	0	77
28	0	92

By refering to the graphical presentation of this reproductive season (Fig. 19), it is clear that the earliest cultch, of June 18th, caught the maximum of spat which had time to grow to about one centimeter in diameter by the end of the season; while the cultch strings of July 30th and August 6th, put in just as the second wave of setting was beginning, caught the maximum number of spat which, because of their tardy setting, did not have time to achieve considerable growth by the end of the season. During this same year (1946) Tollefson made a comprehensive investigation of the matter which is now summarized.

On 9 different dates throught the setting season three sets of 12-shell cultch strings were put out in each of 4 adjacent dikes at Burns Point in Oyster Bay. One set was taken up in early fall on September 11th, another was removed from the dikes on January 6th, and the third was allowed to remain out until April 10th or early Spring of the year following the catch. Surviving spat on the shells was counted and averaged for each string. The results are presented in Tables 53 through 55 and depicted in Figure 56 which also shows the week to week average spatfall in the four dikes during the season (from Table 40, P. 66).

(INSERT Fig. 56)

Spat counts at Burns Point ran somewhat lower than in Dike 5, as noted above, but the same two marked peaks of spatting are evident in the strings taken out of the water on Sept. 11th. At this time most all spat on the cultch put out from June 25 to July 23rd was large while strings set out after that date showed only small spat.

The graphical summary of the results of this study is most instructive. It shows very dramatically that only cultch which was put out in time to catch the first peak of spatfall came through the winter with a substantial surviving set. Although later cultch caught great numbers of spat during a second wave of spatting, the mortality of this spat was around 93% by the following spring. It is also clear that almost all the spat which survived to early January continued to live until April and probably would have continued to survive from then on with what might be called normal mortality, And this was the case even though the month of January in 1947 was unusually cold, the average air temperature at Olympia falling 3.6°F below normal. (Comparison with seasonal floating strings, Table 2, P. 33, is not apropos since there is an unusual fouling of such cultch during the later months of the summer which is not found in dike cultching.)

The critical time for spat mortality therefore fell somewhere between early September and early January and the spats most affected were those caught later in the season. We do not know the reason for this high mortality of young spat but it is easy to surmize, for it is especially clear in the culture of the Japanese, the Eastern and the European flat oyster that mature larvae are very susceptable to cold water, so it is reasonable to suspect that the young spat share something of this sensitivity and are often killed by Fall weather if they have just recently set. With regard to the larvae and the initial spatting ~~of our~~ ~~early~~ in the season, we find that water temperatures in the bays of lower Puget Sound are always favorable. It would be interesting to test ~~this~~ the hypothesis here offered regarding demise of late-caught sp[at] by comparing with appropriate controls the survival of late summer spat kept through fall and winter at summer water temperature in laboratory tanks.

Hence at Burns Point in 1946 shell put out on June 25, before the first setting peak, carried on the following spring a catch of about 75 large spat per shell, but any cultch set out after the first setting peak bore only about 10 spat. These results therefore emphasize the importance of properly timing the cultching operations and the necessity for setting out cultch just at the beginning of the first spatfall of the season. It is the catch of surviving seed oysters that matters, and the sharp drop in the survival curve with lateness of summer set shows that it is as important to cultch early enough as it is not to cultch too early.

So clear-cut are the results from this study of 1946 spat survival that one believes they will bear generalization, especially since experienced oystermen themselves are of the opinion that late-caught spat are of little importance and that considerable "slippage" of late spat occurs. If so, our results show that the Olympia oyster in some of our bays "over-produces" larvae late in the summer which can have no chance of surviving as spat and that it is perhaps never worth while to catch the later spatfalls. Since Hopkins did not take into consideration the survival of spat, he was led to the erroneous assumption that his demonstration of important secondary setting peaks besides the initial early-summer spatfall provided oystermen with additional opportunities for getting seed oysters. Thus he says (1937, P. 499): "of practical importance is the very prolific late setting period, which follows the first on the next third and fourth spring tide periods; for oyster growers are able to plant catch at this time, also, therby improving their chance of obtaining a satisfactory catch of seeds". Our study makes this conclusion highly questionable. [illegible]

The larger early-caught spat on seasonal test cultch are usually definitely set off from spat from later waves of setting, as one would expect. Hence only the larger seed oysters are included in the counts for the seasonal strings given in the bay-year graphs. A review of these seasonal cultch strings for all years in which the information in available confirms the conclusion that the beginning of the first wave of spatfall is the optimum time for cultching. Hence reference to the bay-year graphs shows the following:

SEASON OF 1944

OYSTER BAY Best catch on cultch put out half-way toward first setting peak; seasonal catch drops off soon after setting peak.

MUD BAY Poor set. Best catch on shell put out at beginning of set, decreasing gradually thereafter.

NORTH BAY Best catch from beginning significant set to first setting peak, decreasing rapidly thereafter.

SOUTH BAY Poor catch on shell put out one week before beginning set; maximum catch on cultch put out at beginning of set, decreasing gradually thereafter.

OAKLAND BAY Very long, flat setting curve; best set on cultch put out after Setting Index over 50, decreasing rapidly thereafter.

1945

OYSTER BAY Best catch on shell put out at beginning of set, decreasing thereafter.

MUD BAY Best catch on cultch put out at first sign of set, decreasing to low at first setting peak.

NORTH BAY Precipitious setting peak; best catch at beginning set and first setting peak.

SOUTH BAY Best catch on shell put out at first sign of set, decreasing rapidly thereafter.

OAKLAND BAY Poor set; best catch on shell laid out just before setting peak.

1946

OYSTER BAY Best catch at beginning set, decreasing gradually to time of first setting peak and falling off rapidly thereafter.

MUD BAY Poor set; best catch on shell put out one week before beginning set.

NORTH BAY Best set on cultch put out at beginning set, decreasing rapidly after first setting peak.

SOUTH BAY Poor set; best catch on cultch put out a week before set begins, decreasing gradually thereafter.

1948

MUD BAY Best catch on shell put out at beginning set, (S.I. = 500); only half as much caught on shell placed out 12 days earlier.

SOUTH BAY (Data inadequate, but indicate major spatfall occured after our records ceased.)

1950

OYSTER BAY Best catch at just before first setting peak, falling off very rapidly thereafter; poor catch on cultch put out 6 days before setting peak.

MUD BAY Best catch on cultch placed at beginning of set, decreasing rapidly from first setting peak on; cultch placed 7 days before beginning significant spatfall caught only 65% of best catch.

NORTH BAY Best catch on cultch placed out at beginning set, decreasing gradually to setting peak and falling off very rapidly thereafter.

SOUTH BAY (Spatfall data inadequate.)

From this survey we can conclude that in all years the optimum time for cultching is not at the crest of a wave of setting but before, at the beginning of significant spatfall which is rising towards the first setting peak. Hence maximum surviving catch is assured by cultching at the time determined by the prediction method herein developed which establishes the date when the spatfall may be expected to be rising to its initial, early-summer peak.

HOW TIME OF OYSTER SETS CAN BE PREDICTED*

One of the most interesting and valuable results of these investigations has been the revelation that by following the air temperatures during the first months of the year it is possible by the end of April to foretell the date in June or July on which cultch should be in place for maximum catch of oyster seed. How this method of set-predictions was developed will now be discussed in detail.

We begin with the fact that the rate of chemical reations and therefore of biological processes is greatly influenced by temperature, usually rising rapidly with and in direct relation to increasing temperatures. This means that at warmer water temperatures the oysters should spawn earlier in the year and the period of pelagic larval life be run through in briefer course, while at lower temperature the whole reproductive cycle will be correspondingly retarded. The clue to timing the set must therefore lie in determining the quantitative relationships between temperature and the rate of the aggregate of biological processes which result in setting larvae. Since oysters are cold-blooded animals, the body temperature at all stages in their life-history is that of the surrounding medium and the rate of their internal processes is determined accordingly.

To discover a relationship between the last stage of the reproductive cycle (the beginning of spatfall) and temperature we need to know precisely the dates at which setting began in the various bays over several

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*This method of predicting sets was announced in the Puget Sound Oyster Bulletin of May 24, 1951 and its anticipations for that year were fully confirmed.

years as well as the effective water temperatures experienced by the spawning oyster ~~and the larvae~~ during those years. Our studies with test cultch put out and examined twice weekly have given us the former information, but we lack complete data on water temperatures. This shortcoming however turns out to have been an advantage in the end since, having to rely on air temperature reports of the U. S. Weather Bureau for certain years, it was found that they were adequate to our needs and so there was opened the possibility of circumventing the tedious and expensive gathering of water temperature data.

Our next step is therefore to discuss the relationship between air temperature and water temperature in the oyster bays. For a year and a half thermographs were kept operating in Oyster Bay, North Bay and Oakland Bay with the sensitive bulb at the level of the oysters themselves thereby giving continuous records of the temperatures experienced by spawning oyster stock in the dikes. In addition, a considerable series of determinations of water temperatures at various depths was made by boat trips to all the bays. Data on dike and open-water temperatures for several years and bays are also available in Hopkins' report (1937).

When the water temperature data which we have is compared with monthly air temperature at Olympia or at Grapeview, Washington, the outstanding fact emerges that average water and air temperatures run very close together throughout most of the year. This relationship is shown graphically in Figures 57,58 and 59 .

Granting the close correspondence between water temperatures and air temperatures, we now turn our attention to the differences. For the years figured, in which we have adequate records, the major differences appear to be as follows:

1) Average dike water temperatures follow along generally a degree or two above average air temperatures during spring and fall.

2) Open water temperatures are 4 to 5 degrees cooler than dike water temperatures in the mid-summer since they do not reflect the effect of heating confined water during exposure by low daylight tides as do the dike water temperatures, (Fig. 57).

(INSERT FIGS. 57
58
59
59a)

3) During the cold winter months (December through February) average water temperatures are considerably higher than air temperatures. This is doubtless explained by the high specific heat of water which acts as a brake against extremes of temperature.

4) For the same reason, open water temperatures are somewhat lower than air temperatures during the warmest months of the year. (Fig. 57)

5) Warm or cold early spring air temperatures are directly reflected in correspondingly warm or ~~maid~~ cooler water temperatures (Figs. 58 / 59 & 59a).

The conclusion ~~that we drew~~ drawn from the relation of air to water temperatures is simple: namely, that since water temperatures follow air temperatures the latter may in themselves give us all we need for the practical purpose of predicting the proper time to put out cultch for the greatest effective seasonal catch.

The next question is, How many months of early spring air temperatures shall we take into consideration as relevant to guiding the prediction of set? Here we are guided by three considerations, the first of which is that we must not have to rely on air temperature data of the later months of May, June and July if we want to be able to predict spatting-time well in advance. The second is that we shall use the minimum number of months record which gives us what we need; and the third is that we can expect that gonadal ripening requires several months to bring the sex products to fruition, probably beginning in January if water temperatures are sufficiently above freezing. Although we have yet no study of gonadal ripening in relation to temperature in any oysters with which to check this supposition, we do know that winter oysters put immediately into warm-water aquaria require a whole month at early summer temperature before they begin to spawn, and it is therefore reasonable to suppose that in the bays gametogenesis extends from a stand-still in our coldest month January through February and March and into April.

Now the effective temperature is the measured temperature multiplied by the number of days it acts upon the oysters (time-caloric factor). This means that we cannot jump from January temperatures to April temperatures and take the average as acting over the entire period. Instead we should break down the period into successive increments of temperature multiplied by the number of days during which it acted on the oysters. We will thus give due weight to the effective temperature of each successive month by treating monthly averages as separate factors in obtaining a cumulative characterization of the over-all trend of early spring temperatures.

For this purpose we can choose almost any accurate index of the absolute or of the relative warmth of coolness of any given month. In practice it is simplest to use the deviations from normal of the average monthly air temperatures as calculated and published by the U. S. Weather Bureau. Records from the weather bureau station at Olympia (Priest Point park, at 69 feet elevation, on Budd Inlet) should be and are the most relevant for events in Oyster Bay, Mud Bay, and South Bay; while the data of Grapeview (20 feet elevation above mean low water on Case Inlet) are most appropriate for corresponding events in North Bay (see Fig. 1 for location of these stations).

To obtain an index of the cumulative trend of early spring air temperatures we therefore take the algebraic sum of the deviations from normal of average air temperatures for January, February, March and April. Thus for 1949 Olympia station air temperatures we have -9.4, -4.0, +0.1, +1.3 as the deviation values. Adding the negative and subtracting the positives, we obtain an index, which we shall call the early spring Thermal Trend, of -12.0. This procedure is followed for all the years with which we are concerned, using the Weather Bureau data reproduced here in Tables 56 & 57, Pp. 183,184

Next we turn to our graphs and determine the number of days after April 30th at which setting begins. On good setting years this is approximately the date on which a setting index of 500 is first achieved on an increasing spatfall, but in bays with low setting rates or off years we note our maximal seasonal string catches and measure the period from April 30th to that time at which cultch should have been put out to obtain the maximum surviving set. The two sets of figures are given in tabular form below (Table 58 & 58a)

(INSERT Table 58)
58a)

In order to test whether there is a reliable relationship between air temperatures and time of beginning set we plot Thermal Trend indices against hastening or delay of setting as measured by the time between the end of April and initial significant spatfall. (Figs. 39 - 42). It will be noted at once that the points fall in line in a very beautiful manner indeed. A "best line" can be drawn "through" the points on the graphs and it is a straight line. The mathematical significance of our being able to draw such a line is that a simple and regular relationship is shown to exist between early spring air temperatures and the time of oyster setting. Having the lines, we can note slope and Y-intercept and write the equations of the lines. We also remark the scatter of the actual points with reference to the "ideal" line and understand the variation

TABLE 58 : TIME OF BEGINNING SPATFALL IN RELATION TO EARLY SPRING TEMPERATURES

YEAR	THERMAL TREND*	NUMBER OF DAYS AFTER APRIL 30th ON WHICH FIRST WAVE OF SPATFALL BEGAN		
		OYSTER BAY	MUD BAY	SOUTH BAY
1931	+7.2°F	51	54	
1932	-2.5	55		
1933	-9.1	64	86?	
1934	+17.8	37	41	
1935	-5.8	59	69	
1936	-6.1	66		
1937	-11.4	65		
1938	+5.5	55		
1939	-2.5	60		
1940	+14.1	38		
1941	+20.1			
1942	+1.6	50	45	
1943	-1.4	45		
1944	+2.4	55	55	68
1945	+1.3	52	63	58
1946	+5.2	49	63?	56
1947	+6.1	48	50	
1948	-6.7	62	73	73
1949	-12.0	71	71	
1950	-19.4	73	80	84

* Summated deviations from normal air termperatures, January through April, at Priest Point Park, Olympia,

TABLE 58a: TIME OF BEGINNING SPATFALL IN NORTH BAY IN RELATION TO EARLY SPRING TEMPERATURES

YEAR	THERMAL TREND*	NUMBER OF DAYS AFTER APRIL 30th ON WHICH FIRST WAVE OF SPATFALL BEGAN
1944	+2.6°F	58
1945	+2.1	58
1946	+1.9	53
1947	+6.8	46
1948	-3.1	60
1949	-8.7	66
1950	-15.9	71

*Summated deviations from normal air temperatures, January through April at Grapeview, Wn.

and error involved in each case.

Proceeding in this manner we find the following formulae for predicting the proper time of cultching, on the basis of early spring temperatures, where------

D is the number of days after April 30th that cultch should be in the water to gather maximum set, and

X is the Thermal Trend index or the algebraic sum of the deviations from normal of monthly average air temperatures, January through April, using Grapeview station for North Bay and Olympia (Priest Point Park) for all other bays.

Oyster Bay:

$D = 1.04\ (53.5 - X)$ give the proper date to $\pm$ 3 days.

Mud Bay:

$D = 1.16\ (53 - X)$ gives the date to $\pm$ 4 days.

North Bay:

$D = 1.1\ (52 - X)$ gives the date to $\pm$ 4 days (Grapeview temperature data).

South Bay

$D = 0.97\ (67 - X)$ gives the date to $\pm$ 5 1/2 days.

Oakland Bay is omitted in our consideration because Olympia oyster production is now negligible in this area; but it is clear that if conditions returned to favorable and oystering were successfully resumed, a similar formula could be worked out for this bay.

Thus the relation we sought between early spring air temperatures and time of setting has been discovered and is expressed quantitatively and mathematically in the formulae given. The significance of these equations is that all that oystermen need in timing their cultching operations is the formula for their bay and the temperature data which are already carefully and systematically gathered for ~~them~~ all citizens by the U. S. Weather Bureau and its associates. At the end of April the Thermal Trend for the year so far can be calculated, substituted in the equation, and the probable date of beginning set determined.

Thus in Oyster Bay for example, where the error is + 3 days, the highest probability is that the set will begin on the date predicted, somewhat less probable that the actual set will begin one day earlier or one day later, still less that it will commence two days earlier or two days later, and so on to the situation that it is highly improbable, on the basis of known previous seasons, that spatfall will begin four days earlier or four days later than the date predicted. Consider then the extremes of possible error, plus or minus three days. If cultch is put out three days too early it will still not have time to foul before rising spatfall begins. If on the other hand, the actual setting begins three days before the predicted date for cultching, the first peak of setting will still be "hit" since the prediction date is for the beginning of the initial wave of spatfall. Hence even on the outer limits of error of the method the predictions will assure maximum catches.

At this point it is well to remark that these formulae for timing cultch are based solely on the experience of the years 1944 through 1950. Had they been available during this period, timing of cultching operations could have been successfully made for every one of these years on the basis of these equations alone. Our reason for believing that they will prove to be accurate in future years is that the period on which they are based embraces near-average as well as the extremes exemplified by the extraordinarily warm spring of 1947 when spawning occurred at the end of April and by the record cold spring of 1950. The record of years to come may however serve to refine the formulae by modifying their constants somewhat. Also as the "normal temperature" is recalculated from decade to decade as Weather Bureau data accumulates it may be necessary to change the constants slightly. As they stand the equations are adequate to current practical needs.

Since we cannot foresee the future, one may test the formulae by applying them to the data of earlier years which did not fall under our study.

Hopkins (1937) chronicled the spatfall for several years in Oyster Bay, and Mud Bay, and one of the oystermen, Mr. W. J. Waldrip, has put at our disposal careful records of set on test shell in Oyster Bay for another period of years. Therefore we may calculate from the formulae at what time cultch should have been put out during the years in question and then turn to the actual setting record to see whether this timing would have proved to be the most propitious.

Let us begin by considering the season of 1934 in Oyster Bay and Mud Bay. This was an extraordinarily warm spring. Weather Bureau reports on file enable us to calculate the Spring Thermal Trend Index of +17.8, far above the value for the warmest spring of our own records (1947, + 6.1). Applying the formulae for Oyster Bay and Mud Bay we find that cultch should have been out on June 6 and June 10 respectively, according to our calculations. Now we turn to Hopkins' paper (1937, Fig. 26, and Table 25, PP 482, 483) and note that on June 6, 1934, in Oyster Bay the spatfall was just beginning at about 500 spat per bag of cultch shells per day, attaining a peak of 6761 spat 6 days later. And on June 10 in Mud Bay (Hopkins, 1937, Fig. 31, Table 30, PP 485, 486), spatfall was also just beginning at 100 spat per bag of shells per day, rising to a peak of 305 spat 5 days later. In short, had our formulae been available in 1934 they would have set the date precisely for the very best time for cultching which is just before the first setting peak.

The season of 1935 on the contrary was unusually cold, having a spring Thermal Trend of - 5.8. Calculating the timing of cultch as before, we find predicted dates to be July 1st and July 8th for Oyster Bay and Mud Bay respectively. Refering now to Hopkins' data (1937, Fig. 33, Table 33, PP 488 and 489; Fig. 32, Table 31, P. 486) we find that July 1 marked the crest of the first set in Oyster Bay, while on July 8th in Mud Bay the set was well started and rising to a peak 8 days later. Hence if the dates for cultching had been followed, an ample set could have been obtained in both bays, within the limits of (1) the possible destructive effects of pulp mill liquor and (2) the low spatting rate achieved in Mud Bay during that year.

Turning now to Waldrip's records (Tables 26 -32, Pp. 155-161) we may select for checking our Oyster Bay formula the year 1941 when the spring Thermal Trend was + 20.1, the highest of all years spatfall of record. This figure gives us by calculation June 4th as the proper time for cultching. Now on June 4th, 1941 no spatfall was occuring at Burns Point or on Waldrip's home dike in Oyster Bay. First weak spatting was picked up on June 23rd, dribbling along until a low setting peak of Setting Index = 580 on July 20th. The formula appears to have failed in this case, but it is more reasonable to believe that it was the spatfall that did so instead; for there is little doubt that the first set of this phenomenally warm season should have come long before July 20th. Spatting climax on July 20th then very likely corresponded to the usual second wave of setting. Since the 1941 season was at the height of a "depression" due to pulp mill pollution we may surmise that this factor caused the failure of the first setting peak.

The 1936 season was interesting in that February was an unusually cold month having an average air temperature of 7.4°F below even that of the preceeding month of January. The corresponding deviation from normal February temperatures was - 7.1°F, the lowest for any February during the years of available spatting records. Does the formula prove equal to this abnormal circumstance? Employing the equation for Oyster Bay we calculate the proper cultching date for 1936 to be July 1st or 62 days after April 30th. On that date Waldrip's records (Table 26) show that spatfall had recently begun and was at a rate of 100 spat per 100 shells per day

(S. I. = 100), gradually increasing to a peak of 4000 twelve days later. Cultching on July 1st would therefore have yielded the maximum seasonal catch!

Finally we can check our formulae, against all the years of Hopkins' and Waldrip's records by plotting the actual dates of beginning spatfall against the Thermal Trend of these years. This is done in Figs. 60 and 61 from the data of Table 58 .

(INSERT Fig. 60
Fig. 61)

Examination of Figs 60 and 61 shows excellent agreement when our formulae are used to "predict" the beginning set during the years 1931 to 1940, for the points ~~fat~~ all fall close to the identical line drawn for the 1944 to 1950 data. Time for beginning spatfall in Mud Bay, 1933, alone appears to be far out of line. Turning to Hopkins' Table 29, footnote 1 (1937, P. 485) however, we see that this author supposed that his test cultch placed out on July 18th of that year did not begin catching spats until the last day it was out (July 25th) whereupon it suddenly picked up a catch of 1494 spat! This assumption seems rather dubious and we may reasonably expect that, as in other years generally, the rate of spatfall began at a slower pace and probably actually commenced nearer the 11th of July than the 25th.

The formulae for timing cultch therefore pass the crucial test of applicability to fresh data which they were not originally designed to explain. We should hence expect that future setting seasons to be confirmatory and have good reason to employ the formulae with confidence.

The method here proposed for long range prediction of the date on which spatfall may be expected to begin is unique. In the case of the European flat oyster, *O. edulis*, only short-term anticipations have been possible, in part owning to the fact that chance cooling of the waters may on occassion largely destroy a once-promising abundance of oyster larvae. The same is true of the Japanese or Pacific oyster; both in Japan and on our Pacific coast sets are predicted only on short notice largely from the character of the larvae picture. *Ostrea virginica*, the Eastern oyster has a rather sharp threshold temperature for spawning and these oysters also mutually stimulate each other to spawning via their sex products with the result that spawning occurs simultaneously and a population of larvae all of the same age is developed. Knowing the average duration of larval life one can in some areas therefore predict from the spawning date or from the date on which threshold temperatures is reached approximately when setting should occur.

Hopkins also worked out a method for forecasting the date of beginning spatfall for the Olympia oyster from the date when gravid oysters are first found. His rule was that "Setting of larvae begins in the third tidal period following that during which spawning starts". A "tidal period" was taken to be a period of low low-tides. When this rule is applied to our own bay-year graphs (in which the low low-tides are indicated on the base-line) it is found that for those instances in which the data are sufficiently complete to permit a clear-cut decision (24 bay-years) the rule holds good 63% of the time, whether one considers all the bays of our study or only those which Hopkins studied (Oyster Bay and Mud Bay, plus Little Skookum and Oakland Bay for one season). Probably Hopkins did not strive after a more accurate or a longer-range prediction method since he considered, as already noted, that the second wave of spatfall could profitably be cultched. The use of seasonal cultch has however shown that the ~~[illegible]~~ later-caught spat do not contribute importantly to the recruitment of seed oysters because of the high mortality rate to which they are subject(see pp. 87 - 92).

The dependability of the early summer weather in lower Puget Sound and the adaptation of the oyster larvae to such variations as obtain, together with discovery of the quantitative relationship between air temperature and the tempo of the reproductive cycle of the Olympia oyster has therefore made possible a method for timing beginning spatfall which for ease of determination, accuracy of forecast, and extent of anticipation is without parallel in the prediction of oyster sets.

HOW BEGINNING SPAWNING IS PREDICTED

The method for predicting time of spatfall described above does not even require our determining when the oysters begin to spawn; yet it may conceivably be of practical value for marketing purposes to be able to forecast when oysters will become spawny. To do so we procede in a manner similar to that of predicting the time of beginning set. But in this case we use Grapeview air temperature records for all bays and we omit, in calculating the cumulative deviations from normal during January through April, certain extremely low or unusually high deviations. Whether this procedure be too arbitrary will be discussed in a moment, but first we will show that it does yield workable relationships within the years of record at our disposal.

Thus when the number of days from April 30th to the beginning of significant spawning (5% gravid oysters in our samples) for each bay-year is plotted against the Thermal Trend we obtain the correlations shown in Figs. 62 through 65. Drawning the best straight line through the points of each graph and determining the equations for these lines, we achieve the following formulae, in which

Dsp = number days after April 30th that first significant spawning begins, and

X = the algebraic sum of the deviations from normal of average mean air temperatures at Grapeview for January through April with monthly deviation values of - 4 and less and + 5 and greater omitted from the calculations. (See Table 57, P. 184).

Oyster Bay:

$$Dsp = 3.4 (X - 4.8)$$ gives date of beginning of significant spawning $\pm$ 7 days.

Mud Bay:

$$Dsp = -2.63 (X - 5.8)$$ gives date $\pm$ 7 days.

North Bay:

Dsp = -2.63 (X - 7.0) gives date ± 4 days

South Bay:

Dsp = -3.3 (X - 8.5) gives date, of accuracy undetermined because of insufficient years of data.

The data of Hopkins' years of observation are added to the graphs of Oyster Bay and Mud Bay and they agree reasonably well with the trend of the later years under our own surveillance.

Of course if "Dsp" is negative, on the basis of temperature records for January 1 through April 30th, spawning will have already commenced in April. Hence for unusually warm years we need a foretelling from March 31st. On this score we can say that if the index of the Thermal Trend for January through March is + 4 or greater, spawning may be expected to begin during April in most bays. For such unusually warm years one can look for spawning sometime after the middle of April and before the first of May.

In order to obtain the measure of correlation between air temperature and time of spawning shown in the graphs we have had simply to omit the excessive deviations of February (-4.9) for 1933, of April (+5.4) for 1934, of March (-4.2) for 1935, of January (-7.1) for 1949 and January (-10.3) for 1950 when calculating the Thermal Trend for these years. I can hear my scientific friends screaming in horror! How arbitrary! What a ruthless and biased manipulation of the data! But note what has been gained thereby: we have formulae which, had they been available in 1932-1935 and 1944-1950, would have told us the probable date of beginning spawning using only the Grapeview air temperature records for January through March and April. And since these equations were applicable in those disparate years, when spawning was as much as a month earlier in some years than in others, we have good reason to hope that they will hold also for future years.

Now to reply to possible objections to our rather arbitrary handling of the temperature data. In the first place, it is obviously the water temperature and not the air temperatures that affect the oysters directly and determine the rate of the reproductive processes. If we had representative annual water temperature records for all our bays over a considerable number of years one should, I am sure, be able to make very neat correlations between these temperatures and the rate of progression of the reproductive cycle. And after one had thus kept weekly thermograph records in 4 bays for a dozen years he should also be able to work out a more accurate mathematical relation between air temperatures and water temperatures characteristic for each bay whereby he could then dispense with reading further water temperatures and obtain close predictions by following air temperatures alone. But we simply do not have this data on water temperatures over a long period of years so we have to do the best we can with the available air temperature data. Fortunately, it turns out that air temperature records are adequate for the practical objective.

In handling this problem we try to use to full advantage what air vs. water temperature records we have. These are shown in Figs. 57 through 59 (PP.94 a-c) which should be consulted in connection with the following remarks.

We are justified in omitting the extreme low deviations in air temperature when they occur during the beginning months of the year because water temperatures do not "follow them down" but remain much higher, due to the high specific heat or "thermal conservatism" of water.

We are similarly justified in omitting positive deviations of +5 or higher from normal air temperature either for the same reason of thermal lag or because generation of the spawn requires a certain minimum period of time and probably cannot in nature be hastened further by increases in temperature above certain values.

Finally, one may ask, Why switch to Grapeview temperature data when the unmanipulated Olympia records gave such good correlations for timing of initial spatfall? The answer is simply that we use them because they work better. How can that be? Quite possibly because the recording station at Grapeview is at 20 ft. above mean low water while that at Olympia it is 69ft. Also, Grapeview is surrounded by the waters of Case Inlet. The result is that the air mass thermally tested at Grapeview is more moderated by water temperatures than at Olympia, January and February normal temperatures being somewhat higher at the former station. Grapeview air temperatures therefore correspond more closely during these months to water temperatures in the region generally and therefore probably reflect more closely the effective temperatures involved in initiating the production of spawn. From the fact that such temperature data may be used satisfactorily in this manner for practical results we should expect that a comprehensive study of water temperatures in the bays themselves would show that excluding the excessive variations in plus or minus direction give the best reflection of water temperatures during the development of spawn.

It was stated by Korringa in 1940 that "No investigator in Europe has succeeded so far in deducing a reliable mathematical formula, exclusively built up of easily observable factors, such as water temperatures, for the purpose of forecasting swarming [liberation of spawn]. Such a formula would render the time-consuming plankton-investigations superfluous". The procedure just detailed allows us to predict from data much easier to obtain than water temperatures, namely, air temperatures alone, not only the probable date of spawning but also the date of beginning spatfall.

The derivations given for the empirical formulae by which beginning spawning time is determined may seem in certain of their steps to be quite arbitrary and the predicted dates have an accuracy of only plus or minus 7 days in certain bays. All that need be said on this score is that if one should desire a more precise forecast, such could undoubtedly be obtained by more extensive spawning surveys of the bays (not just at one location in each bay) together with an investigation of actual over-all water temperatures. A direct study of the water temperatures themselves would eliminate the need for manipulating air temperatures but it would prove a very tedious study indeed. The even more successful prediction of time of beginning spatfall renders such increased accuracy of spawning prediction unnecessary in relation to the problem of cultching.

The formulae herein offered will, however, allow us to predict within a period of not greater than two weeks when spawning will begin in the various oystering bays, and for most years and bays the foretelling may be expected to be a good deal closer than this. This prediction may be of considerable value in anticipating at what time each year marketable oysters will become "spawny".

The circumstance that each bay has its own characteristic time of spawning and of setting in relation to air temperatures is explainable in terms of the differences from bay to bay in all those topographical features which contribute to the rate of seasonal change in water temperature. Hence, in particular, the less the volume of a bay and the closer its mouth to the main tidal channels from central Puget Sound the greater will be its tidal flushing and the tempering of its thermal change by "outside" waters.

One can get a rough idea of the volume of the bays by integrating (i.e. adding up) all the rather evenly distributed soundings figures provided for each bay in the U. S. Coast and Geodetic Survey chart of the region. The values so calculated, which represent the relative volumes of the oystering bays, are as follows:

[illegible]

Case Inlet	1,396
North Bay proper	109
Oyster Bay (Totten Inlet)	337
Little Skookum	8
Mud Bay (Eld Inlet)	209
Oakland Bay	88
(to East entrance to Hammersley Inlet)	
South Bay (Henderson Inlet)	55

North Bay, which merely subtends Case Inlet, draws on the largest body of "enclosed" water while South Bay, at the other extreme, is susceptable to the greatest amount of flushing within a given tidal range and its beds lie the closest to the main tidal channels (Fig. 1).

Using the data of Hopkins (1937, P. 453) we can compute from vertical samples at various depths average monthly water temperatures at Mud Bay and Oyster Bay in 1932 and compare them with those of the large, more central mass of water at Seattle as recorded by the U. S. Coast and Geodetic Survery. This gives us the following table of --

AVERAGE WATER TEMPERATURES IN 1932

MONTH	SEATTLE	OYSTER BAY	MUD BAY
January	46.4	44.6	43.8
February	45.1	42.6	43.6
March	45.5	45.6	45.8
April	47.5	50.6	49.6
May	49.8	54.8	54.0
June	53.4	58.2	58.2
July	55.4	61.4	60.3
August	55.2	62.2	61.6
September	54.7	59.2	58.6
October	53.4	56.2	55.8
November	50.7	51.0	51.0
December	47.8	46.6	46.0

The above tabulation shows of course that the shallower, more inland waters of the bays are colder in winter and warmer in summer than waters more proximate to the main water mass of Puget Sound. More significantly, it is also shown that Mud Bay waters are somewhat cooler than those of Oyster Bay as is reasonable from the lesser volume of the former and its closer proximity to main tidal channels. Hence it is rendered reasonable, for example, that the Oyster Bay oysters spawn and set before those in Mud Bay and, on the same type of argument, that South Bay should "come in" last of all. As for North Bay, the great extent of water in Case Inlet probably balances the effect of the proximity of its mouth to main channels, leading to a timing of the reproductive cycle very similar to that of Oyster Bay.

It remains to ask why the prediction of the initial, ouvert stage of the reproductive cycle (spawning) should present a more involved problem than that of predicting the final stage (setting) which involves both the tempo of spawning and rate of larvae development. The reason is implied in what has already been suggested; namely, (1) that the development of the gonad, while dependent on water temperature, apparently does not follow pronounced deviations in air temperatures; but (2) that these deviations are reflected in the early summer temperatures attained in the bays which do influence the rate of development of the larvae to setting.

HOW INTENSITY OF SET IS PREDICTED

Even if cultching operations can be accurately timed, oystermen need to know also whether the set will be of sufficient magnitude to justify the expense of preparing the cultch. To approach a solution to this problem we analyze the data from the bay-year graphs of the setting seasons in order that we may uncover what factors contribute to a good set.

In the first place, we may discard at once certain factors which appear to have no relation to setting intensity. One of these is the early or late beginning of the reproductive season, for in 1946 setting began on June 18 while beginning spatfall did not occur until July 12 in 1950 and yet the catch was very similar, etc. A second is the percentage of gravid oysters during the first wave of spawning, for neither the maximum percentage nor the cumulative percentage by 10 day periods over the initial spawning peak is significantly related to success of set. It will be noted however that the total abundance of larvae and particularly the abundance of large larvae are directly related, as expected, to the magnitude of the rate of spatfall or Setting Index which, during the first wave of spatting, is correlated with the final surviving seasonal catch.

These relationships permit of certain general rules which guide us in the anticipation of over-all magnitude of spatfall. They have already been presented on Pp. 23 - 24.

Since Oyster Bay and North Bay seem now to yield consistantly good catches we conclude that prediction of intensity of spatfall in these bays is of little importance. In Mud Bay however, the set may be a complete failure, and this we desire to be able to foretell.

POSSIBLE CAUSES OF SPATTING FAILURES IN MUD BAY

(1) Abnormal Salinity

The situation in Mud Bay is unique among the areas of our study in that good plankton larvae populations may be present during the early part of the season without yielding significant spatfall. It would therefore be of great value to be able to foretell such setting failures in order that cultch may be withheld and not wasted; or transfered to other bays where good catches may be expected.

Although we had at first suspected that spat failures in Mud Bay may be due to the flushing of larvae out of the bay by spring tides, the plankton-tidal cycle study of 1950 (P. 82) rather conclusively demonstrates that this is not the case and that, if anything, the larvae in Mud Bay are even kept crowded up toward the head of the bay by the tidal currents. Hence it was necessary to look in other directions for a possible explanation.

We therefore focus our attention on the efficiency of conversion of larvae into spat or in other words, the relative proportion of the larvae that actually participate in the spatfall. To indicate this we could find what percentage of the larvae finally survive to large size, but still better it would seem is to determine the ratio of larvae abundance to rate of actual spatfall. To do this we divide the maximum Setting Index by the maximum larvae count preceeding the first setting peak. The resulting figure (here called an "index of setting efficiency") is at least a rough expression of the favorability of conditions for the development of larvae to setting, whatever may be the circumstances which determine their actual abundance.

When such calculations are made for the Mud Bay seasons we have the following:

YEAR	1944	1945	1946	1947	1948	1949	1950	1951
INDEX OF SETTING EFFICIENCY	.06	1.1	.04	1.1	.92	.16	.93	.02

Note that in the years of spat failure (1944, 1946, and 1951) the Index was lowest, in the low catch year of 1949 it was only slightly higher, while during good years we have a value near unity, Larvae size studies may therefore indicate whether lowered setting efficiency was due to disappearance of larvae before attaining full development.

In the years for which we have ~~adequate~~ available larvae-size studies (1944 - 1950) the setting seasons of 1944 and 1946 were complete failures in Mud Bay. An investigation of the problem in this bay may therefore begin with an analysis of the plankton larvae picture during these years, comparing the Mud Bay larva size measurements both with that of other bays during the same year and with Mud Bay itself during years of satisfactory spatfall.

It is clear from the bay-year graphs of 1944 (Figs. 9 through 11) that spawning and abundance of larvae in Mud Bay during this year did not differ in any striking way from the same in Oyster Bay and North Bay, but the spatfall was as nothing compared to that of the latter bays. Hence the spatting failure cannot be attributed to failure in the production of oyster larvae.

When we compare the larvae picture in these bays with reference to size of oyster larvae, however, a marked difference is manifest. Figures 66 through 68 show the proportionate distribution of larvae size groups in plankton samples during 1944 in the three bays, size in microns (1 micron = 0.000039 inches) being the maximum diameter of the larval shell parallel with the hing. This data has also been tabulated in Tables 59, 60 and 61.

By comparing the above charts it is apparent at once that no significant proportion of oyster larvae ever reached near setting size in Mud Bay during ~~the~~ this year (1944) of spat failure. The cause of spat failure may therefore be sought in whatever condition resulted in the demise of the larval oysters after they were half grown. New larvae were fairly continuously being supplied to the bay all during June and July but only a very few survived to setting size and the Setting Index never exceeded 42. It is further to be noted that all the larvae, both large and small, did not succumb at one time as in a mass killing. Only the large larvae dropped out. Hence we may further conclude that the causative condition was one that acted slowly and that the oyster larvae eventually died after being exposed to it for about a fortnight.

Is this conclusion confirmed by the data of other years? 1946 was also a year of set failure in Mud Bay. Proportions of large, medium and small larvae found in the plankton tows of the three principle bays during this year is graphically shown in Figure 69 . Again it will be noted that in Mud Bay no major group of large larvae was found in the plankton as was the case in the other two bays. In Oyster Bay expecially it is clear that the two setting peaks of the season were preceded by the attainment of near-setting size by a significant portion of the larvae population.

(INSERT FIGS. 66
67
68
69)

Now 1945 was a year of good spatfall in Mud Bay, the Setting Index forming a smooth mode with a peak value of 3400 around July 11th (Fig. 15). Comparable spatting rate in Oyster Bay was 7400, and in North Bay, 9000 during this year. Some precise measurements on plankton larvae were made during June (Table 59), but for the most part we simply counted the number of obviously large larvae of around 250u diameter and over in the samples and calculated the percentages thereof. This is rather rough procedure to be sure, but it is sufficient to answer the question: In a year of good spatfall is the larvae picture different from that in a bad year? Reference to Table 14, p. 143 shows that during the 1945 season oyster larvae in Mud Bay survived to near-setting size in about the same degree as in the other bays, attaining a peak density of 240 per 20 gallon sample and a peak proportion of 15 per cent.

A comparison of the larvae picture in Mud Bay during years of spatting failure and of success therefore indicates that in Mud Bay setting failures may be the direct result of failure of the larvae to survive to setting size. It is further indicated that the primary cause is a condition which acts with cumulative effect on the larvae, permitting them to survive the early weeks of larval life but eventually resulting in their death before setting can take place. This condition may be such that when it occurs the larvae are always killed off soon after they pass the mid-point of their pelagic life in which case one could reliably foretell spatting failures by the larvae picture obtained through plankton samples; but it is also conceivable that if the hypothetical deleterious condition is of a somewhat lower intensity the larvae may not succumb to it until about the eve of their setting. In the latter case we will have to learn the nature of the unfavorable conditions in order for prediction of the spatting failure to become possible at all.

Now we do not yet know what causes eventual death of the larvae and consequent spatting failures in Mud Bay during certain years. The answer must be found through field investigations, but we need an hypothesis to guide our studies since a blind striking in the dark would probably get us nowhere. Until evidence proves otherwise we should procede on the simplest assumption that a single cause is responsible for this phenomenon. It has already been shown in the horizontal plankton sections during a tidal cycle that the large larvae are not swept out of any of the bays by tidal action. Our suggestion at the present time is that spatting failures in Mud Bay are due to abnormal salinities, whether above or below a certain optimum range.

That salinity may be the key to the problem in Mud Bay is a speculation arising from certain suggestive relationships between rainfall recorded at Priest Point Park, Olympia, (Table 63), and spatting failures in this bay. If we assemble the precipitation data as in Table 61 , these relationships vaguely appear.

(INSERT Table 61)

In pursuing this possibility one seeks in every way for a correlation between peculiarities in rainfall and set failures; test and confirmation come later. Now reference to Table 61 will substantiate the following statements. Failure in spatfall occured in those years in which:

1) Winter precipitation was exceedingly low, (1944).

2) Precipitation during the "larvae months" of April through June was abnormally low even though that of the early months was high (1934, 1935, 1951); and

3) April through June precipitation was abnormally high, but did not compensate an abnormally low rainfall in the winter months.

TABLE 61 : SUMMATED DEVIATIONS FROM NORMAL RAINFALL IN RELATION TO SPATFALL IN MUD BAY

YEAR	MAXIMUM SETTING INDEX		RAINFALL DEVIATION FROM NORMAL December through March	April through June
1932	1150*		+5.19 inches	-1.12 inches
1933	4000*		+4.98	-1.91
1934	300*	(failure)	+5.45	-4.86
1935	60	(failure)		
1944	42	(failure)	-11.77	-0.86
1945	3500		-4.94	-2.15
1946	14	(failure)	+0.34	+3.73
1947	1600		-3.67	-1.26
1948	5000		-4.74	+5.07
1949	600	(fair)	-8.83	-2.63
1950	2800		+8.98	-2.52
1951	70	(failure)	6.08	-4.28

* Number spat daily per bag of shell, Hopkins' data (1937).
For reminder, Setting Index equals number spat per 100 Japanese oyster shell faces per day.

(1946, as contrasted with 1948).

In pursuing this speculation we assume that the only way rainfall could affect survival of larvae is through decreasing salinity by diluting a bay with rainwater or by increasing it in dry spells when evaporation from the bay is not compensated. We further note that the effect of rainfall and run-off should be most noticeable in the upper half of the bays where the water is shallow and major stream inflow received, which is just the part of the bay to which the oyster larvae are confined. Now we add the further notion that a bay may behave somewhat like a bowl: if it is filled to overflowing additional water poured in merely spills out (1) and we remain at a constant, full bowl; but if the bowl is warmed and evaporation encouraged no equilibrium is reached and the level of water in the receptacle becomes lower and lower.

Applying these hypotheses to the above statements we come out with the following interpretations of them in terms of salinity:

1) If winter precipitation is extremely low and April through June does not compensate for this by high precipitation, then salinity is abnormally high and affects the larvae adversely (1944).

2) If winter rainfall is high it will "spillout" of the bay and an abnormally low precipitation in the "larval months" (2) will still result in abnormally high salinity detremental to larvae (1951, 1934, 1935).

3) If April through June precipitation is abnormally high but does not compensate an abnormally low rainfall in the winter months (i.e. merely "filling up the bay" to normal), then salinity will be abnormally low and larvae will be affected thereby.

Hence it may be possible that rainfall can affect salinity of the bay water in either direction of increase or decrease to such an extent that the survival of larvae is affected.

It is interesting to note the setting season of 1949 in Mud Bay in this connection. Maximum rate of spatfall attained was equivalent to a

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[1] This is a hydrographical speculation, but it may in time be discovered that salinity of tidal bays is more affected by decreased than by increased rainfall.

[2] April and May are included in the "larvae months" on the assumption that rainfall during these months carries over as a salinity difference effective during the months (May and/or June and/or July) in which the larvae which produce the initial set are present in the bays.

Setting Index of 600. Hence this set was "betwixt and between", neither a failure nor half the magnitude of the spatting in good years. Now it can be seen in Table 61 that the winter months deviation from normal in precipitation was - 8.83 inches and that of the later months - 2.52 inches, giving a total of - 11.46 inches which is only a bit more rainfall than in 1944 in which the set was a failure and the comparable figure was - 12.63 inches. Thus 1949 precipitation may have been just on the borderline as regards adverse effect on survival of oyster larvae.

If the circumstances are such that the set in Mud Bay can be wiped out by abnormal precipitation, then we might expect that the other bays would be affected also at least to a minor extent. That such may be the case is indicated in the following table of setting maxima in the three principal bays during the years of our survey:

MAXIMUM SETTING INDEX
first peak of setting

Year	MUD BAY	OYSTER BAY	NORTH BAY
1944	42	2300	6500
1945	3500	9000	9000
1946	14	2700	1300
1947	1600	17500	3500+
1948	5000+	7000	9500
1949	600	9000	2500
1950	2800	4000	4200
1951	50	4000	1200

It will be seen from this table of comparative setting figures that, in general, the years of spatting failure in Mud Bay were also years of decreased setting intensity in other bays. In this connection it should be noted that Oyster Bay had a lower over-all spatfall in 1946 than in 1944 even though the maximum Setting Index for the former year was higher, for the area under the setting curve (i.e. the cumulative set regardless of "peaks"; see Figs. 9 and 19) was greater in 1944. Hence the diminution in setting in Oyster Bay paralleled that in Mud Bay for these two years, though at a far higher level.

All these remarks are presented as and clearly stated to be mere speculation. They may be wholly invalidated by further investigations. It is not claimed that they make a convincing argument nor a clear picture. All that is asserted is that in the absence of any other or better clues to the setting failures in Mud Bay which stand out as an anomaly in the oyster situation in lower Puget Sound, there is sufficient probability that salinity is the significant factor to justify expenditures in time and equipment to settle the question one way or another. Such a study could reveal that the weaknesses in "the case for rainfall" here presented are due to the fact that rainfall at Priest Point Park, Olympia, is not always characteristic also of Mud Bay and its watershed, and that evaporation and other factors complicate the picture so that the relationship between Priest Point precipitation, and salinity of Mud Bay is a complex one. Direct and adequate study of the primary factor, the salinity of the water itself to which the oyster larvae are subjected during their pelagic life, may cut through all these difficulties and eventually allow one to predict spatting failures in Mud Bay on the basis of abnormal salinity. If this proves to be the case, then these speculations will have amply justified themselves in originating such a study. Furthermore it could appear that optimum salinity is a vital secret in the culture of oyster larvae to setting in the laboratory and in artificial ponds. In the meantime, one may be on the lookout for setting failure in Mud Bay in any year in which early spring rainfall is markedly abnormal.

If abnormal salinities are the cause of collapse of setting during certain years in Mud Bay, then these failures should be more closely correlated with the actual salinity of the bay water than with rainfall which affects salinity far more indirectly than air temperature affects water temperature. For rainfall is generally more sharply localized than air temperature and, as mentioned, precipitation recorded at Priest Point Park may be different from that at Mud Bay itself which in turn may be different from rainfall on the watershed of streams emptying into Mud Bay. Factors determining evaporation no doubt further complicate the relationship between rainfall and salinity.

What then of the salinities (or chlorinities) of the water relative both to rainfall and to spatfall failure in Mud Bay? We have made large series of chlorinity determinations on water samples from the bays of lower Puget Sound and Hopkins (1937) presents many tables of such data. A contientious and laborious review of the salinity data however has not proved rewarding. After careful analysis we can at most conclude the following:

1) There is an annual cycle of salinity but the variation is not great, During the rainy early months of the year salinity is lowest and rises to a peak late in the summer, thereupon decreasing through the winter to the spring low.

2) Salinity does not contradict rainfall, for seasons of high rainfall never show high salinity; but the correlation between rainfall as recorded at Priest Point Park, Olympia, and salinity is very inexact, doubtless owing to the multiple factors mentioned above. Thus there is a very general relationship between rainfall data and available bay water salinities, as one would expect from the diluting action of precipitation, but the correlation appears to be so loose that one cannot obtain a precise indication of salinities from rainfall record.

3) Since good oyster sets occur regularly in Oyster Bay and North Bay salinity data from these waters can be of little value anyway and it is probable

that spat failures in Oakland Bay and South Bay are due to other factors.

4) Hopkins' extensive salinity data unfortunately does not extend to 1934 and 1935 in Mud Bay which were just the years of setting failure during the period of his investigation. His studies, did, however, lead him to remark that "The salinity on the oyster grounds in Mud Bay is more variable than in Oyster Bay------and heavy rains affect the water more quickly in the former" (1937, p. 449). That greater variability occurs in salinity of off-shore waters in Mud Bay than in Oyster Bay was also noted. In this place it may also be mentioned that although Hopkins found lower prevailing salinites in Little Skookum and Oakland Bay than in Mud Bay, this fact does not render untenable the hypothesis that spat failure in Mud Bay may be due to abnormal (eg. low) salinity, for it must be remembered that each bay is a genetically isolated population of oysters which do not interbreed with oysters of other bays. Hence the oysters in any one of these bays may have physiological, as they undoubtedly have morphological, differences from those of other bays. In a manner of speaking, this means of course that oyster larvae of Oakland Bay (but not of Little Skookum?) could have "learned" to tolerate lower salinities. In any event the sets in Oakland Bay and Little Skookum have in our time and in that of Hopkins been much lower than those of the major oystering bays.

6) Water bottle samples as usually taken are simply inadequate to a determination of the summated average effective salinity to which oyster larvae are subjected from week to week during their pelagic life. Certain general cycles and trends as mentioned above are evident, but the variation in such samples is much too "jumpy" to permit correlation with events in the life cycle of the oyster. Either a <u>very extensive</u> water-bottle survey should be made of salinity in Mud Bay during the larvae season or some sort of integrating electrical conductivity recorder might be set up

to determine the average over-all salinity changes in the water mass of the upper half of the bay to which the larvae are mostly confined. Only such a study might demonstrate that salinity is a crucial factor in success of setting in Mud Bay and permit one, from a precise knowledge of the water salinity during the two weeks following initial major liberation of larvae from spawning, to forecast whether those larvae may be expected to survive through to setting. In the meantime we shall have to be guided as best we may be the empirical rules (given on P. 118) derived from the apparent relationship between abnormal rainfall and spat failure.

2) Range and Stage of Tide in Reference to Setting

The demonstration of a Larvae Mass which moves back and forth in the bay with the ebb and flooding of the tide enables one to clear up very simply a question concerning the relation of stages of tide to rate of setting brought up by Hopkins in his 1937 paper (pp. 489 - 493). Hopkins determined the spat caught hourly during a complete tidal cycle at three locations in Oyster Bay and found a marked change in spatfall from hour to hour. Heaviest setting occured generally during "half-tides", ie. during mid-flooding water, mid-ebbing or during a low high tide. Water temperature, pH, salinity and current-velocity were also determined along with setting rate because it was assumed that the variation in the spatfall was due to <u>conditions of the water</u> as such. However, no satisfactory correlation between any of these factors and intensity of setting was shown.

Turning to one of the studies on variation in larvae abundance with stage of tide (Fig. 45) we note that the abundance of larvae and therefore of setting larvae at Station 9 (near Dike 5) presents a curve strikingly similar to Hopkins' histograms of setting rate in ~~height~~

relation to height of tide. Hence it follows that the very simple and reasonable explanation of Hopkins' results is that larvae set more when there are more larvae to set! That is to say, the center of the Larvae Mass passes over a given spot like Station 9 or Dike 5 at a certain stage of the tide, in this case during half-ebb and especially at half-flood tide. Setting still occurs at high or ebb tide not in spite of changes in physical or chemical state of the water but simply because the outer fringe of the Larvae Mass is still over the station and so some larvae are available for setting.

If this reasoning be valid then setting intensity at down-bay stations like Hopkins' designated Dike S on the Steele grounds should show maximum spatting on late ebb and early flood tide according to the larvae counts there during these stages of the tide (Station H-6 in Fig. 50 and Station G in Figure 52). This expectation is not confirmed by Hopkins' findings (see his Fig. 35, P.490) which showed instead highest setting at the peak of the highest high tide in Dike S. But this east shore location was not included among the sampling stations in any of our plankton tidal cycles so it is possible that local off-channel, in-shore eddies may determine hourly fluctuations in larvae abundance at this particular point somewhat different from the back and forth movement of the Larvae Mass of the bay in general. Since larvae abundance so simply explains the fluctuations in setting rates at Hopkins' up-bay stations it is considered likely that a local study of larvae density over Dike S in reference to tide would clear up the discrepancy. At any rate the markedly <u>lower</u> intensity of spatting which he continually observed at Dike S as compared to Dike 5 shows that by reason of its location down-bay Dike S fails to tap the major Larvae Mass.

The possibility of this interpretation of Hopkins' results was anticipated by Korringa (1940, p. 200) who noted that Hopkins neglected the all-important factor of abundance of setting larvae in connection with both his hourly setting studies and his tests of vertical distribution of spatting intensity. Investigations in variation in larvae abundance at different stages of the tide specifically confirm that this abundance and not water conditions is one of the most important factors in determining rate of spatfall.

Attention to the fluctuation in larvae abundance at any point in relation to the stages of the tide thus clearly indicates that this is the major factor in hourly rate of setting and that conditions of the water, if influential, play but a minor part. Hopkins' experiments can then be used in a different manner, namely, to demonstrate that cultch over which the Larvae Mass passes draws on the maximum density of setting larvae in the mass for its cumulative spatfall, picking up spat as the mass passes over it going up-bay on the flood and again as it comes down the bay on ebbing tide.

We conclude that physical factors like current velocity, correlated with stage and range of the tides themselves, are probably not relevant to the problem of spat failure in Mud Bay. Prevailing salinities, at any stage or range of tide may be involved as discussed above. Yet range of tide may possibly account for cultching failures in certain years, not through conditions of the water but with reference to distribution of the setting larvae, as will now be developed.

In his paper on the Olympia oyster (1937), Hopkins considered that there was sufficient correlation between spatting intensity and range of tides to permit the conclusion that "times of maximum frequency of setting fall within periods of spring tides when tidal range is greatest". His figure 33 (p. 489) is stated to show this relationship most clearly since 2 to 3 day test cultch was used for the data therein visualized, and the ambiguities in his other bay-year diagrams are attributed to the fouling of 7 - day test cultch resulting in a less definite location of the precise peaks in spatfall. We shall see again, however, that certain of Hopkins' conclusions are vitiated by the incompleteness of his data;

for he did not make quantitative studies of the planktonic oyster larvae and a reliable correlation between range of tide and setting cannot be established unless one can show, for example, that setting on neap tides is low even though there is an abundance of setting larvae available at the time.

It has just been shown how Hopkins' results on setting intensity in relation to stage of tide are most simply explainable by the fact that only at half-tide are the larvae brought up to Dike 5, Oyster Bay, in near their maximum abundance. On this basis it was suggested by Mr. Cedric Lindsay that range of tide at time of setting might affect delivery of setting larvae to the cultch in Mud Bay and therefore have a bearing on success or failure of the set in that bay. This possibility was therefore surveyed as follows:

Reference is made to Figure 53 showing a horizontal plankton section through Mud Bay on a cycle of tides. It will be noticed that maximum larvae counts were obtained at Station A, fartherest up toward the head of the bay and that they appeared at this location in maximum abundance only after the height of the tide was 12 1/2 feet or higher. Although from this one study it remains a mystery where the larvae are at low tide, it may be a general rule that only tides of height + 12 1/2 feet* or greater will bring the larvae in the region of Station A. Now this is just the area of the bulk of commercial cultching in Mud Bay as it is also the location of our station for test cultch.

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* Since there is no reference tide station for Mud Bay we use the +3.6 feet correction factor for Burns Point, Oyster Bay, applied to Seattle tide tables.

Although the 1951 season is not included in this review paper, we wish to refer to it in the present connection. Suffice it to say that in 1951 the larvae abundance reached a satisfactory maximum of over 3000 per 20 gallons in Mud Bay and somewhere between 2% and 5% of these attained near-setting size in July 9th samples. Nevertheless the setting intensity never exceeded 70 spat per 100 Pacific oyster shells per day, which is poor.

That is to say, according to the larvae data the peak of spatting in Mud Bay should have been reached around July 9th. Refering to 1951 tide tables we see however that on July 8 through July 13 only half of the high tides attained a height of +12 1/2 feet or greater. On the hypothesis suggested this would mean that the larvae which were apparently ready to set had only half a chance of reaching the cultching area though it is difficult to explain why the set was not therefore at least half as good as normal instead of being in fact unusually low.

Turning how to the other years of our study in Mud Bay we may analyze them with reference to whether (1) the larvae picture was favorable, ie., showed a thousand or so larvae in the samples and growth toward setting size, (2) the tides were favorable or not when the larvae were ready to set in abundance i.e. whether both daily high tides were of height + 12 1/2 feet or greater, or whether only one high tide a day reached this height, and (3) whether the rainfall of the season was normal or abnormal and therefore the salinity presumably altered accordingly (see Table 62) This survey reveals the following:

(INSERT Table 62)

TABLE 62 :

SPATFALL SUCCESS IN MUD BAY IN RELATION TO CERTAIN FACTORS

YEAR	MAXIMUM SETTING INDEX	LARVAE PICTURE	TIDES AT LARVAE PEAK	RAINFALL
1944	42	insufficient large larvae	good	very abnormal
1945	3500	good	good	not very abnormal
1946	14	insufficient large larvae	good	abnormally high June precipitation
1947	1600	fair	poor only for a few days, then good	not very abnormal
1948	5000+	good	good	early dry season balanced by later rain
1949	600	good	poor	quite abnormal
1950	2800	good	good	not very abnormal
1951	70	good	poor	early rain possibly balanced by later dry months

From this review of the setting seasons in Mud Bay we see that spatting failures can be accounted for either by abnormal rainfall (1944, 1946, and possibly 1951) or by the occurence of neap tides at the time of setting (possibly 1949 and 1951).

When we return to Hopkins' observations on Mud Bay, we find that his Figure 33, P. 486, shows that in 1935 the setting peak in Mud Bay did coincide sharply with a run of spring tides. The same is the case with the set in all the other seasons of his study of this bay (1931 - 1934). In fact we note that Hopkins' principle of maximum setting at spring tides holds very well for Mud Bay, although perhaps for different reasons than he thought (ie. "Frequency of setting appears to be associated with swiftness of current"), while the case for this rule does not seem to me at all clear-cut with reference to Oyster Bay. Of course we do not know the larvae picture for Mud Bay, 1931 through 1935, and so can never in any instance tell whether the larvae happened to be ready to set on a spring tide or were picked up on the cultch because there was a spring tide maximum. It is improbable however that this relation of setting maxima to spring tides was in every case a coincidence and therfore Hopkins' observations do add some evidence for the idea that two daily high high-tides were necessary to bring the setting larvae to his Mud Bay setting stations, which were even farther up the bay than ours.

If absence of spring tides in Mud Bay at the time when the larvae are prepared to set in abundance may explain setting failures during some years, why then are sets in Oyster Bay and in North Bay so generally successful in spite of the fact that during some years neap tides come during the setting maxima? To answer this question we refer to plankton studies in these bays during a tidal cycle. In the case of Oyster Bay we note that the maximum larvae abundance was found at just up-bay from Station 9 (station C in Fig. 52).during the second half of flooding tide and that the larvae never appeared in great abundance farther up the bay. If one can generalize from this one study it may be said that in Oyster Bay the larvae are not carried all the way up to the head of the inlet as is the case in Mud Bay. Practice confirms this, for the seed grounds in Oyster Bay are relatively down-bay, in the region of Station 9 or Dike 5 and Burns Point. This being the case, Oyster Bay should not be affected by tidal range in this area and it is not. This circumstance rather than imprecise location of dates of maximum setting due to fouling of 7-day cultch explains the exceptions to his rule in the case of Oyster Bay which Hopkins could not otherwise account for.

Refering now to the one tidal study in North Bay (Fig. 55) we find that there is not much difference between larvae abundance at the three stations in North Bay proper at the end of Case Inlet and therefore again we do not have in this bay, as in Mud Bay, any indication of the concentrating of the larvae toward the head of the bay at high water. Hence in North Bay, too, the set appears to be largely independent of range of tides as can be seen by noting setting peaks in relation to spring tides which is shown in the bay-year graphs.

Let it be repeated that Mud Bay setting failures represents the one anomaly in the picture of the bays of lower Puget Sound. Poor spatting in Oakland Bay and South Bay are due to the failure for one reason or another to produce sufficient abundance of setting larvae. Variation in spatfall from year to year in Oyster Bay and North Bay is probably correlated with changes in spawning population due to marketing of oysters as well as to changes in weather, abundance of larvae predators (eg. Noctiluca, Pleurobrachia), etc., and in any case a satisfactory catch now seems always possible. But in Mud Bay there may be poor sets although larvae are annually produced in rather favorable numbers. Now we have only three years during our study in which distinct Mud Bay set failures occured; two of these (1944 and 1946) were toward the beginning of our investigations and the third (1951) almost falls outside the perview of this paper. Hence at this time the best we can do on the basis of these three cases is to conjecture the reasons for spat failures in Mud Bay in the hope of providing some degree of probability in anticipating such bad seasons when cultching is unprofitable. Future studies, based on these suggestions, may then in time lead to a thorough knowledge of the conditions for a satisfactory set in Mud Bay.

It has already been described how in 1944 and 1946 the larvae in Mud Bay apparently failed to develop in sufficient numbers to setting size and how this might be attributed indirectly to abnormal rainfall.

The notion regarding the relation of range of tide to spatting success complicates the picture in Mud Bay but this complexity is by no means unmanageable. We can cut right through it by stating that, until we have more certain knowledge from further cases of spat failures in Mud Bay, one may be on the lookout for such failures when-------

1) the total abundance of larvae is less than 1000 per 20 gallons and the number of near-setting size larvae less than 100, and/or

2) the precipitation as recorded at Priest Point Park, Olympia is definitely abnormal in the manner discussed on P. 118 , and / or

3) a period of neap tides follows the predicted date for the beginning of the first wave of setting. When any one or any combination of these circumstances is the case, then the spatting possibilities are precarious and the chances are small that a profitable catch will be obtained in commercial cultch accord'ng to the observations so far accumulated.

TABLE 4 : FIELD DATA, 1942

	DATE	PERCENT OF OYSTERS SPAWNING* AS FEMALES			MID-DATE	RATE OF SPATFALL**
		White-sick	Gray-sick	Total		
OYSTER BAY (Dike 5, Olympia Oyster Co.)	May 5	8	0	8		
	May 8	16	0	16		
	May 12	14	0	14		
	May 15	17	0	17		
	May 18	16	0	16		
	May 23	31	1	32		
	May 29	12	9	21		
	June 1	11	4	15		
	June 5	9	0	9		
	June 8	7	0	7		
	June 12	2	4	6	June 12	0
	June 15	10	7	17	June 15	0
	June 19	6	1	7	June 19	3
	June 23	0	0	0	June 23	13
	June 26	3	2	5	June 26	19
	June 29	1	0	1	June 29	2
	July 3	4	0	4	July 3	1
	July 7	3	0	3	July 7	10
	July 10	0	0	0	July 10	2
	July 13	4	1	5	July 13	10
	July 17	4	3	7	July 17	17
	July 20	2	0	2	July 20	23
	July 24	0	0	0	July 24	22
	July 31	0	0	0	July 31	16
	Aug. 3	0	0	0	Aug. 3	9
	Aug. 7	0	0	0	Aug. 7	0
	Aug. 10	0	1	0	Aug. 11	0
	Aug. 14	0	0	0	Aug. 14	0
	Aug. 17	0	0	0	Aug. 17	5
	Aug. 21	0	0	0	Aug. 21	0
	Aug. 24	0	0	0	Aug. 24	0
MUD BAY (Dike B, Brenner Oyster Co.)	May 23	19	3	22		
	May 29	11	8	19		
	June 5	4	5	9		
	June 12	10	1	11	June 12	0
	June 19	9	0	9	June 19	12
	June 26	4	6	10	June 26	1
	July 3	2	5	7	July 3	0
	July 31	0	2	2	July 10	7
					July 17	21
					July 24	2
					July 31	3
	Aug. 7	1	0	1	Aug. 7	0
	Aug. 14	0	0	0	Aug. 14	0
	Aug. 21	0	0	0	Aug. 21	0

TABLE 4 : FIELD DATA, 1942 (cont'd)

	DATE	PERCENT OF OYSTERS SPAWNING* AS FEMALES			MID-DATE	RATE OF SPATFALL**
		White-sick	Gray sick	Total		
OAKLAND BAY (State Dike)	May 29	5	0	5		
	June 5	15	2	17		
	June 12	3	5	8	June 12	0
	June 19	9	0	9	June 19	0
	June 26	5	2	7	June 26	2
	July 3	1	0	1	July 3	1
	July 10	13	0	13	July 10	4
	July 13	3	2	5		
	July 17	0	2	2	July 17	4
					July 24	0
	July 31	0	0	0	July 31	0
	Aug. 7	0	0	0	Aug. 7	0
	Aug. 14	0	0	0	Aug. 14	0
	Aug. 21	0	0	0	Aug. 21	0

*Percentage of oysters in a sample of 100 mature individuals bearing unshelled (White-sick) and conchivarous larvae (Gray-sick).

**Number of spat per 20 Ostrea gigas shells per week. Mid-date of the 7-day period is given. Sample of 20 shells from a chicken wire bag containing about 100 were examined for spat.

TABLE 5: FIELD DATA, 1943

	DATE	PERCENT OF OYSTERS SPAWNING* AS FEMALES White-sick	Gray-sick	Total	MID*DATE	NO. DAYS CULTCH EMERSED	RELATIVE RATE OF SPATFALL**
OYSTER BAY (Dike 5, Olympia Oyster Co.)	May 3	0	0	0			
	13	2	0	2			
	18	4	0	4			
	21	3	1	4			
	25	8	1	9			
	29	11	6	17			
	June 2	8	10	18			
	4	20	4	24			
	8	21	6	27	June 10	3	1.7
	11	8	15	23	13	4	0.5
	15	12	16	28	17	3	2.0
	18	4	9	13	20	4	0.3
	22	2	10	12	24	3	0.2
	25	7	1	8	27	4	10.8
	29	2	2	4	July 1	3	0.7
	July 2	0	7	7	4	4	0.3
	6	2	0	2	8	4	0.1
	10	3	1	4	12	3	0.5
	13	0	3	3	15	3	0
	16	0	1	1	18	4	1.0
	20	2	0	2	22	4	1.3
	24	1	1	2	26	3	7.5
	27	0	1	1	29	3	3.3
	30	1	0	1	Aug. 1	4	1.4
	Aug. 3	0	1	1	7	8	0
					15	7	3.9
					22	?	7.9
MUD BAY	May 3	0	0	0			
	13	2	0	2			
	18	3	0	3			
	21	8	2	10			
	24	16	1	17			
	29	16	5	21			
	June 2	15	9	24			
	4	20	9	29			
	8	17	5	22	June 10	3	1.7
	11	12	16	28	13	4	0.5
	15	7	19	26	17	3	1.3
	18	11	16	27	20	4	0.2
	22	2	10	12	24	3	0.5
	25	7	13	20	27	4	0
	29	4	1	5	July 1	3	1.7
	July 2	5	1	6	4	4	0
	6	6	6	12	8	4	0
	10	8	3	11	12	3	0.7
	13	1	4	5	15	3	0
	16	11	5	16	18	4	0.8
	20	3	1	4	22	4	0.1
	24	0	6	6	26	3	0.3
	27	0	0	0	29	3	3.3
	30	0	0	0	Aug. 1	4	1.1
	Aug. 4	1	0	1	15	7	6.1
					22	8	0.9

TABLE 5 : FIELD DATA, 1943 (cont'd)

	DATE	PERCENT OF OYSTERS SPAWNING* AS FEMALES			MID-DATE	NO. DAYS CULTCH EMERSED	RELATIVE RATE OF SPATFALL
		White-sick	Gray-sick	Total			
NORTH BAY (State Dike)	May 15	3	0	3			
	19	4	1	5			
	23	12	4	16			
	26	17	5	22			
	29	9	8	17			
	June 2	11	15	26			
	5	5	13	18			
	9	13	8	21	June 11	3	0
	12	4	9	13	14	4	0.1
	16	1	20	21	18	3	0.2
	19	8	9	17	21	4	0
	23	6	6	12	27	5	0
	26	6	3	9	28	3	0.8
	30	2	2	4	July 2	4	0.1
	July 3	4	1	5	5	4	0
	7	3	2	5	9	3	0
	10	4	2	6	12	4	0
	14	0	1	1	16	3	0.1
	17	4	0	4	20	3	0.4
	21	4	0	4	23	3	0
	24	0	4	4	26	4	0.1
	27	0	1	1	30	3	0.8
	31	1	0	1	Aug. 2	5	0
					16	7	0
					23	8	0.05
OAKLAND BAY	May 29	0	0	0			
	June 2	1	0	1			
	4	1	0	1			
	8	0	0	0	June 10	3	0
	11	0	0	0	13	4	0.4
	15	1	0	1	17	3	0
	18	9	1	10	20	4	0
	22	2	2	4	24	3	0
	25	5	3	8	27	4	0
	29	2	2	4	July 1	3	0
	July 2	1	3	4	4	4	0
	6	11	1	12	8	4	0
	10	5	0	5	12	3	0
	13	1	2	3	15	3	0
	16	5	1	6	18	4	0.1
	20	2	0	2	22	4	0
	24	0	0	0	26	3	0.1
	27	0	0	0	29	3	0
	30	0	0	0	Aug. 1	4	0
	Aug. 3	0	1	1	15	7	0.2
					22	8	0

* Percentage of oysters in a sample of 100 mature individuals bearing unshelled (White-sick) and conchivarous larvae (Gray-sick).

** Maximum spat per day per glass plate (70 square inches, under surface only).

TABLE 6 : SPAWNING, 1944

OYSTER BAY

DATE		PERCENT OF OYSTERS SPAWNING AS FEMALES		
		White-sick	Gray-sick	Total
May	5	0	0	0
	11	32	0	32
	19	16	12	28
	22	20.7	10.3	31.0
	26	14.5	26.1	40.6
June	3	9.3	2.9	11.6
	6	1.6	8.1	9.7
	10	0	4	4
	14	0	3.2	3.2
	17	5	0	5
	20	7.3	1.8	9.1
	23	4.0	11.8	15.8
	28	3.5	1.8	5.3
	30	4.0	11.8	15.8
July	4	7.1	3.6	10.7
	7	6.0	4.0	10.0
	11	7.3	1.8	9.1

MUD BAY

DATE		PERCENT OF OYSTERS SPAWNING AS FEMALES		
		White-sick	Gray-sick	Total
May	4	0	0	0
	11	7.6?	0	7.6
	19	13.8	1.1	14.9
	22	10.9	0	10.9
	26	18.0	3.9	21.9
June	3	16.7	6.7	23.4
	6	8.6	8.6	17.2
	10	20.0	6.0	26.0
	14	1.5	7.5	9.0
	17	1.7	8.3	10.0
	20	6.8	1.7	8.5
	23	6.0	0	6.0
	28	0	5	5
July	1	2	8	10
	4	3.4	0	3.4
	7	3.2	1.6	4.8
	11	5.3	0	5.3

NORTH BAY

DATE		PERCENT of OYSTERS SPAWNING AS FEMALES		
		White-sick	Gray-sick	Total
May	4	0	0	0
	11	0	0	0
	19	18.8	6.2	25.0
	26	8.2	8.2	16.4
June	3	4.4	4.4	8.8
	6	8.6	10.3	18.9
	10	28.0	0	28.0
	17	0	5.7	5.7
	20	0	3.0	3.0
	23	3.8	3.8	7.6
	30	2.8	1.4	4.2
July	4	5.1	0	5.1
	7	8.9	0	8.9
	11	3.3	0	3.3

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SOUTH BAY

DATE		PERCENT OF OYSTERS SPAWNING AS FEMALES		
		White-sick	Gray-sick	Total
May	12	0	0	0
	19	0	1.5	1.5
	26	3.1	0	3.1
June	3	5.7	3.6	9.3
	6	1.9	0	1.9
	10	6.0	2.0	8.0
	17	0	3.6	3.6
	20	6.8	3.4	10.2
	23	6.0	0	6.0
July	1	1.6	3.2	4.8
	4	6.0	2.0	8.0
	7	1.8	1.8	3.6
	11	0	0	0

OAKLAND BAY

DATE		PERCENT OF OYSTERS SPAWNING AS FEMALES		
		White-sick	Gray-sick	Total
May	4	0	0	0
	11	0	0	0
	19	3.9	0	3.9
	22	6.5	0	6.5
	26	10.0	4.0	14.0
June	3	6.6	11.5	18.1
	6	5.4	5.4	10.8
	10	6.8	8.5	15.3
	14	0	10.3	10.3
	17	0	3.2	3.2
	20	3.3	1.7	5.0
	23	1.9	5.8	7.7
	28	0	0	0
	30	1.2	7.1	8.3
July	4	7.1	3.6	10.7
	7	4.8	6.5	11.3 3
	11	0	3.8	3.8

TABLE 7 : SPAWNING, 1945

OYSTER BAY
(Dike 5b, Olympia Oyster Co.)

DATE	PERCENT OF OYSTERS SPAWNING AS FEMALES		
	White-sick	Gray-sick	Total
May 4	0	0	0
11	7.3	0	7.3
22	9.0	0	9.0
26	13.0	9.3	22.3
30	10.2	10.2	20.4
June 4	10.0	14.0	24.0
9	8.3	5.6	13.9
12	1.9	9.4	11.3
16	1.7	1.7	3.4
19	3.4	1.7	5.1
24	3.5	7.4	10.9
27	3.1	9.2	12.3
30	1.7	8.4	10.1

MUD BAY
(Bremner Dike)

DATE	PERCENT OF OYSTERS SPAWNING AS FEMALES		
	White-sick	Gray-sick	Total
May 4	0	0	0
11	0	0	0
26	12.3	0	12.3
30	20.6	3.2	23.8
June 4	10.0	16.7	26.7
12	8.8	7.0	15.8
16	1.5	13.4	14.9
19	5.0	8.4	13.4
24	2.7	11.0	13.7
27	1.4	9.6	11.0
30	0	3.4	3.4

NORTH BAY
(Nelson Dike)

DATE	PERCENT OF OYSTERS SPAWNING AS FEMALES		
	White-sick	Gray-sick	Total
May 4	0	0	0
26	4.7	9.3	14.0
30	5.7	8.6	14.3
June 4	4.7	10.6	15.3
12	1.3	3.8	5.1
16	2.9	10.1	13.0
19	1.8	5.4	7.2
24	1.4	1.4	2.8
27	2.6	2.6	5.2

SOUTH BAY

DATE		PERCENT OF OYSTERS SPAWNING AS FEMALES		
		White-sick	Gray-sick	Total
May	4	0	0	0
	30	12.5	12.5	25.0
June	12	3.8	17.0	20.8
	16	4.8	2.4	7.2
	19	2.0	5.9	7.9
	24	3.7	3.7	7.4
	27	0	3.2	3.2
	30	10.0	4.0	14.0

OAKLAND BAY
(State Dike)

DATE		PERCENT OF OYSTERS SPAWNING AS FEMALES		
		White-sick	Gray-sick	Total
May	4	0	0	0
	11	0	0	0
	22	5.4	0	5.4
	26	18.5	0	18.5
	30	1.7	10.3	12.0
June	2	3.6	1.8	5.4
	9	15.9	9.5	25.4
	12	21.2	0	21.2
	16	3.6	7.1	10.7
	19	7.5	6.7	14.2
	24	6.1	4.6	10.7
	27	2.9	2.9	5.8
	30	3.2	6.3	9.5

TABLE 8 : SPAWNING, 1946

DATE	OYSTER BAY: PERCENT OF OYSTERS SPAWNING AS FEMALES			MUD BAY: PERCENT OF OYSTERS SPAWNING AS FEMALES			NORTH BAY: PERCENT OF OYSTERS SPAWNING AS FEMALES		
	White-sick	Gray-sick	Total	White-sick	Gray-sick	Total	White-sick	Gray-sick	Total
May 8	0	0	0	0	0	0	0	0	0
20	14	8	22	6	0	6	8	0	8
27	0	4	4	6	2	8	30	2	32
June 4	8	0	8	18	8	26	12	0	12
11	0	10	10	2	4	6	10	4	14
18	6	0	6	8	2	10	4	0	4
25	0	4	4	6	4	10	6	6	12
July 2	4	2	6	6	0	6	16	0	16
9	0	0	0	2	0	2	0	4	4
15	12	0	12	4	8	12	6	0	6
23	2	2	4	2	0	2	0	0	0

137 cont.

SOUTH BAY

DATE		PERCENT OF OYSTERS SPAWNING AS FEMALES		
		White-sick	Gray-sick	Total
May	8	0	0	0
	20	4	0	4
	27	20	0	20
June	4	20	8	28
	11	10	12	22
	18	4	14	18
	25	0	4	4
July	2	2	2	4
	9	8	2	10
	15	6	4	10
	23	2	0	2

OAKLAND BAY

DATE		PERCENT OF OYSTERS SPAWNING AS FEMALES		
		White-sick	Gray-sick	Total
May	8	0	0	0
	20	0	0	0
	27	4	0	4
June	4	12	2	14
	11	6	6	12
	18	16	2	18
	25	0	4	4
July	2	6	0	6
	9	4	2	6
	15	4	0	4
	23	2	0	2

TABLE 9 : SPAWNING, 1947

DATE	OYSTER BAY PERCENT OF OYSTERS SPAWNING AS FEMALES			MUD BAY PERCENT OF OYSTERS SPAWNING AS FEMALES			NORTH BAY PERCENT OF OYSTERS SPAWNING AS FEMALES		
	White-sick	Gray-sick	Total	White-sick	Gray-sick	Total	White-sick	Gray-sick	Total
May 21	6.7	8.3	15.0	5.3	0	5.3	3.4	0.8	4.2
June 4	6.0	1.2	7.2	--	--	--	4.5	7.5	12.0
7	--	--	--	9.2	3.4	12.6	--	--	--
10	4.8	7.9	12.7	--	--	--	5.9	7.8	13.7
16	3.7	1.8	5.5	7.8	15.7	23.5	0	3.9	3.9
25	0	8.3	8.3	0	2.5	2.5	0	10.6	10.6
July 1	6.8	0	6.8	3.0	0	3.0	0	0	0

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SOUTH BAY			OAKLAND BAY		
PERCENT OF OYSTERS SPAWNING AS FEMALES			PERCENT OF OYSTERS SPAWNING AS FEMALES		
White-sick	Gray-sick	Total	White-sick	Gray-sick	Total
3.0	0	3.0	2	0	2
--	--	--			
--	--	--			
--	--	--			
16.7	0	16.7			
0	7.3	7.3			
9.4	6.2	15.6			

TABLE 10: SPAWNING, 1948

DATE	OYSTER BAY PERCENT OF OYSTERS SPAWNING AS FEMALES			MUD BAY PERCENT OF OYSTERS SPAWNING AS FEMALES			NORTH BAY PERCENT OF OYSTERS SPAWNING AS FEMALES			PERCEN
	White-sick	Gray-sick	Total	White-sick	Gray-sick	Total	White-sick	Gray-sick	Total	White-
May 27*	0	0	0	0	0	0	0	0	0	0
June 3	1.9	0	1.9	4.4	0	4.4	16.3	0	16.3	2.[illegible]
7	16.2	0	16.2	3.9	0	3.9	19.0	1.9	20.9	3.[illegible]
10	15.9	8.2	24.1	2.4	0	2.4	16.5	8.6	25.1	
14	19.6	5.4	25.0	10.6	5.6	16.2	5.3	14.0	19.3	9.6
18	11.1	1.6	12.7	13.4	1.2	14.6	17.3	6.7	24.0	14.
21	16.3	2.5	18.8	21.4	2.9	24.3	5.8	5.8	11.6	0.8
24	7.2	16.4	23.6	10.0	10.0	20.0	9.5	1.6	11.1	8.9
28				4.1	8.2	12.3				13.

* Adequate samples of both May 24 and May 27 showed no spawning.
This is quite interesting in showing a preciptous development of spawn, especially in the always precipitous North Bay.

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SOUTH BAY			OAKLAND BAY		
PERCENT OF OYSTERS SPAWNING AS FEMALES			PERCENT OF OYSTERS SPAWNING AS FEMALES		
White-sick	Gray-sick	Total	White-sick	Gray-sick	Total
0	0	0	0	0	0
2.6	0	2.6			
3.3	0	3.3	0	0	0
			0	0	0
9.6	0	9.6			
14.0	2.3	16.3	3.0	1.0	4.0
0.8	4.2	5.0			
8.9	0	8.9	0	0	0
13.5	0.9	14.4			

TABLE 11: SPAWNING, 1949

DATE	OYSTER BAY PERCENT OF OYSTERS SPAWNING AS FEMALES			MUD BAY PERCENT OF OYSTERS SPAWNING AS FEMALES			NORTH BAY PERCENT OF OYSTERS SPAWNING AS FEMALES		
	White-sick	Gray-sick	Total	White-sick	Gray-sick	Total	White-sick	Gray-sick	Total
May 27	8.0	0	8.0	12.3	0	12.3	6.4	0	6.4
June 2	11.5	1.2	12.7	21.3	0	21.3	7.9	0	7.9
8	14.6	13.3	27.9	16.0	4.0	20.0	6.6	5.3	11.9
13	18.7	2.7	21.4	12.0	10.7	22.7	6.6	1.3	7.9
16				2.7	6.7	9.4	10.7	6.7	17.4

TABLE 12: SPAWNING, 1950

DATE	OYSTER BAY PERCENT OF OYSTERS SPAWNING AS FEMALES			MUD BAY PERCENT OF OYSTERS SPAWNING AS FEMALES			NORTH BAY PERCENT OF OYSTERS SPAWNING AS FEMALES		
	White-sick	Gray-sick	Total	White-sick	Gray-sick	Total	White-sick	Gray-sick	Total
June 3	10.0	0	10.0	4.0	0	4.0	6.0	0	6.0
8	15.0	0	15.0	12.0	0	12.0	3.0	0	3.0

TABLE 13: PELAGIC LARVAE, 1944

OYSTER BAY
(Combined Stations 7, 8 & 9)

DATE	MAXIMUM TOTAL COUNT	% LARGE LARVAE	NUMBER LARGE LARVAE
May 10	0	0	0
17	32	0	0
25	252	0	0
June 2	1,152	0	0
12	17,400		
15	7,040	2.7	90
19	3.840	2.6	100
26	7,896	6.5	434
July 3	836	3.7	31
17	7,152	6.9	493
27	2,000*	4.7	94
Aug. 7	100*	13.1	13
14	2*	0	0
28	200*	7.0	14
Sep. 5	5*	5.9	0

MUD BAY
(Combined Stations 3 & 4)

DATE	MAXIMUM TOTAL COUNT	% LARGE LARVAE	NUMBER LARGE LARVAE
May 10	44	0	0
17	36	0	0
June 2	544	0	0
15	700	0	0
26	563	1.6	9
July 3	3,200	3.2	102
17	1,472	0.4	6
24	512	0	0
27	300	0.8	2
31	36	0	0
Aug. 7	8	0	0
9	44	0	0
14	0	0	0

(

DATE
May 11
17
25
June 2
12
15
19
20
July 3
20
24
27
31
Aug. 7
14
28
Sep. 5
12
Oct. 9

*Average, plus.

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VAE, 1944

NORTH BAY
(Combined Stations 10, 11, 12)

DATE	MAXIMUM TOTAL COUNT	% LARGE LARVAE	NUMBER LARGE LARVAE
May 11	36	0	0
17	4	0	0
25	12	0	0
June 2	568	0	0
12	360	0	0
15	3,884	4.6	179
19	2,884	9.6	277
20	456	15.3	70
July 3	700	11.2	78
20	496	4.5	22
24	184	9.7	18
27	212	7.7	16
31	40		
Aug. 7	80	5.0	4
14	12		
28	20		
Sep. 5	4		
12	4		
Oct. 9	0		

SOUTH BAY

DATE	MAXIMUM TOTAL COUNT	% LARGE LARVAE	NUMBER LARGE LARVAE
May 17	0	0	0
June 2	8	0	0
15	28	0	0
26	252	0.8	2
July 3	2,132	4.9	104
7	676	1.8	12
24	56	0	0
27	24		
31	172	13.9	24
Aug. 7	0		
8	32		
9	16		
14	20		
28	0		
Sep. 2	0		

OAKLAND BAY
(Combined stations 19 & 20)

DATE	MAXIMUM TOTAL COUNT	% LARGE LARVAE	NUMBER LARGE LARVAE
May 17	0	0	0
25	8	0	0
June 2	144	0	0
12	904	0	0
15	1,316	0	0
19	1,036	0.8	8
July 3	180	1.1	2
20	520		
24	656	1.4	9
27	1,200	1,8	22
31	1,800	4.0	72
Aug. 7	160	14	22
14	12		
21	8		
28	16		
Sep. 5	32		
12	12		
Oct. 9	0	0	0

E 14 : PELAGIC LARVAE, 1945

NORTH BAY
(Combined Stations 11, 12, 12A)

DATE		MAXIMUM TOTAL COUNT	% LARGE LARVAE	NUMBER LARGE LARVAE
May	29	4	0	0
June	8	1,012	0	0
	20	1,348	36	485
	29	648	15	97
July	10	600	1	6
	20	416	4.5	19
Aug.	3	56	17.5	10
	8	44	43	19

SOUTH BAY
Combined Stations 15, 15A & 15B)

DATE		MAXIMUM TOTAL COUNT	% LARGE LARVAE	NUMBER LARGE LARVAE
May	23	0	0	0
June	2	12	0	0
	15	0	0	0
	22	176	0	0
	26	956	2	19
July	3	1,060	0.1	1
	6	868	1.4	12
	9	552		
	10	816	2.5	20
	13	336	19	64
	17	236	9	21
	24	132	7.5	10
	30	144	3	4
Aug.	3	168	7	12
	8	32	0	0
	30	12	33	4
Sep.	8	0	0	0

OAKLAND BAY
(Combined Stations)

DATE		MAXIMUM TOTAL COUNT	% LARGE LARVAE	NUMB LARG LARV
May	18	0	0	0
	23	0	0	0
	29	4	0	0
June	2	36	0	0
	8	616	0	0
	15	(8)	0	0
	20	9,304	0	0
	22	1,084	0	0
	26	216	0	0
	29	28	16	4
July	3	488	0.2	1
	6	288	1.7	5
	9	256		
	13	104	0	0
	17	572	6	34
	20	332	0	0
	24	232	1.7	4
	27	512	0	0
	30	124	0	0
Aug.	3	600	11	66
	8	124	9	11
	15	16	25	4
	24	0	0	0

143 cont.

TABLE 14

OYSTER BAY
(Combination of Stations 8 & 9)

DATE		MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE
May	18	0	0	0
	23	16	0	0
	29	420	0	0
June	2	2,836	0	0
	8	6,484	0	0
	15	4,216	0	0
	20	38,578	Under 1	-
	22	2,588	6	155
	29	15,880	3	476
July	3	7,784		
	13	13,104	4,5	590
	17	9,816	9.7	952
	20	3,628	21	762
	24	3,532	7	247
	30	3,896	9.7	378
Aug.	3	7,472	9	672
	7	1,868	16	299
	15	644	31	200
	30	52	13	7
Sep.	8	16	25	4

MUD BAY
(Average of Stations 3 & 4)

DATE		MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE
May	23	0	0	0
June	2	12	0	0
	15	324	0	0
	22	1,152	0.3	3
	26	1,760	2	35
	29	2,792	1.8	50
July	3	2.432	4	97
	6	516	3.3	9
	10	572	3	17
	13	4,812	5	240
	17	1,076	7	75
	24	152	15	23
	30	248	1.5	4
Aug.	3	48	8	4
	8	124	2	2
	30	0	0	0
Sep.	8	12	33	4

TABLE 15 : PELAGIC LARVAE, 1946

OYSTER BAY
(Combined Stations 7, 8 and 9)

DATE		MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE
May	28	1744	0	0
June	4	7816	0	0
	14	14832		80
	19	2940		44
	27	636		50
July	1	3120		416
	9	11432		288
	23	1652		32
Aug.	1	1292		16
	7	1352		32
	14	312		96
	20	6680	7.0	496
	29	76		4

MUD BAY
(Combined stations 3 and 4)

DATE		MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE
May	28	4	0	0
June	4	0	0	0
	16	272	0	0
	19	2748	0	0
	27	468	0	0
July	2	(36)	0	0
	9	412	1.5	6
	23	524	0	0
Aug.	1	24	0	0
	7	4	0	0

NORTH BAY
(Combined, Allyn Dock & Station 12)

DATE		MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE
June	4	20	0	0
	14	400	0	0
	21	884	0	0
	25	128	3.1	4
July	2	64	0	0
	9	96	12.5	12
	17	32	0	0
	23	40	0	0
	30	40	0	0
Aug.	1	856	0	0
	14	4	0	0

SOUTH BAY

DATE		MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE
June	4	0	0	0
	13	0	0	0
	19	240	0	0
	25	344	0	0
July	2	416	0	0
	9	260	0	0
	17	952		4
	23	56	0	0
Aug.	1	96	0	0
	7	96	10	10
	14	0	0	0

OAKLAND BAY
(Combined stations 19 and 20)

DATE		MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE
May	28	0	0	0
June	4	36	0	0
	13	656		4
	19	424	0	0
	27	172	0	0
July	2	132		4
	9	80	0	0
	17	44	0	0
	23	8	0	0
Aug.	1	56	0	0
	7	32	0	0

TABLE 16: PELAGIC LARVAE, 1

OYSTER BAY				MUD BAY			
DATE	MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE	DATE	MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE
May 27	520	0	0	June 7	116	0	0
June 12	7472	6.7	501	12	184	0	0
19	10880	12.3	1338	19	164	0	0
30	1096	22	241	30	1452	9.5	138

1947

NORTH BAY				SOUTH BAY			
DATE	MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE	DATE	MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE
May 27	220	0	0	June 19	616	0	0
June 12	92	0	0	30	1336	2	27
19	128	3.7	5				
30	388	20	78				

TABLE 17: PELAGIC LARVAE, 1948

DATE	OYSTER BAY MAXIMUM TOTAL COUNT	OYSTER BAY AVERAGE % LARGE LARVAE	OYSTER BAY NUMBER LARGE LARVAE	MUD BAY MAXIMUM TOTAL COUNT	MUD BAY AVERAGE % LARGE LARVAE	MUD BAY NUMBER LARGE LARVAE	NORTH BAY MAXIMUM TOTAL COUNT	NORTH BAY AVERAGE % LARGE LARVAE	NORTH BAY NUMBE[R] LARGE LARVA[E]
June 15	1124	0	0				620	0	0
22	3824	0	0	1224	0	0	3216	0	0
28	2088	0	0	4912	0	0	112	1	1
July 1	6320	1	63	804	0	0	4364	4	175
5	12,224	9	1100	6416	0	0	5440	4	218
12				192	50	96			
15				2424	33	808			
19	2472	?	?	5200	?	?			

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SOUTH BAY			OAKLAND BAY		
MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE	MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE
148	0	0			
112	0	0			
724	0	0	108	0	0
1168	0	0			
40	5	2			
328	12	39	0	0	0
832	?	?			

TABLE 18: PELAGIC LARVAE, 1949

ATE		OYSTER BAY MAXIMUM TOTAL COUNT	OYSTER BAY AVERAGE % LARGE LARVAE	OYSTER BAY NUMBER LARGE LARVAE	MUD BAY MAXIMUM TOTAL COUNT	MUD BAY AVERAGE % LARGE LARVAE	MUD BAY NUMBER LARGE LARVAE	NORTH BAY MAXIMUM TOTAL COUNT	NORTH BAY AVERAGE % LARGE LARVAE	NORTH BAY NUMBER LARGE LARVAE	SOUTH BAY MAXIMUM TOTAL COUNT	SOUTH BAY AVERAGE % LARGE LARVAE	SOUTH BAY NUMBER LARGE LARVAE
ay	27	16	0	0	8	0	0	0	0	0			
une	2	416	0	0	0	0	0	72	0	0			
	8	8032	0	0	712	0	0	688	0	0	32	0	0
	13	12928	0	0	1592	0	0	1208	0	0	8	0	0
	16	16256	?	?	1280	0	0						
	17							344	0	0			
	20	3096	?	?	1376	0	0	976	4	39	216	0	0
	23	8736	?	?	584	?	?	112	?	?	68	0	0
	26	10864	9	978	3552	?	?	228	4	9	152	0	0
	30	3976	19	755	608	10	61	112	7	8			
uly	5	13536	3.5	474	3632	4	145	1016	11	112	368	0	0
	8	11856	5	593	384	6	23	1488	8	119			
	11	8640	1.5	130	768	19	146	344	25	86	250	0	0
	18	6960	10?	696	448	2	9	384	16	61	96	0	0
	21	2088	25	522	1192	2.5	30	400	13	52			
	27	2632	16	421	328	7	23	128	11	14	144	0	0

TABLE 19: PELAGIC LARVAE, 1950

DATE	OYSTER BAY			MUD BAY			NORTH BAY		
	MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE	MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE	MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE
June 3	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
12	36	0	0	0	0	0	0	0	0
15	604	0	0	0	0	0	0	0	0
19	556	0	0	0	0	0	0	0	0
22	1164	0	0	44	0	0			
23							24	0	0
26	7656	0	0	352	0	0	2544	0	0
29	5200	0	0	960	0	0	4936	0	0
July 3	(548)	0	0	1396	0	0	(40)	0	0
6	10400	5	520	3328	0	0	(136)	0	0
10	6112	13	795	(172)	0	0	1640	11	180
13	7368	26	1916	1440	2	29	420	20	42
17	4776	33	1576	712	36	250	352	5	18
20	2836	66	1872	1416	22	312	1048	20	210
24	6928	9	2161	2472	8.5	210	1008	14	141
27	9046	20	1809	2144	29	622	5360	22	1179
31	2216	39	864	572	7	40	1097	30	328
Aug. 3	2312	0.7	16	52	38	20			

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SOUTH BAY			OAKLAND BAY		
MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE	MAXIMUM TOTAL COUNT	AVERAGE % LARGE LARVAE	NUMBER LARGE LARVAE
0	0	0	0	0	0
0	0	0			
4	0	0			
			4 per 5 minute tow		
88	0	0			
			16 " " " "		
548	0	0			
			20 " " " "		
(14)	0	0			
648	0	0	18	0	0
416	8	33	34	12	4
240	18.5	44	8	0	0

Blank

TABLE 21: COMPARISON OF REPEAT SAMPLES AT ALL STATIONS DURING CERTAIN DATES in 1945

STATION	NUMBER OF LARVAE PER 20 GALLON SAMPLE		
	First Sample	Repeat Sample	Repeat Sample
No. 1	372	536	
2	1444	3200	
3	760	1324	1472
4	836	388	
5	200	168	220
6	132	172	80
7	7152	3656	6768
8	392	328	
9	528	944	
10	3884	2832	
11	1120	292	
12	116	496	
13	172	252	
14	664	2132	
15	0	24	
16	240	68	676
17	32	4	
18	20	0	
19	1316	196	
20	776	1036	
21	520	84	120
22	4	0	

Blank

TABLE 23 : COMPARISON OF LARVAE SAMPLES AT ADJACENT STATIONS ON THE SAME DATE AND HOUR, 1945

Number of Larvae per 20 gallon sample

DATE		STATION NUMBERS								
		9	9A	12	12A	15	15A	15B	20	20A
May	29			0	0				4	0
June	2	280	2836							
	8	6484	1956	940	1012				616	36
	15	564	4216						0	8
	20	1956 3224	33984 33600	1136-	1144				1436	9304
	22	2588	700						1084	88
	29			344	388				16	28
July	3	3688	5408			700	636		488	412
	6					480	28		288	4
-	9								132	256
	10					488	816			
	13					220	240	336	40	52
	17	9816	716			236	92		436	108
	20	1940	2068	124	416				332	252
	24					68	132		232	16
	27								4	76
	30	244	276			108	144		0	64
Aug.	3	7472	1356	28	56	168	20		600	24
	8						4	32	124	92
	15	644	392						0	0
	30	44	0			4	12			
Sep.	8	0	0			0		0		

TABLE 24b VERTICAL DISTRIBUTION OF PLANKTON LARVAE, 1945

	DEPTH IN FEET	NUMBER OF LARVAE
	STATION 3	
June 26	0	1760
	1/2	1384
	2	1356
	5	856
June 29	0	496
	3	2792
July 13	0	896
	3	4812
	6	1240
July 17	0	24
High tide	1	4
Bottom 22 ft.	2	32
	3	36
	6	104
	9	196
	15	612
	20	1076
July 24	0	0
	3	152
	6	120
	9	108
	15	116
	20	56
	30	16
	STATION 8	
June 29	0	4
	3	140
July 20	0	28
1 1/2 hrs.	6	136
after low	9	1972
tide	15	3628
	20	1636
	STATION 9	
June 20	0	33,600
(9A)	3	38,528
	6	20,048
June 29	0	8480
(9A)	3	468
	5	452
June 29	0	5784
(9)	1	4044
	[illegible]	[illegible]

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(9)	3	4748
	5	3092
July 3	0	5408
(9A)	1	3888
	2	7850
	3	5696
	5	7784
July 20	0	2068
(9A)	9	1980
1/4 flood		
1 1/2 hrs after		
low tide		

STATION 10

July 20	0	24
3/4 flood to .1	1	4
flood	2	36
chart depth = 60'	3	16
4 1/2 hrs	6	0
after	9	0
low tide.	15	12
	20	16
	29	36

STATION 12

June 29	0	344
	1	648
	3	296

STATION 15

July 3	0	700
	1	760
	3	1060
July 17	0	236
	2	108

STATION 20

July 17	0	436
low	3	52
water		
July 27	0	76
	9	512

TABLE 25 : MOVING VS STATIONARY PUMP SAMPLES, 1945

Depth of sample: one foot unless otherwise indicated

		NUMBER OF LARVAE PER 20 GALLONS
STATION 3	June 26	
	Moving 6 inches	1384
	Stationary 1 foot	1760
	Stationary 2 feet	1356
STATION 8	July 3	
	Moving	608
	Stationary	972
STATION 4	July 3	
	Moving	1720
	Stationary	2432
STATION 8	June 29	
	Moving	16
	Stationary	4
STATION 8	July 3	
	Moving	7424
	Stationary	3928
STATION 9	June 20	
	Moving	3960
	Stationary	3224
STATION 9	June 29	
	Moving	15,880
	Stationary	8,480
STATION 9	July 3	
	Moving (station 9 to 9A)	2280
	Stationary (station 9)	3688
	Stationary (station 9A)	5408
STATION 11	June 20	
	Moving	620
	Stationary	548
STATION 12	June 20	
	Moving (station 12 to 12A)	1348
	Stationary (station 12)	1136
	Stationary (station 12A)	1144
STATION 12	June 29	
	Moving (station 12 to 12A)	144
	Stationary (station 12A)	388
STATION 15	June 26	
	Moving	556
	[illegible]	[illegible]

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STATION 15 July 3		
	Moving	636
	Stationary	700
STATION 15 July 13		
	Moving	240
	Stationary (station 15)	220
	Stationary (station 15B)	336
STATION 20 June 29		
	Moving (station 20 to 20A)	0
	Stationary (station 20)	16
	Stationary (station 20A)	28
STATION 20 July 3		
	Moving (station 20 to 20A)	412
	Stationary (station 20)	488
	Stationary (station 20A)	412

TABLE 26: SETTING RECORDS OF W. J. WALDRIP AT TWO LOCATIONS IN OYSTER BAY, 1936

	Burns Point Dike			Waldrip's Home Dike		
DATE	NUMBER OF DAYS SHELL IN BAY	TOTAL SPAT PER 5 SHELLS	SETTING INDEX*	NUMBER OF DAYS SHELL IN BAY	TOTAL SPAT PER 5 SHELLS	SETTING INDEX
June 16	1	0	0	1	0	0
17	1	0	0	1	0	0
18	1	0	0	1	0	0
19	1	0	0	1	0	0
20	1	0	0	1	0	0
21	1	0	0	1	0	0
22	1	0	0	1	0	0
23	1	0	0	1	0	0
24	1	0	0	1	0	0
25	1	0	0	1	0	0
26	1	0	0	1	0	0
27	1	0	0	1	0	0
28	1	0	0	1	0	0
29	1	1	20	1	0	0
30	1	1	20	1	0	0
July 1	1	5	100	1	0	0
2	1	5	100	1	0	0
3	1	15	300	1	2	40
5	2	30	300	2	10	100
6				1	10	200
7	2	68	680	1	10	200
9	2	130	1300	2	20	200
13	4	800	4000	4	39	195
14	1	158	3160	1	29	580
15	1	75	1500			
16	1	54	1080	2	17	170
17	1	85	1700			
18	1	94	1880			
19	1	80	1600			
21	2	170	1700	5	49	196
23				2	20	200
29	8		"Shells covered with seed"			
30	1	0	0			
31	1	0	0			
Aug. 3	3	1	7			

* Average spat per 100 shells per day

TABLE 27: SETTING RECORDS OF W. J. WALDRIP AT TWO LOCATIONS IN OYSTER BAY, 1937

DATE	BURNS POINT DIKE: NUMBER OF DAYS SHELL IN BAY	BURNS POINT DIKE: TOTAL SPAT PER 5 SHELLS	BURNS POINT DIKE: SETTING INDEX	WALDRIP'S HOME DIKE: NUMBER OF DAYS SHELL IN BAY	WALDRIP'S HOME DIKE: TOTAL SPAT PER 5 SHELLS	WALDRIP'S HOME DIKE: SETTING INDEX
June 23	Put out 5 shells					
30	7	17	49	7	0	0
July 4	4	88	440	4	118	590
5	1	103	2060	1	165	3300
6				1	242	4840
7	2	148	1480	1	245	4900
8				1	225	4500
10				2	500	5000
12				2	500	5000
16				4	250	1250
17				1	18	360
18				1	36	720
19				1	22	440
20				1	19	380
21	14	175	250	1	17	340
23	2	45	450	1	21	420
24				1	24	480
25				1	24	480
27				2	41	410
Aug. 1				5	1	20

TABLE 29: SETTING RECORDS OF W. J. WALDRIP AT TWO LOCATIONS IN OYSTER BAY, 1939

	BURNS POINT DIKE			WALDRIP'S HOME DIKE		
DATE	NUMBER OF DAYS SHELL IN BAY	TOTAL SPAT PER 5 SHELLS	SETTING INDEX	NUMBER OF DAYS SHELL IN BAY	TOTAL SPAT PER 5 SHELLS	SETTING INDEX
June 7	Put out first shells					
8			0			0
10			0			0
12			0			0
13			0			0
14			0			0
15			0			0
16			0			0
17			0			0
18			0			0
19			0			0
20			0			0
21			0			0
22			0	1	1	20
23	A tow by Townsend & Erickson showed only 2 in advanced stage					
24				1	3	60
25				1	5	100
26				1	5	100
27	5	31	125	1	9	180
28				1	20	400
29				1	5	100 (bag upset)
30	3	113	733	1	13	260
July 1	1	124	2480	1	37	740
2				1	80	1600
3	2	180	1800	1	98	1960
4				1	100	2000
5				1	65	1300
6				1	61	1250
7				1	71	1420
8				1	64	1280
11				3	368	2453
12				1	158	3160
13				1	102	2040
14				1	53	1060
15				1	42	840
17				2	44	440
18				1	8	160

TABLE 30: SETTING RECORDS OF W. J. WALDRIP AT TWO LOCATIONS IN OYSTER BAY, 1940

DATE	BURNS POINT DIKE: NUMBER OF DAYS SHELL IN BAY	BURNS POINT DIKE: TOTAL SPAT PER 5 SHELLS	BURNS POINT DIKE: SETTING INDEX	WALDRIP'S HOME DIKE: NUMBER OF DAYS SHELL IN BAY	WALDRIP'S HOME DIKE: TOTAL SPAT PER 5 SHELLS	WALDRIP'S HOME DIKE: SETTING INDEX
June 1	Put out test shells					
2			0			0
3			0			0
4			0			0
6			0			0
7	1	0	0	1	1	20
8	1	up set		1	2	40
9				1	2	40
10	2	2	20	1	2	40
11				1	0	0
12				1	0	0
14				2	0	0
15				1	1	20
16				1	1	20
17	5	1	4	1	1	20
18	1	0	0	1	0	0
19				1	1	20
21				1	0	0
22				1	1	20
24				1	2	40
25	Neap tide			1	4	80
27				2	6	60
29				2	4	40
30	12	13	20	1	3	60
July 1	1	3	60	1	2	40
2				1	2	40
3	2	20	200	1	7	140
4				1	11	220
5	2	13	130	1	3	60
6				1	9	180
7				1	4	80
8				1	8	160
9				1	4	80
12				3	1	7
13				1	1	20
14				1	2	40
15	9	35	78	1	0	0
16				1	5	100
19				3	2	13
21				2	5	50
24				3	12	80
29				5	16	64

TABLE 31: SETTING RECORDS OF W. J. WALDRIP AT TWO

LOCATIONS IN OYSTER BAY, 1941

DATE	BURNS POINT DIKE NUMBER OF DAYS SHELL IN BAY	BURNS POINT DIKE TOTAL SPAT PER 5 SHELLS	BURNS POINT DIKE SETTING INDEX	WALDRIP'S HOME DIKE NUMBER OF DAYS SHELL IN BAY	WALDRIP'S HOME DIKE TOTAL SPAT PER 5 SHELLS	WALDRIP'S HOME DIKE SETTING INDEX
May 27	Test shells put out					
28	1	0	0	1	0	0
29	1	0	0	1	0	0
30	1	0	0	1	0	0
31	1	0	0	1	0	0
June 2	2	0	0	2	0	0
3				1	0	0
5				1	0	0
6				1	0	0
7	1	0	0	1	0	0
8	1	0	0	1	0	0
9	1	0	0	1	0	0
10	1	0	0	1	0	0
11				1	0	0
12				1	0	0
13				1	0	0
14				1	0	0
15				1	0	0
16				1	0	0
17				1	0	0
18				1	0	0
19				1	0	0
20				1	0	0
21				1	0	0
22				1	0	0
23				1	1	20
24				1	0	0
25				1	1	20
26				1	0	0
27				1	0	0
28	1	0	0	1	0	0
29				1	0	0
30				1	0	0
July 1				1	1	20
2				1	1	20
3				1	0	0
4				1	0	0
5				1	1	20
6				1	1	20
7	8	4	10	1	0	0
8	1	3	60	1	0	0
9	1	2	40	1	3	60
10	1	2	40	1		
11				2	3	30
12				1	1	20
13				1	1	20
19				1	21	420
20				1	29	580
21				1	4	80
22				[illegible]	[illegible]	[illegible]

TABLE 32: SETTING RECORDS OF W. J. WALDRIP AT TWO LOCATIONS IN OYSTER BAY, 1942

DATE	BURNS POINT DIKE			WALDRIP'S HOME DIKE		
	NUMBER OF DAYS SHELL IN BAY	TOTAL SPAT PER 5 SHELLS	SETTING INDEX	NUMBER OF DAYS SHELL IN BAY	TOTAL SPAT PER 5 SHELLS	SETTING INDEX
June 25	Put out shells					
29	4	0	0	5	0	0
July 1	3	0	0	3	0	0
2				1	0	0
3				1	0	0
4				1	0	0
5				1	0	0
6				1	0	0
7				1	0	0
8				1	0	0
10	8	0	0			
11	9	0	0			
12				3	0	0
13	2	1	10			
14				2	0	0
15	2	0	0			
16				2	0	0
17	2	5	50	1	0	0
18	1	3	60	1	0	0
21				1	1	20
23	2	32	320	1	1	20
24	1	3	60	1	1	20
26	1	1	20	1	1	20
27	1	0	0	1	0	0
28				1	0	0
30	2	2	20			
31	0	0	0			
Aug. 2	2	1	10			
5				1	1	20
6	1	1	20			
7	1	1	20			

TABLE 33: SETTING INDEX, 1944

OYSTER BAY

MID-DATE		NUMBER OF: SPAT FOUND	SHELLS COUNTED	DAYS IN BAY	SETTING INDEX
June	16	2	24	3	3
	17	31	24	6	21
	20	171	24	6	102
	24	1,963	24	8	1,022
	27	1,838	24	7	1,094
July	1	1,319	24	6	916
	4	1,542	23	8	838
	8	1,774	24	7	1,056
	11	3,287	24	6	2,282
	15	2,000	24	7	1,190
	18	1,742	23	7	1,082
	22	3.890	24	7	2,315
	27	4,677	24	11	1,772
	29	3,480	24	8	1,812
Aug.	3	1,053	24	14	1,097
	5	1,001	24	6	695
	9	1,079	23	7	670
	12	926	24	7	551
	15	728	23	6	527
	19	1,144	24	7	681
	23	1,283	24	10	534
	26	1,115	23	8	606
	31	375	22	5	341
Sep.	3	1,652	24	7	983
	11	1,470	24	9	681
	15	109	24	7	65
	22	157	24	14	47
	24	74	24	11	28
Oct.	3	16	24	8	8
	12	15	24	5	12
	18	9	12	12	6

MUD BAY

MID-DATE		NUMBER OF: SPAT FOUND	SHELLS COUNTED	DAYS IN BAY	SETTING INDEX
June	17	0	24	6	0
	22	11	24	4	11
	26	10	12	4	21
	28	74	24	7	44
July	1	34	24	6	23
	4	18	24	6	12
	8	1	24	7	1
	11	9	24	7	5
	15	1	24	7	1
	18	15	24	7	9
	22	38	24	7	23
	27	18	24	11	7
	29	10	24	8	5
Aug.	5	0	24	6	0
	9	0	24	7	0
	12	0	24	7	0
	15	0	24	6	0
	19	0	24	7	0
	23	0	24	10	0

162 cont.

NORTH BAY

MID-DATE	NUMBER OF: SPAT FOUND	SHELLS COUNTED	DAYS IN BAY	SETTING INDEX
June 19	61	22	4	69
20	933	22	6	707
26	2,271	24	9	1,051
30	12,750	18	11	6,439
July 4	2,684	24	7	1,598
8	3,511	24	8	1,829
12	1,179	24	9	546
15	1,454	24	6	1,010
18	241	25	5	193
22	4,193	24	7	2,496
25	1,150	25	8	575
29	840	24	7	500
Aug. 2	193	24	7	115
5	284	24	7	169
9	45	24	7	27
12	246	24	7	146
15	68	24	6	47
19	236	12	7	281
23	58	24	10	24
27	74	24	9	34
31	8	24	5	7
Sep. 1	35	12	6	48
7	13	24	9	6
11	32	24	9	15
13	0	24	4	0
21	48	24	12	17
Oct. 2	2	24	10	1

SOUTH BAY

MID-DATE	NUMBER OF: SPAT FOUND	SHELLS COUNTED	DAYS IN BAY	SETTING INDEX
July 2	16	24	3	22
4	19	24	6	13
8	190	24	7	113
11	900	24	7	536
15	19	24	3	26
16	128	24	10	53
21	155	24	8	81
25	257	24	8	134
29	104	24	7	62
Aug. 1	81	23	6	59
5	21	24	7	12
8	63	24	8	33
12	39	24	7	23
15	13	24	6	9
19	2	24	7	1
23	5	24	10	2
26	5	24	8	3
31	0	24	5	0
Sep. 11	0	12		0
18	1	12		0
30	0	24		0
Oct. 7	0	24		0
12	0	24		0
24	0	24		0

162 Cont.

OAKLAND BAY

MID-DATE	NUMBER OF: SPAT FOUND	SHELLS COUNTED	DAYS IN BAY	SETTING INDEX
June 17	13	22	6	10
20	36	24	6	25
24	29	23	8	16
27	34	24	7	20
July 1	23	23	6	17
4	30	12	7	36
8	11	26	7	6
11	21	12	7	25
15	3	24	7	2
18	89	24	7	53
22	140	24	7	83
25	320	24	8	167
29	240	24	7	143
Aug. 2	515	24	7	306
5	361	24	7	215
9	26	24	7	15
12	21	24	7	12
15	16	24	6	11
19	11	24	7	6
24	19	24	12	7
26	10	24	8	5
Sep. 1	9	24	3	12
5	34	24	12	12
15	15	24	7	9
24	5	24	11	1
Oct. 7	0	24		0
12	0	24		0
29	0	24		0

TABLE 34: SETTING INDEX, 1945

MID-DATE	OYSTER BAY	MUD BAY	NORTH BAY	SOUTH BAY	OAKLAND BAY
June 18	3	0	1065	1	0
20	124	0	9818	1	3
23	706		7550		6
24		10		5	
27	1161	21	4179	11	14
July 1	779	36	1081	33	7
4	1905	930	1408	38	4
8	3039	1806	1748	66	11
11	5342	3397	2804	109	
13					42
15	6796	2326	1876	199	30
18	7378	1191	689	132	48
22	3317	443	102	53	40
25	1983	215	218	40	66
29	1687	71	281	21	48
Aug. 1	3439	17	119		15
2				7	
4	3082	35	71	0.2	15
8	5026	61	451	3	27
12	6043	18	416	17	49
14		12	177	4	10
17	9135				
19	1950				
20	1686	53	14	5	12
25	3029				
27	2120	147	28	3	8
Sep. 4	211	54	33	2	0
12	405				
20	3				

TABLE 35: SETTING INDEX, 1946

MID-DATE		OYSTER BAY		MUD BAY		NORTH BAY		SOUTH BAY		OAKLAND BAY	
		Days out	Index	Days out	Index	Days out	Index	Days out	Index	Days out	Index
June	8	7	0	7	0			7	0	7	0
	15	7	191	7	0	7	0.6			7	0
	22	7	549	7	0	7	452	7	0	7	0
	29	7	504	7	0	7	1310	7	0	7	4.7
July	4							5	0		
	6	7	2668	7	0.6	7	617			7	0
	7							4	0		
	12	6	585	6	13.2	6	324	6	2.7	6	0
	18							5	5.5		
	19	8	207	8	4.1	8	145			8	0
	22							3	.6		
	27	7	150	7	0.6	7	452	7	1.6	7	17
Aug.	3			7	0.6	7	216	7	10.5	7	14
	4	7	234								
	10	7	1554	7	0.7	7	2.4	7	6.1	7	0.7
	17	7	2048	7	0	7	7.7	7	11.6	7	0
	24	8	848	8	0.5	8	3	8	37.2	8	0.5
Sep.	10			26	0	26	6	26	4	26	0.7

TABLE 36: SETTING INDEX, 1947

MID-DATE	OYSTER BAY	MUD BAY	NORTH BAY	SOUTH BAY	OAKLAND BAY
June 18	1485		500		
21		477	3318		
22	17500				
29	8883	1627	3136	123	
July 4	7500				
12	7000	30	1000	24	

TABLE 37: SETTING INDEX, 1948

MID-DATE	OYSTER BAY	MUD BAY	NORTH BAY	SOUTH BAY	OAKLAND BAY
June 30	165		124		
July 3	1107	0	9478		
7	4340	125	4221	180	
10	6535	203	5200	6	
14	7020	1713	1780	50	39
17		4625		162	

TABLE 38 : SETTING INDEX, 1949

MID-DATE	OYSTER BAY	MUD BAY	NORTH BAY	SOUTH BAY	OAKLAND BAY
July 3	166	2	162		
7	80	16	423		
10	86	60	1503		
15	653	580	2561		
20	5653	176	356		
24	2800		885		
31	9333	143	245		

TABLE 39: SETTING INDEX, 1950

MID-DATE	OYSTER BAY	MUD BAY	NORTH BAY	SOUTH BAY	OAKLAND BAY
July 8	375				
12	835				
15	1935	27.5	1147		
18	3796	253	1626		
22	3703	2652	1785		
25	1763	2813	4250		
29	960	1180	2445		
Aug. 2	1073	507	920	8.5	
6	552	155	450		

TABLE 41: SEASONAL CULTCH, 1944

OYSTER BAY		MUD BAY		NORTH BAY		SOUTH BAY		OAKLAND BAY	
DATE	SPAT* PER SHELL	DATE	SPAT* PER SHELL	DATE	SPAT* PER SHELL	DATE	SPAT* PER SHELL	DATE	SPAT PER SHELL
June 23	80	June 24	5.25	June 23	37	July 1	4	June 24	5.4
30	85	July 2	4.17	30	39	7	14	30	5.1
July 8	81	7	3.33	July 7	33	14	7	July 7	8.8
11	79	14	3.33	16	0	21	5	14	1.8
14	68	21	1.17	21	2.5	29	2	21	3.0
21	63	Aug. 1	0	29	1.2	Aug. 8	0	29	0
Aug. 1	1			Aug. 5	1.0	15	0		
				12	0.4	22	0		
				18	0	28	0		

* 4 mm or over in diameter; both sides of shell counted.

TABLE 42: SEASONAL STRINGS, 1945* SPAT PER SHELL**

DATE PUT OUT	OYSTER BAY	MUD BAY	NORTH BAY	SOUTH BAY	OAKLAND BAY
June 19,20	107	70	34	2.5	--
27	62	52	43	2.5	0.7
July 4	63	61	33	2.0	0.7
11	77	27	16	0.7	0.4
18	45	4	16	0.4	2.6
25	17	1	8	0	1.4

* Strings were taken to laboratory Oct. 3, 1945

** These are spat counts for strings put out during first setting peak. Large and small spat were not distinguished. We therefore assume that they were large and that fouling prevented late-catch spat----as the magnitude of the counts indicates.

TABLE 43: SEASONAL STRINGS, 1946 SUMMARY OF LIVE SPAT PER SHELL

DATE		OYSTER BAY			MUD BAY			NORTH BAY			SOUTH BAY		
		LARGE	SMALL	TOTAL	LARGE	SMALL	TOTAL	LARGE	SMALL	TOTAL	LARGE	SMALL	TOTAL
June	18	134.6	62.9	197.5									
	25	115.4	62.4	177.8	.72	.27	.99	72.7	56.8	129.5	2.0	.66	2.66
July	2	92.8	85.5	178.3	.83	.083	.91	45.9	20.4	66.3	1.91	.583	2.49
	5										1.58	1.08	1.66
	9			158.5*	.5	.4	.9	25.6	22.1	47.7	1.45	1.9	3.35
	15	2.75	208.9	211.6	.16	.33	.49	14.0	26.6	40.6	1.09	3.36	4.45
	20										1.0	4.4	1.44
	23			209.9*		.25	.25	.72	7.54	8.3	1.09	4.81	5.9
	30			242.5*		.25	.25	1.8	37.4	39.2	1.18	5.0	6.18
Aug.	6	85.9	155.7	241.6		.25	.25	.083	1.0	1.1	.41	3.16	3.57
	13	81.7	127.9	209.6		.083	.083		.67	.67	.16	3.66	3.72
	20	.4	76.7	77.1		.083	.083		.75	.75		5.0	5.0
	28		91.6	91.6		.083	.083		.583	.583		1.75	1.75

* read as "small" only.

TABLE 44: SEASONAL STRINGS, 1947* AVERAGE SPAT PER SHELL

DATE PUT OUT	OYSTER BAY	MUD BAY	NORTH BAY	SOUTH BAY
July 1	257.36	32.3	2.4	2.75
8	149.2	3.9	7.8	1.16
17	70.25	67.7	3.1	5.6
Aug. 5			.33	

* Strings were taken in Sep. 11, 1947

TABLE 45: SEASONAL STRINGS, 1948** SPAT PER SHELL

DATE PUT OUT	OYSTER BAY	MUD BAY	NORTH BAY	SOUTH BAY	OAKLAND BAY
July 1	992.1*	59.5*	987.5	--	--
5	530.6*	84.9*	536.0	23.7	--
8	597.6*	74.1*	193.6	50.9	8.0
12	674.4*	115.1*	42.0	62.5	--
15	--	108.9	--	42.8	--
19	362.4	--	20.9	--	--

** Taken in Sep. 5, 1948 except those marked * which were taken in July 15, 1948.

NB Totals represent both large spat from the first wave of setting and small, late-set spat, the two not being distinguished.

TABLE 49: Tidal Cycle Study of Oyster Larvae at Oyster Bay
Station 9A, July 9, 1945

Standard Time	Depth	Number Larvae per 20 Gal.	Standard Time	Depth	Number Larvae per 20 Gal.
10:00AM	0	904	4:30PM	0	4,216
9:42	6	0	4:45	9	4,108
10:12	0	342	5:00	0	1,964
10:30	0	388	5:15	3	4,812
10:35	6	4	5:30	0	3,964
10:40	3	260	5:35	9	3,060
11:00	0	528	6:00	0	7,196
11:05	3	164	6:05	3	5,804
11:10	6	4	6:30	0	6,732
11:30	0	1,604	6:35	9	4,348
11:35	3	84	7:00	0	4,080
11:40	6	0	7:05	3	5,600
12:00	0	1,496	7:30	0	220
12:05PM	3	500	7:35	9	1,100
12:30	0	2,036	8:00	0	200
12:35	3	224	8:05	3	592
12:40	6	16	8:30	0	648
1:00	0	412	8:35	9	632
1:05	3	156	9:00	0	340
1:10	6	36	9:05	3	852
1:17	9	12	9:30	0	60
1:30	0	472	9:35	9	364
1:35	3	36	10:00	0	144
1:40	6	72	10:05	3	96
1:45	9	56	10:30	0	164
2:00	0	396			
2:05	3	476			
2:10	6	552			
2:15	9	344			
2:40	0	1,480			
2:45	3	1,653			
3:00	0	3,276			
3:30	0	5,508			
3:35	9	4,940			
4:00	0	3,456			
4:05	3	3,964			

TABLE 50: PLANKTON LARVAE SURVEY, OYSTER BAY, Aug. 7, 1945

STANDARD TIME	NUMBER OF LARVAE PER 20 GAL. SAMPLE AT STATION:			
	9	9a	Bowman's	8
10:00 AM	36			
10:30	72			
10:50			112	
11:00	80			
11:30	36		248	
11:45				
12:00 N	24			
12:30 PM	16			368
12:45			356	
1:00	116			
1:20		456		
1:30	128			
1:45			2204	
2:00	1304			
2:15		1208		
2:30	2684			
2:43				1572
2:50			3428	
3:00	3060			
3:15		804		
3:30	1412			
3:45				168
3:50			2816	
4:00	1868			
4:15		800		
4:30	1508			
4:40				248
4:50			2268	
5:00	1256			
5:15		840		
5:30	1020			
5:45				504
5:50			1392	
6:00	604			
6:15		1256		
6:30	2360			
6:40				364
6:50			856	
7:00	916			
7:15		392		
7:30	1936			
7:40				468
7:50			740	
8:00	2564			
8:10		1140		
8:30	3252			
9:00	2916			
9:30	1140			
10:00	3408			
10:30	1176			

TABLE 51: HORIZONTAL TIDAL CYCLE, July 1, 1946

TIME	DEPTH	NUMBER LARVAE PER 20 Gal.
STATION A		
8:00 AM	Surface	76
8:50		9
9:42		5
4:58 PM		3
6:20		56
7:00		174
7:50		106
5:45		78 7
STATION B		
8:16 AM	surface	19
9:00		32
10:07		5
10:42		12
4:15 PM		7
4:45		158
5:15		176
5:50		712
6:40		722
7:25		1251
STATION C [illegible]		
8:25 AM	surface	18
9:10		57
10:22		11
10:50		8
11:30		9
3:30 PM		2
4:00		4
4:30		138
4:43		89
5:15		1562
5:45		2028
6:20		2458
6:50		3292
STATION D		
7:10 AM	surface	252
7:45		64
8:20		738
8:56		1074
9:35		316
10:00		98
10:45		92
11:12	5	53
11:30		88
12:05		21
12:45		20
1:30 PM		25
2:15		45
2:45		9
STATION D (cont'd)		
3:15	surface	23
4:12		45
4:35		71
5:06		356
5:37		2208
6:13		1956
6:42		1564
7:25		846
STATION E		
7:07 AM	surface	112
8:00		14
8:30		61
9:03		546
9:45		582
10:21		94
10:55		244
11:50		124
12:25 PM		16
1:15		19
1:45		25
2:20		28
2:55		33
3:38		26
4:05		43
4:28		613
5:00		448
5:30		1471
6:00		1131
6:33		956
7:15		1112
STATION F		
7:00 AM		54
8:10		11
8:40		28
9:10		583
9:57		544
10:30		456
11:05		404
11:45		45
12:10 PM		32
12:45		16
1:10		16
2:15		7
2:40		14
3:00		55
3:30		39
3:58		303
4:50		1132
4:50	6 ft.	591

TABLE 51 (Cont'd)

TIME	DEPTH	NUMBER LARVAE PER 20 Gal.
STATION F (cont'd)		
5:45	surface	1796
6:28		2412
6:28	6 ft.	1015
7:05	surface	809
STATION G		
6:55 AM	surface	33
8:00		178
8:40		321
8:40	6 ft.	308
9:18	surface	2964
10:00		1424
10:00	6 ft.	2524
10:40	surface	346
11:12		124
11:55		44
12:35 PM		27
1:00		6
1:50		34
1:50	6 ft.	46
2:40	surface	55
3:15		48
3:30		476
3:30	6 ft.	1415
4:10	surface	779
5:40		716
5:40	6 ft.	780
5:40	3 ft.	392
5:50	surface	243
6:36		772
6:36	6 ft.	668
7:20	surface	94
STATION H		
6:35 AM	surface	11
8:06		17
8:47		93
8:47	6 ft.	212
9:38	surface	47
10:10		36
10:10	6 ft.	704
10:48	surface	7
11:10		104
11:10	6 ft.	708
11:53	surface	124
12:35 PM		138
12:35	6 ft.	1110
2:35	surface	303
2:35	6 ft.	1546
2:35	3 ft.	2035
2:45	surface	131
3:45	6 ft.	653
4:22	surface	156

TIME	DEPTH	NUMBER LARVAE PER 20 Gal.
STATION H (cont'd)		
5:07	surface	284
5:07	6 ft.	452
6:00	surface	364
6:00		92
6:50	6 ft.	262
7:30	surface	86
STATION I		
6:30	surface	10
8:15		6
9:02		11
9:02	6 ft.	31
9:44	surface	6
10:20		43
10:20	6 ft.	329
10:55	surface	2
11:25		15
11:25	6 ft.	291
12:00	surface	25
12:45 PM		19
12:45	6 ft.	732
2:40	surface	32
2:40	6 ft.	1197
2:40	3 ft.	270
3:55	surface	110
3:55	6 ft.	247
4:30	surface	16
5:20		44
5:20	6 ft.	44
6:06	surface	148
STATION J		
11:00 AM	surface	0
11:40		29
11:40	6 ft	154
12:07 PM	surface	7
12:55		89
12:55	6 ft.	289
2:00	surface	227
3:00	6 ft.	337
STATION K		
12:12 PM	surface	0
1:00		42
1:00	6 ft	27

*Larvae counts are number of larvae per 20 gallon sample. All samples taken at surface (1 foot depth) unless otherwise designated.

TABLE 52: HORIZONTAL TIDAL CYCLE, JULY 30, 1950 Showing Number of Larvae per 20 Gal. Sample

Standard	Section A				Section B				Section C				Section D				Section E			
Time	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
7:00 - 7:15 AM	448				64				0				48							
7:15 - 7:30		16	120			24				0	0			0						
7:30 - 7:45				0			8	32				0			0					
7:45 - 8:00	128				16				0							0				
8:00 - 8:15		288				16				8			0							
8:15 - 8:30							24	24			0			0						
8:30 - 8:45			616									24			0					
8:45 - 9:00					0				0							0				
9:00 - 9:15	8					16							0							
9:15 - 9:30		0					40			0				0	0					
9:30 - 9:45				88				80			0					0				
9:45 -10:00			16	24	96							8	24							
10:00-10:15	0					16			32					0						
10:15-10:30		8					72			80	24				0					
10:30-10:45			0					0								8				
10:45-11:00				0					120			40					0			
11:00-11:15					0					56			0					0		
11:15-11:30						8					16			16					8	
11:30-11:45							8					0			0	8		32		0
11:45-12:00								0	56											
12:00-12:15 PM					88															
12:15-12:30																				
12:30-12:45																				
12:45- 1:00																				
1:00 - 1:15																				
1:15 - 1:30																				
1:30 - 1:45																				
1:45 - 2:00									56											
2:00 - 2:15					160					40			464				0			
2:15 - 2:30						24					88			56				16		
2:30 - 2:45							120					160			8	40			8	
2:45 - 3:00						8		144					64							8
3:00 - 3:15		0	0		48	352			0											
3:15 - 3:30	0						128			626				72						
3:30 - 3:45				0				320			152				96	0				
3:45 - 4:00					40							408	264							
4:00 - 4:15			408			696			672					48						
4:15 - 4:30				232			232			8					24					
4:30 - 4:45		1256						472			0					96				
4:45 - 5:00	192				128							752	176							
5:00 - 5:15			1616				1008							32						

179 cont.

5:15 - 5:30 PM	32			576			88		200						0	16
5:30 - 5:45		728						304		32			96			
5:45- 6:00			2664		1158	208					8	64				16
6:00 - 6:15				1736			200		8					16		
6:15 - 6:30	376							534								
6:30 - 6:45		48														

TABLE 53: AVERAGE LIVE SPAT PER SHELL ON SEASONAL CULTCH AT FOUR BURNS POINT DIKES ON SEPTEMBER 11, 1946

DATE CULTCH PUT OUT	DIKE STATIONS No. 1	No. 2	No. 3	No. 4	AVERAGE OF 4 STATIONS
June 25	81	135	75	97	97
July 2	122	141	60	60	96
9	80	42	48	64	59
15	33	128	35	19	54
23	21	81	10	46	40
30	92	206	55	22	94
Aug. 8	34	170	94	82	95
14	229	125	130	187	168
20	78	83	48	65	69

TABLE 54: AVERAGE LIVE SPAT PER SHELL ON SEASONAL CULTCH AT FOUR BURNS POINT DIKES ON JANUARY 6, 1947

DATE CULTCH PUT OUT	DIKE STATIONS No. 1	No. 2	No. 3	No. 4	AVERAGE OF 4 STATIONS
June 25	78	133	87	98	99
July 2	74	108	57	60	75
9	27		64	47	46
15	15	46	21	12	23
23	1	44	17	7	17
30	12	48	29	19	27
Aug. 8	10	42	7	1	15
14	11	48	31	0	23
20	0	4	1	0	1

TABLE 55: AVERAGE LIVE SPAT PER SHELL ON SEASONAL CULTCH AT FOUR BURNS POINT DIKES ON APRIL 10, 1947

DATE CULTCH PUT OUT	DIKE STATIONS No. 1	No. 2	No. 3	No. 4	AVERAGE OF 4 STATIONS
July 2	68	89	51	59	67
9	49	54	29	34	42
15	23	31	10	10	18
23	0	50	7	5	16
30	0	34	12	6	13
Aug. 8	9	33	20	1	16
14	13	36	18	0	17
20	0		0	1	0

TABLE 56:

AVERAGE AIR TEMPERATURES: Priest Point Park, Olympia, Wash.

YEAR	JANUARY n = 38.4		FEBRUARY n = 40.5		MARCH n = 44.6		APRIL n = 49.4		MAY n = 55.0		JUNE n = 59.8	
	A	D	A	D	A	D	A	D	A	D	A	D
1931	42.0	+ 3.6	41.2	+0.7	45.5	+0.9	50.4	+1.0	57.9	+2.9	59.1	-0.7
1932	38.4	0.0	38.1	-2.4	44.5	-0.1	49.4	0.0	54.6	-0.4	61.2	+1.4
1933	37.2	- 1.2	35.2	-5.3	43.0	-1.6	48.4	-1.0	51.1	-3.9	58.2	-1.6
1934	42.8	+ 4.4	44.3	+3.8	49.5	+4.9	54.1	+4.7	56.9	+1.9	60.7	+0.9
1935	38.4	0.0	40.6	+0.1	40.3	-4.3	47.8	-1.6	54.4	-0.6	59.9	+0.1
1936	40.8	+ 2.4	33.4	-7.1	41.6	-3.0	51.0	+1.6	56.3	+1.3	60.4	+0.6
1937	29.2	- 9.2	37.6	-2.9	46.9	+2.3	47.8	-1.6	54.8	-0.2	61.2	+1.4
1938	40.0	+ 1.6	41.6	+1.1	44.8	+0.2	52.0	+2.6	57.4	+2.4	62.2	+2.4
1939	41.2	+ 2.8	36.0	-4.5	41.6	-3.0	51.6	+2.2	56.2	+1.2	59.4	-0.4
1940	41.4	+3.0	44.2	+3.7	48.4	+3.8	53.0	+3.6	59.8	+4.8	64.2	+4.4
1941	42.3	+ 3.9	43.8	+3.3	51.4	+6.8	55.5	+6.1	57.2	+2.2	62.8	+3.0
1942	37.2	- 1.2	41.5	+1.0	44.6	0.0	51.2	+1.8	56.4	+1.4	61.2	+1.4
1943	34.2	- 4.2	41.8	+1.3	43.4	-1.2	52.1	+2.7	54.2	-0.8	60.2	+0.4
1944	39.4	+1.0	40.8	+0.4	44.3	-0.3	50.6	+1.3	55.8	+0.8	60.4	+0.7
1945	40.8	+ 2.4	42.0	+1.5	43.4	-1.2	48.0	-1.4	57.9	+2.9	60.0	+0.2
1946	41.8	+ 3.4	41.6	+1.1	45.2	+0.6	49.5	+0.1	59.5	+4.5	59.2	-0.6
1947	34.8	- 3.6	42.0	+1.5	48.6	+4.0	53.6	+4.2	59.8	+4.8	61.2	+1.4
1948	38.2	-0.2	38.8	-1.7	43.0	-1.6	46.2	-3.2	54.4	-0.6	63.4	+3.6
1949	29.0	-9.4	36.5	-4.0	44.7	+0.1	50.7	+1.3	58.1	+3.1	59.1	-0.7
1950	27.9	-10.5	38.7	-1.8	40.7	-3.9	46.2	-3.2	53.0	-2.0	61.2	+1.4
1951												

n = normal average temperature for the month since
A = Average temperature
D = Deviation from normal

Data from U. S. Weather Bureau Reports.

TABLE 57:

AVERAGE AIR TEMPERATURES: Grapeview, Wash.

YEAR	JANUARY n= 39.0		FEBRUARY n = 41.2		MARCH n = 45.6		APRIL n = 50.2		MAY n = 55.6		JUNE n = 60.7	
	A	D	A	D	A	D	A	D	A	D	A	D
1931	43.4	+4.4	43.1	+1.9	46.2	+0.6	51.0	+1.4	58.4	+2.8	59.8	-0.9
1932	38.1	-0.9	40.4	-0.8	45.2	-0.4	50.4	+0.2	54.6	-1.0	61.8	+1.1
1933	37.8	-1.2	36.3	-4.9	43.5	-2.1	48.6	-1.6	52.1	-3.5	58.6	-2.1
1934	43.5	+4.5	45.5	+4.3	49.6	+4.0	55.6	+5.4	57.6	+2.0	61.2	+0.5
1935	38.6	-0.4	42.0	+0.8	41.4	-4.2	49.0	-1.2	55.8	+0.2	61.4	+0.7
1936	42.4	+2.4	35.8	-5.4	43.6	-1.0	53.1	+2.9	58.0	+2.4	62.4	+1.7
1937	31.7	-5.3	39.8	-1.4	47.2	+1.6	48.0	-2.2	55.4	-0.2	61.4	+0.7
1938	40.8	+1.8	41.8	+0.6	44.2	-1.4	51.6	+1.4	57.0	+1.4	61.8	+1.1
1939	42.8	+3.8	39.6	-1.6	45.3	-0.3	52.9	+2.7	56.8	+1.2	59.6	-1.1
1940	43.2	+4.2	45.2	+4.0	48.8	+3.2	53.4	+3.2	59.4	+3.8	63.6	+2.9
1941	43.0	+4.0	45.5	+4.3	52.0	+6.4	54.6	+4.4	57.0	+1.4	61.6	+0.9
1942	39.4	+0.4	42.6	+1.4	45.4	-0.2	52.7	+2.5	56.5	+0.9	60.2	-0.5
1943	35.4	-3.6	42.6	+1.4	44.1	-1.5	52.1	+1.9	54.6	-1.0	59.2	-1.5
1944	41.0	+2.0	42.5	+1.3	44.6	-1.0	50.5	+0.3	55.4	-0.2	60.2	-0.5
1945	42.4	+3.4	42.7	+1.5	44.6	-1.0	48.4	-1.8	57.8	+2.2	60.1	-0.6
1946	41.1	+2.1	42.2	+1.0	45.0	-0.6	49.6	-0.6	58.8	+3.2	59.4	-1.3
1947	37.2	-1.8	44.4	+3.2	48.8	+3.2	52.4	+2.2	59.2	+3.6	60.6	-0.1
1948	41.4	+2.4	40.2	-1.0	44.1	-1.5	47.2	-3.0	54.4	-1.2	63.4	+2.7
1949	31.9	-7.1	37.9	-3.3	46.2	+0.6	51.3	+1.1	58.6	+3.0	59.9	-0.8
1950	28.7	-10.3	40.3	-0.9	43.5	-2.1	47.6	-2.6	53.7	-1.9	62.0	+1.3
1951	39.2	+0.2	41.7	+0.5	46.0	+0.4	52.2	+2.0				

n = normal average temperature for the month
A = Average temperature
D = Deviation from normal

Data from U. S. Weather Bureau Reports.

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TABLE 59 : LARVAE SIZE GROUPS, 1945

Percentages of each size

BAY	STATION	DATE	Diameter in Micrens: under 1 58	158	164	170	177	183	189	196	202	208	215	221
Mud Bay	3	June 26		4	8.5	9	16	7	10	7	11	8	8.5	2
Oyster Bay	9	June 8		0.6	4.5	13	15	14	20.5	5	9	3	3	1
	8	June 15			1	7	14	16	14	9	11	8	6.5	3
	9	June 15			7	18	36	17	7	6	4		2	1
	9	June 22		1	4	14	14	20	20	2	5	3	6	2.5
North Bay	12	June 8			8	8	23	23	22	2	5	2	5	
	12	June 20				1	6	10	10	6	10	6	4	4
South Bay	15	June 26			2	17	24	24	16	7	2	3	1	
Oakland Bay	20	June 26		1	3	15	20	10	10	11	7	7	7	3

*Approximately 100 specimens measured

186 cont.

227	234	240	246	253	257	266	272	279	285	298	over 298
2	3	1	1			2					
4	2	1	0.6	2	1						
	2	1	3	2		1	2				
1	1		1							1	
1		2	1	2	1			1		2	2
			2								
	4	1	1	1	1	3	2	2	5	6	17
		1	2						1		
1	1		1	1							

TABLE 60

NORTH BAY, Larva Size Groups: 1944

Percentages of each size: Best Average

Date	Stations	156u	168u	180u	192u	204u	216u	228u	240u	252u	264u	276u	288u	300u	312u	324u
		Diameter in Microns														
May 25	11	33	67													
		33*	67*													
June 2	10		13	83		4.3										
	11		8	64	20	8										
			10.5	73.5	10	6.1										
June 15	10		8	42	11	9.4	6.2	7.8	7.8	4.7	3.1					
	11		26	43	8.6	10.3		1.7	5.2	5.2						
	12		18	45	21	4.8	4.8		4.8			1.6				
			17	45	13.5	8.1	5.5	4.7	5.9	4.9	1.5	0.8				
June 19	10		15	43	17	2.9	2.9	5.8	7.3	1.5	2.9	2.9	2.9			
	11		18	26	14.5	16	3.2	10	3.2	6.4	1.6	1.6				
	12	1.3	13	29	12	27	5.3	2.7	1.3	1.5		2.7	4.0			
		0.4	15.3	32.7	14.5	15.3	3.8	14.2	3.9	3.1	1.5	2.4	2.3			
June 26	10		22	50	5.8	5.8	2.9		2.9		2.9		1.5	4.4		1.5
	11	1.8	14	20	12.5	11	7.1	5.4	7.1		7.1	3.6	3.6	5.4		
	12	4.8	21	27	8	6.3	13	1.6	6.3	1.6	7.9	3.2	3.2	1.6		
		2.2	19	32.3	8.8	7.7	7.7	2.3	5.4	0.5	5.9	2.2	2.8	3.8		0.5
July 3	10		27	38	14	6.1	9.1	1.5	1.5		1.5			1.5		
	11	1.1	22	33	6.8	4.5	4.5	4.5	8	5.7	2.3	3.4	2.3	1.1	1.1	
	12		12	41	8	2.7	15	2.7	4.0	4.0	2.7	2.7	2.7	1.3	1.3	
		0.3	20	37	9.6	4.4	9.5	2.9	4.5	3.6	2.1	2.0	1.7	1.3	0.8	
July 24	11	20	35	30	2.2	2.2	2.2		2.2		2.2	4.4				
	12	6.4	29	16	6.4	9.7	13		6.4			3.2	6.4	3.2		
		13.2	32	23	4.3	6.0	7.6		4.3		1.1	3.8	3.2	1.6		
July 20	12	7.7	27	15	7.7	19	7.7		11.5				3.8			
	12a	56	22	6.8	3.4	3.4		1.7	1.7			3.4		1.7		
		31.8	2.4	10.9	5.5	11.2	3.9	0.8	6.6			1.7	1.9	0.9		
July 27	11	5.7	20	46	8.6	2.9		2.9	2.9		5.7	2.9		2.9		
	12	13	43	17	5.7	3.8	5.7	1.9	5.7		3.8					
		9.3	31	32	7.1	3.3	2.8	2.4	4.3		4.8	1.4		1.5		

*Best Average of all stations

TABLE 61: LARVAE SIZE GROUPS, 1946

OYSTER BAY

DATE	STATION	SIZE GROUP IN PERCENT. Small: under 184u	Medium: 185 to 250u	Large: 255u & over
May 28	9A	68.7	31.2	0
June 14	8	59.4	40.6	0
June 19	8	41.9	50.0	8.1
June 27	8&9A	60.4	35.8	3.8
July 1	9 & 8	14.6	39.8	45.5
July 9	8&9A	84.4	11.7	3.9
July 23	8&9	64.2	33.6	2.2
Aug. 1	9	44.4	47.8	7.8
Aug. 7	8&9	28.3	63.0	8.7
Aug. 14	8&9	28.8	15.8	55.4
Aug. 20	9&9A	75.0	11.2	13.8
Aug. 29	8	46.2	43.6	10.3

MUD BAY

DATE	STATION	SIZE GROUP IN PERCENT. Small: under 184u	Medium: 185 to 250u	Large: 255u & over
June 14	4	100	0	0
June 19	3	98.5	1.5	0
June 27	3&4	95.0	5.0	0
July 2	3	80.9	17.5	1.6
July 9	3&4	51.3	42.7	6.0
July 23	4&4A	66.1	33.9	0

NORTH BAY

DATE	STATION	SIZE GROUP IN PERCENT. Small: under 184u	Medium: 185 to 250u	Large: 255u & over
June 14	Allyn dock	66.7	33.3	0
June 21	12 & dock	75.6	21.9	2.4
June 25	dock	50	20	30
July 2	dock	51.7	38.0	10.3
July 9		89.5	7.0	3.5
July 23		55.3	44.7	0
Aug. 8		100	0	0

188 cont.

SOUTH BAY

DATE	STATION	SIZE GROUP IN PERCENT. Small: under 184u	Medium: 185 to 250 u	Large: 255u & over
June 19	15 & 15B	92.1	7.8	0
June 25	15	66.7	33.3	0
July 2	15C	84.4	15.6	0
July 9	15	67.2	32.8	0
July 17	15	65.6	34.4	0
July 23	15	70.6	29.4	0
Aug. 1	15 B	81.2	18.8	0
Aug. 7	15 15 A&B	73.7	26.3	0

OAKLAND BAY

DATE	STATION	SIZE GROUP IN PERCENT. Small: under 184u	Medium: 185 to 250u	Large: 255u & over
June 13	20	94.4	2.8	2.8
June 19	19 & 20	57.4	42.6	0
June 27	19 & 20	100	0	0
July 2	19 & 20	71.1	26.7	2.2
July 9	20A	88.9	11.1	0
July 17	20A	55.2	41.4	3.4
Aug. 1	19 & 20	54.5	43.2	2.3

TABLE 63

AVERAGE RAINFALL: Priest Point Park, Olympia, Wash.

YEAR	JANUARY n = 8.46		FEBRUARY n = 6.48		MARCH n = 5.09		APRIL n = 3.34		MAY n = 2.42		JUNE n = 1.59	
	A	D	A	D	A	D	A	D	A	D	A	D
1931	8.99	+0.53	5.71	-.77	6.80	+1.71	4.39	+1.05	1.63	-0.79	4.49	+2.90
1932	6.87	-1.59	10.05	+3.57	7.65	+2.56	4.93	+1.59	1.20	-1.22	0.10	-1.49
1933	11.08	+2.62	4.37	-2.11	17.92	+2.83	0.35	-2.99	3.32	+0.90	1.77	+0.18
1934	12.49	+4.03	2.14	-4.34	5.92	+0.83	1.26	-2.08	2.69	+0.27	0.07	-1.52
1935	12.95	+4.49	4.39	-2.09	7.25	+2.16	1.38	-1.96	0.57	-1.85	0.54	-1.05
1936	12.94	+4.48	9.34	+2.86	4.71	-0.38	0.71	-2.63	3.88	+1.46	4.78	+3.19
1937	4.55	-3.91	11.72	+5.24	3.71	-1.38	7.43	+4.09	1.66	-0.76	5.40	+3.81
1938	5.34	-3.12	4.46	-2.02	7.50	+2.41	3.87	+0.53	0.83	-1.59	0.13	-1.46
1939	8.18	-0.28	9.14	+2.66	3.73	-1.36	0.54	-2.80	1.88	-0.54	1.42	-0.17
1940	4.59	-3.87	11.33	+4.85	7.12	+2.03	3.54	+0.20	3.94	+1.52	0.07	-1.52
1941	5.59	-2.87	2.45	-4.03	1.93	-3.16	1.21	-2.13	4.22	+1.80	1.48	-0.11
1942	3.87	-4.59	4.38	-2.10	3.58	-1.51	1.84	-1.50	1.91	-0.51	2.80	+1.21
1943	3.13	-5.33	5.42	-1.06	7.03	+1.94	4.67	+1.33	3.27	+0.85	1.95	+0.36
1944	6.25	-2.21	3.49	-2.99	2.34	-2.75	3.94	+0.60	1.11	-1.31	1.44	-0.15
1945	6.58	-1.88	8.15	+1.67	7.29	+2.20	2.42	-0.92	2.74	+0.32	0.04	-1.55
1946	8.91	+0.45	7.14	+0.66	6.04	+0.95	4.17	+0.83	0.43	-1.99	6.48	+4.89
1947	7.86	-0.60	7.07	+0.59	3.68	-1.41	3.54	+0.20	0.15	-2.27	2.40	+0.81
1948	5.90	-2.56	6.80	+0.32	5.33	+0.24	5.26	+1.92	5.79	+3.37	1.37	-0.22
1949	2.71	-5.75	12.16	+5.68	3.81	-1.28	1.44	-1.90	2.14	-0.28	1.14	-0.45
1950	7.25	-1.21	10.41	+3.93	10.28	+5.19	3.35	+0.01	0.98	-1.44	0.50	-1.09
1951	10.26	+2.34	8.71	+2.23	5.41	+0.32	0.73	-2.61	2.34	-0.08	0.00	-1.59

n = normal average rainfall for the month
A = Average rainfall
D = Deviation from normal

Data from U. S. Weather Bureau Reports.

189 cont.

DECEMBER
n = 9.21

A	D
9.86	+0.65
10.85	+1.64
27.12	+17.91
10.10	+0.89
6.52	-2.69
10.64	+1.43
13.30	+4.09
6.02	-3.19
13.33	+4.12
4.86	-5.35
9.48	+0.27
7.29	+1.92
5.39	-3.82
2.28	-6.93
7.49	-1.72
6.96	-2.25
6.47	-2.74
1.73	-7.48
10.28	+1.07
10.40	+1.19

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TABLE 46 : SEASONAL STRINGS, 1949* SPAT PER SHELL

DATE PUT OUT	OYSTER BAY	MUD BAY	NORTH BAY
June 20	241	251	1061
23	314	178	790
26	380	307	1026
30	351	586	495
July 5	590	449	1069
8	398	374	804
11	436	554	823
18	477	215	290
21	372	192	336
27	292	95	537
Aug. 2	100	55	299

* Taken into the Laboratory Aug. 9, 1949

TABLE 48: PLANKTON LARVAE SURVEY OF OYSTER BAY

STATION 9, Aug. 8, 1944

STANDARD TIME	HEIGHT OF TIDE IN FEET	NUMBER OF LARVAE PER 20 GAL. SAMPLE
9:00 AM	12.4	8
9:30	11.3	48
10:00	10.2	40
10:30	8.6	612
11:00	6.9	32
11:30	5.6	140
12:00 N	4.3	224
12:30 PM	2.9	100
1:00	1.7	48
1:30	0.9	84
2:00	0.45	12
2:30	0.4	64
3:00	0.8	8
3:30	1.5	8
4:00	2.8	4
4:30	4.3	36
5:00	5.9	212
5:34	7.4	772
6:00	9.4	720
6:30	11.2	444
7:00	12.6	148
7:30	14.0	120
8:00	15.0	84
8:30	15.6	56
9:00	15.8	76
9:30	15.5	76
10:00	14.5	420

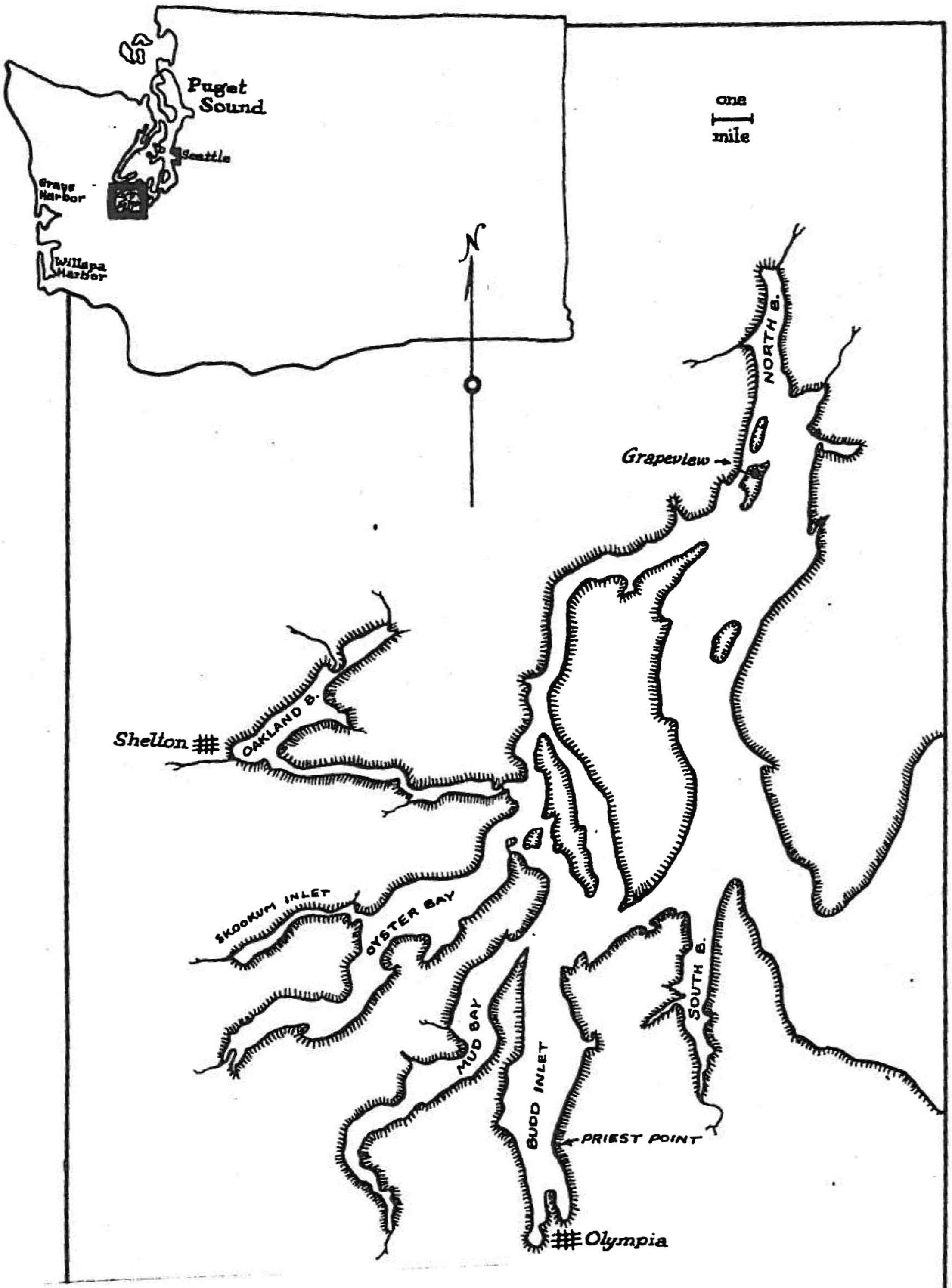


Figure 1 Olympia Oyster Bays in Southern Puget Sound and Their Location in the State of Washington.

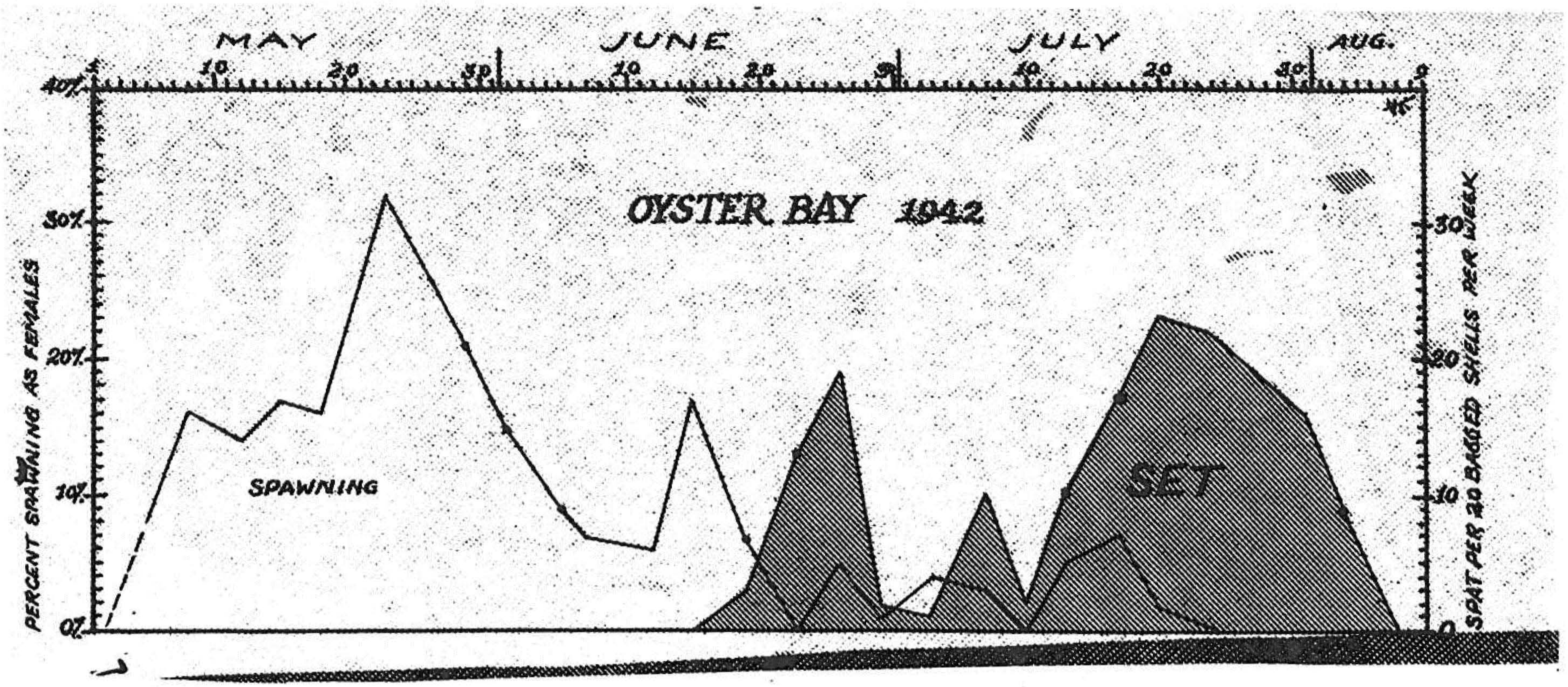


Figure 2 Oyster Bay Reproductive Season, 1942

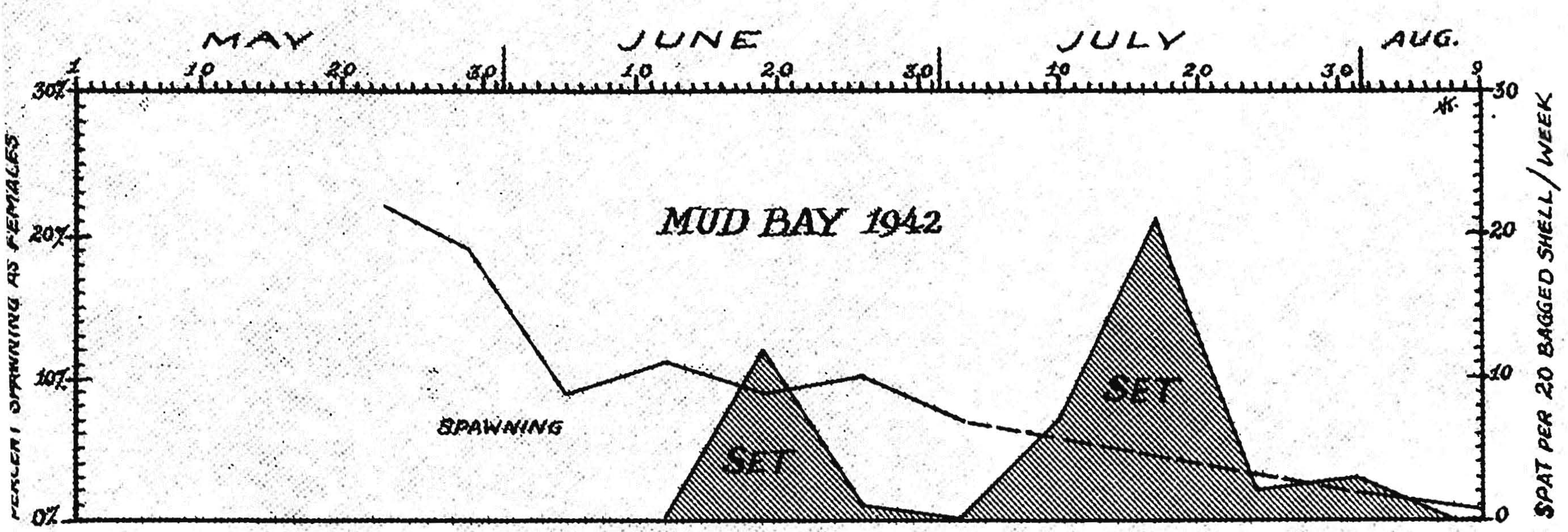
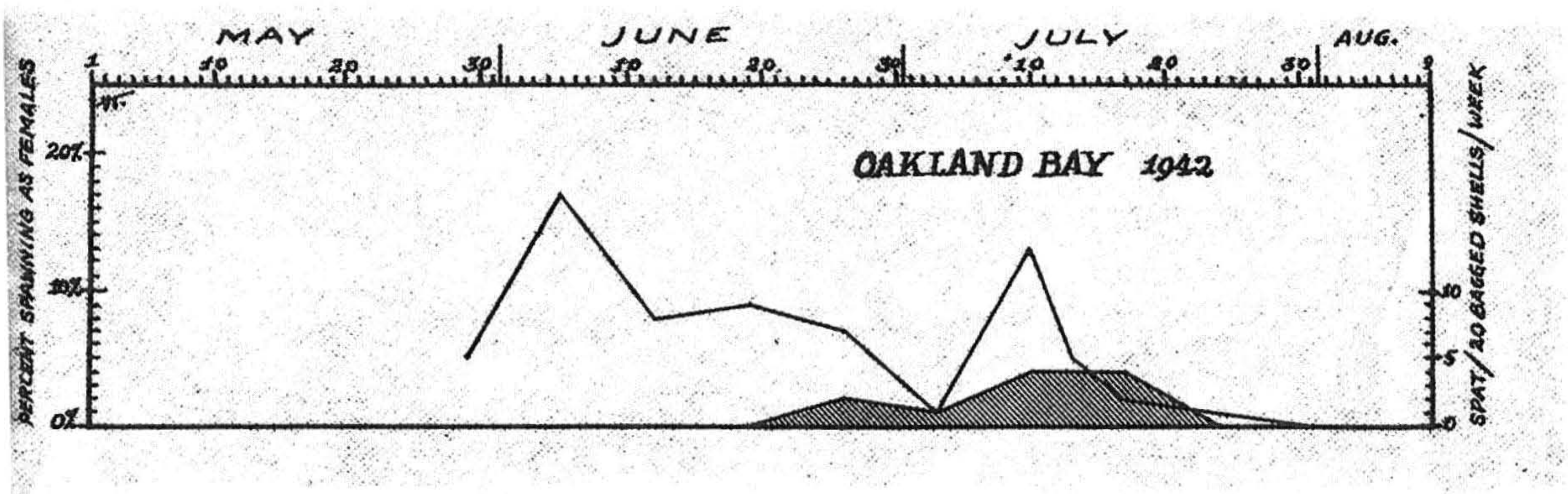
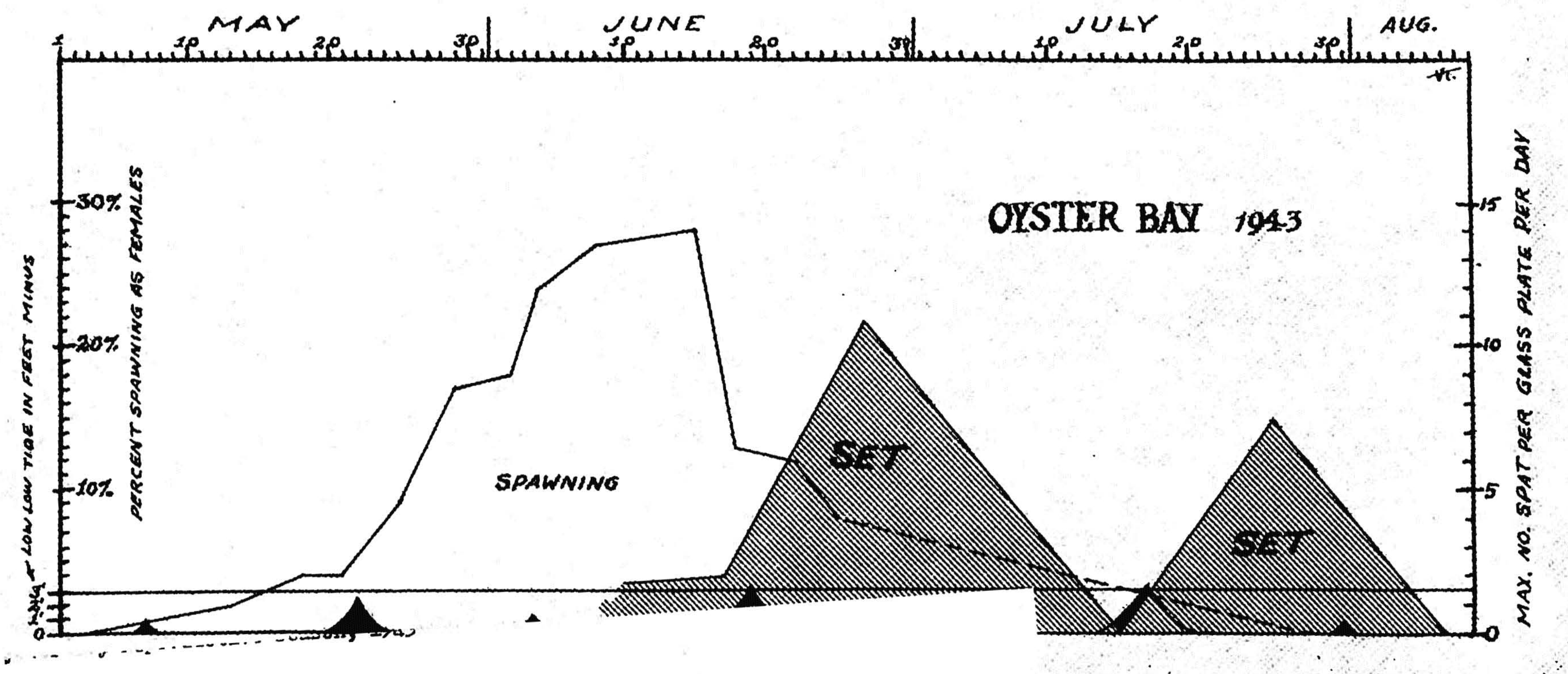


Figure 3 Mud Bay Reproductive Season, 1942.



~~Mud Bay~~

Figure 4 Oakland Bay, Reproductive Season, 1942.



igure 5 Oyster Bay Reproductive Season, 1943

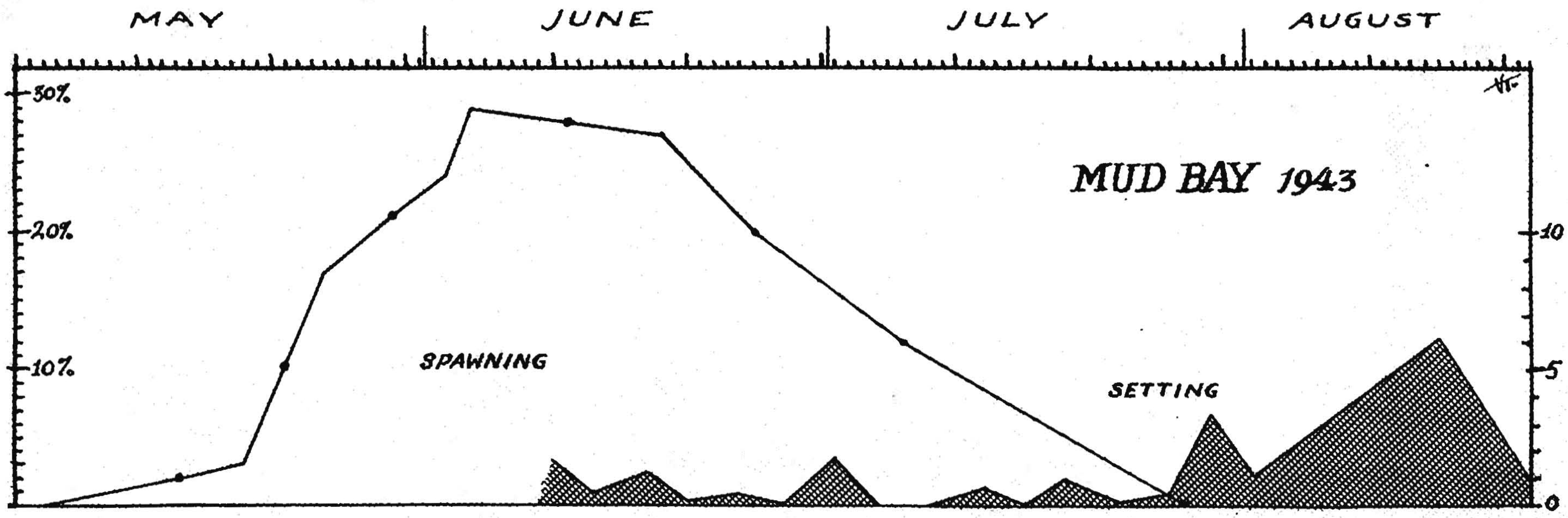


Figure 6 Mud Bay Reproductive Season, 1943.

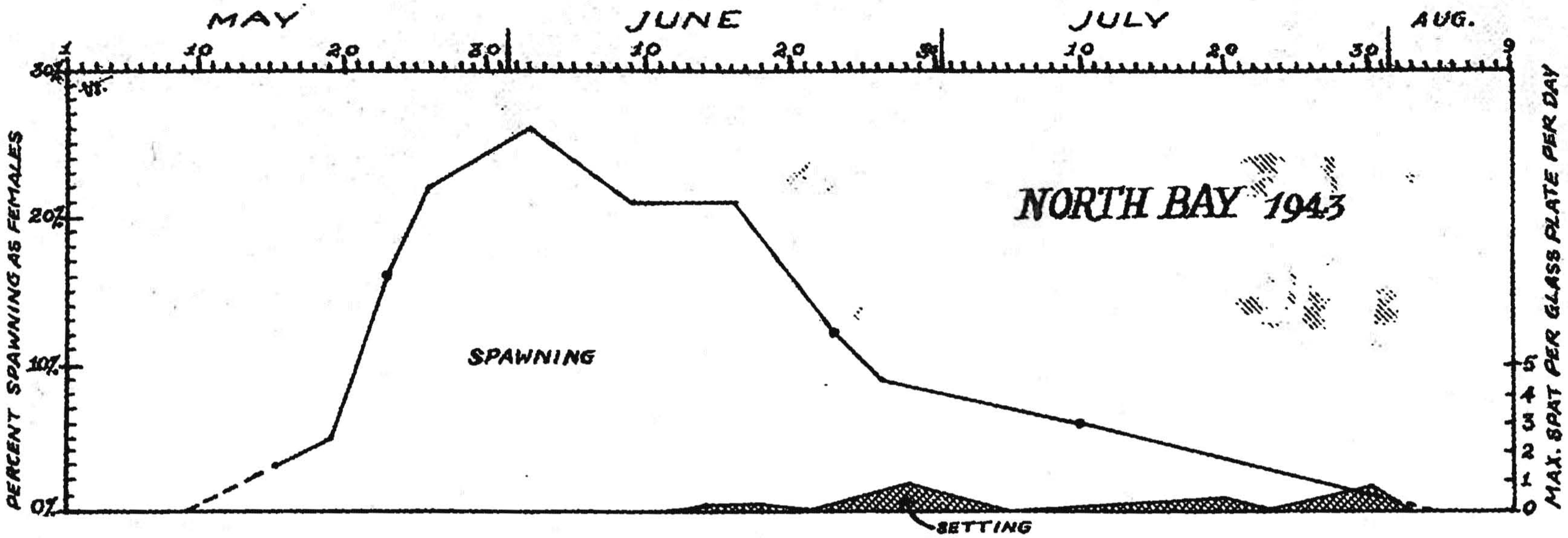
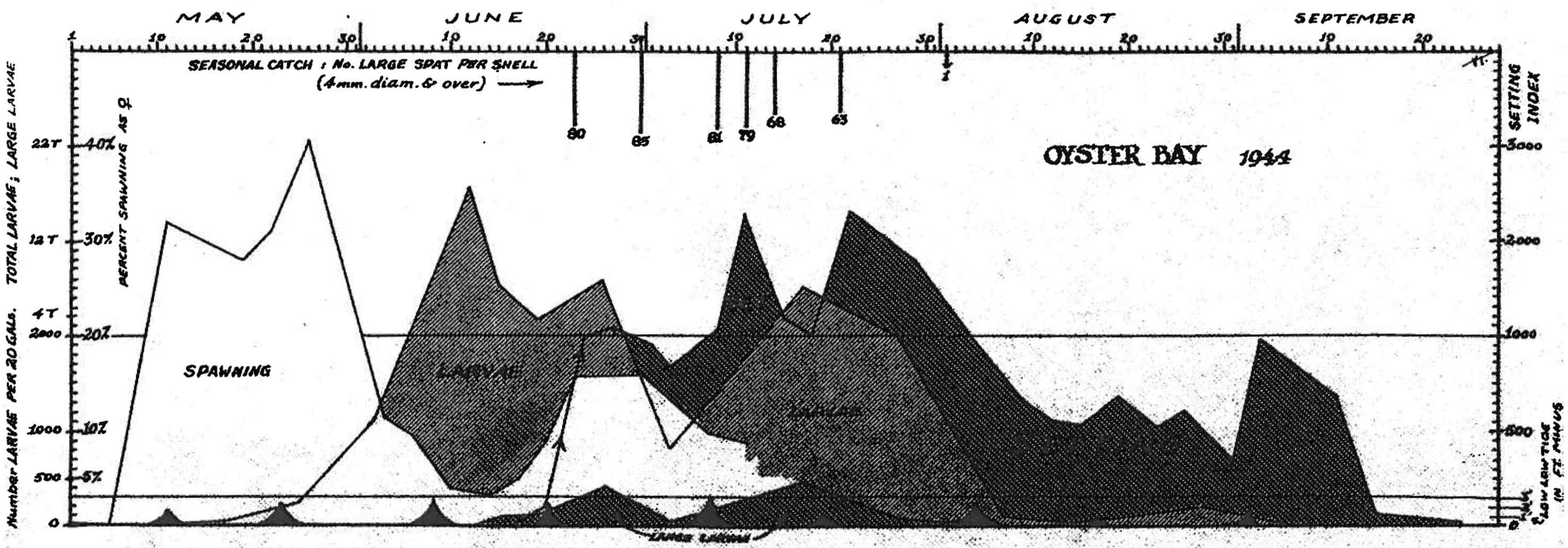


Figure 7 North Bay Reproductive Season, 1943.


MAY
JUNE
JULY
AUGUST
SEPTEMBER
SEASONAL CATCH : No. LARGE SPAT PER SHELL
(4mm. diam. & over)
80
85
81
79
68
63
1
OYSTER BAY 1944
SPAWNING
LARVAE
LARGE LARVAE
Number LARVAE PER 20 GALS. TOTAL LARVAE; LARGE LARVAE
PERCENT SPAWNING AS ♀
SETTING INDEX
LOW LOW TIDE IN FT. MINUS
22T
12T
4T
2000
1000
500
0
40%
30%
20%
10%
5%
3000
2000
1000
500
0

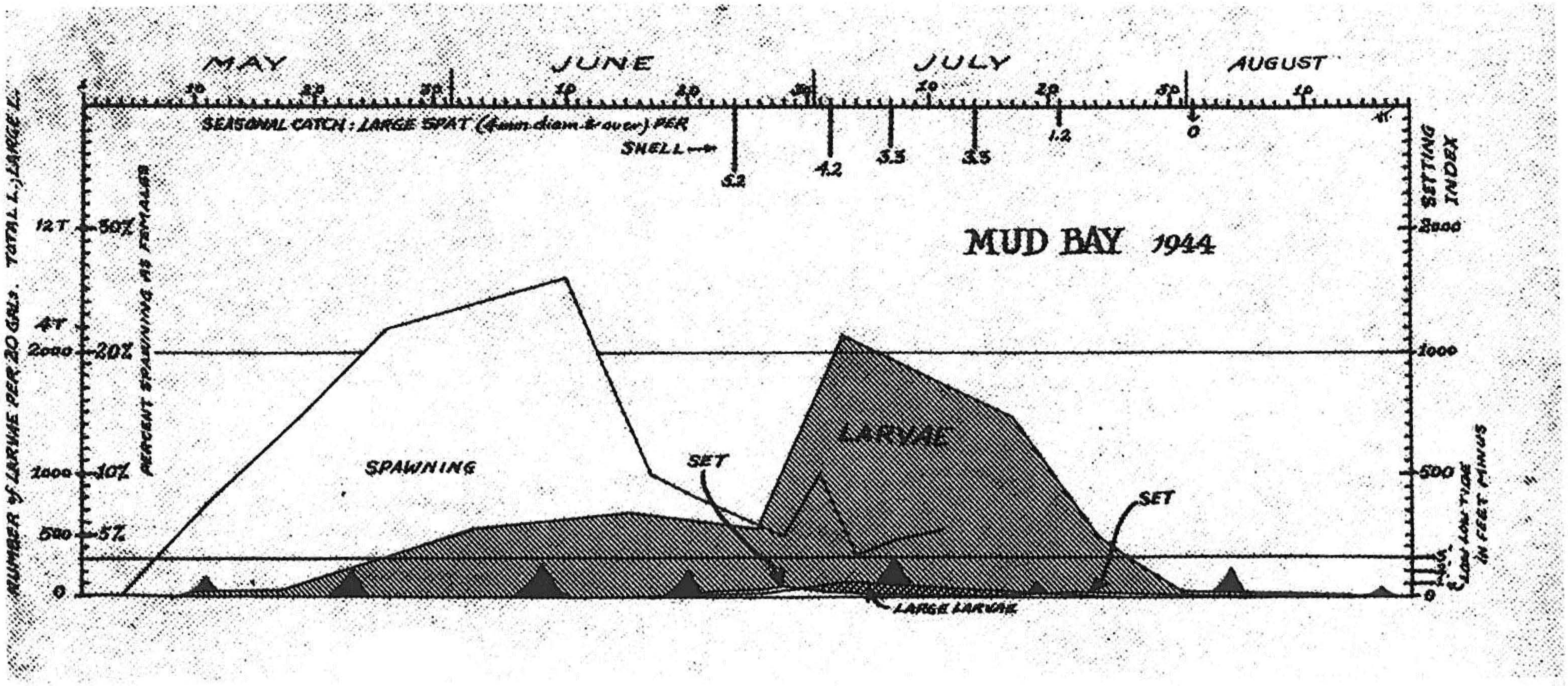


Figure 10 Mud Bay Reproductive Season, 1944.

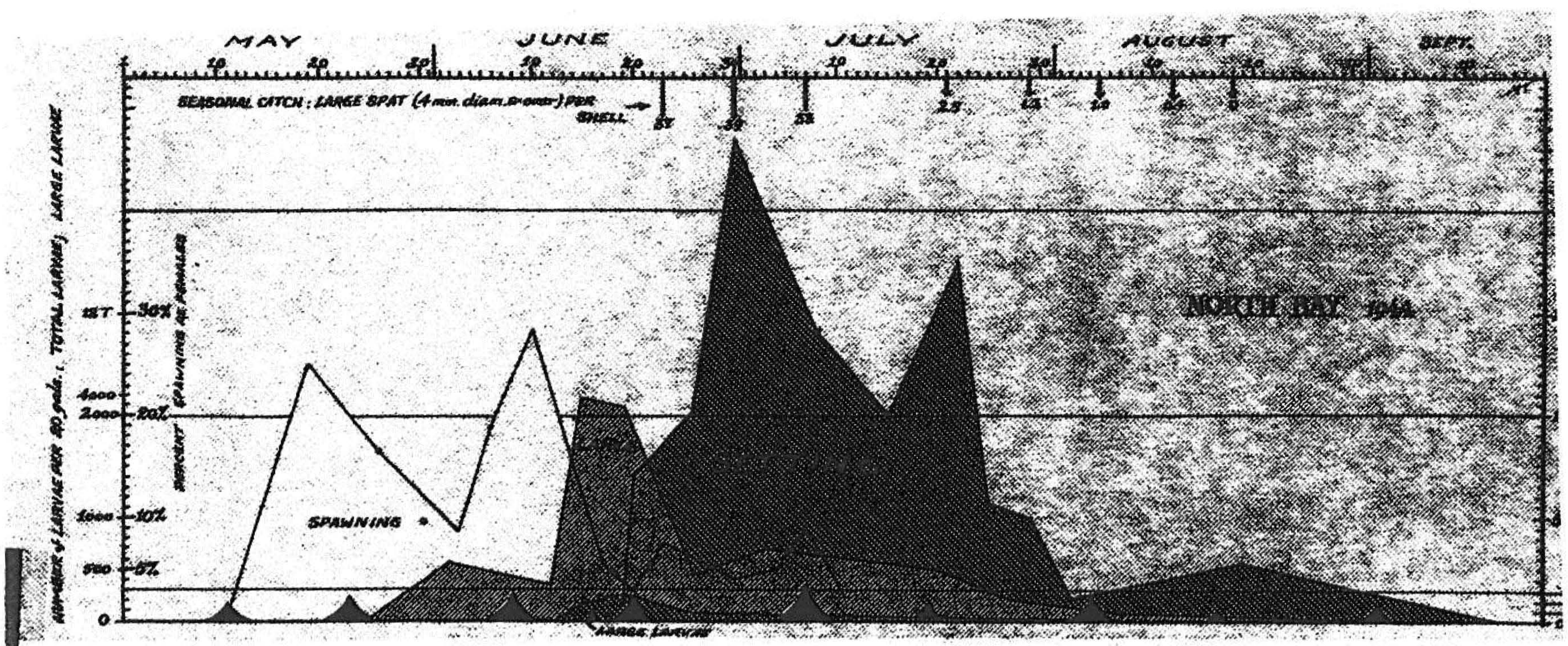


Figure 11 North Bay Reproductive Season, 1944

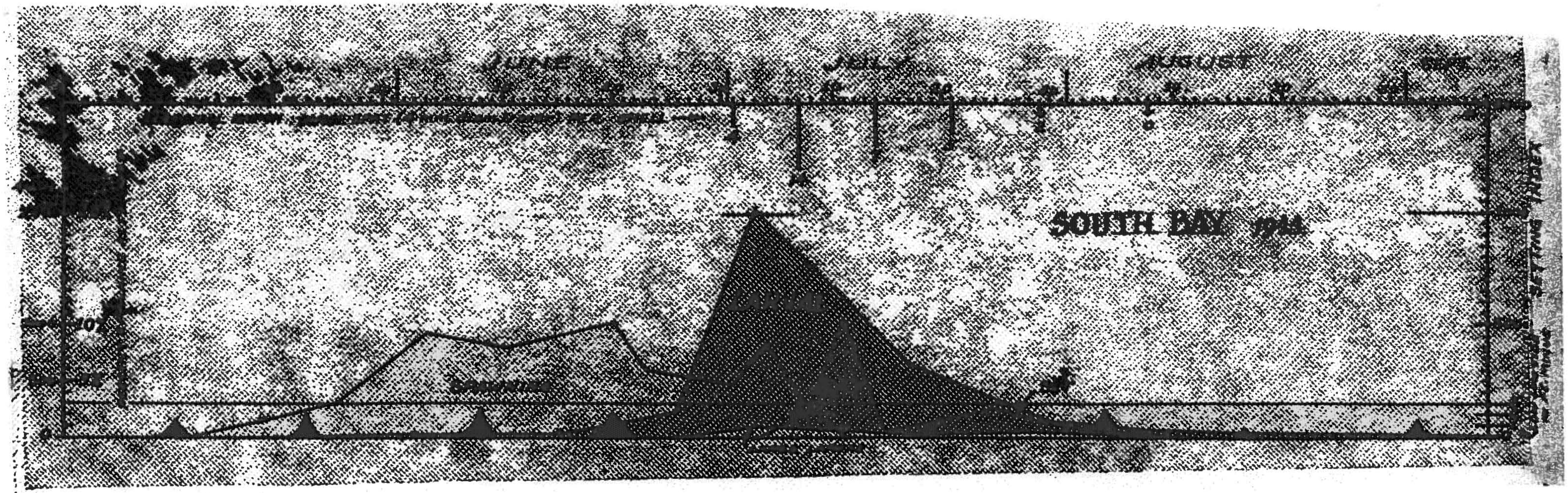


Figure 12 South Bay Reproductive Season, 1944

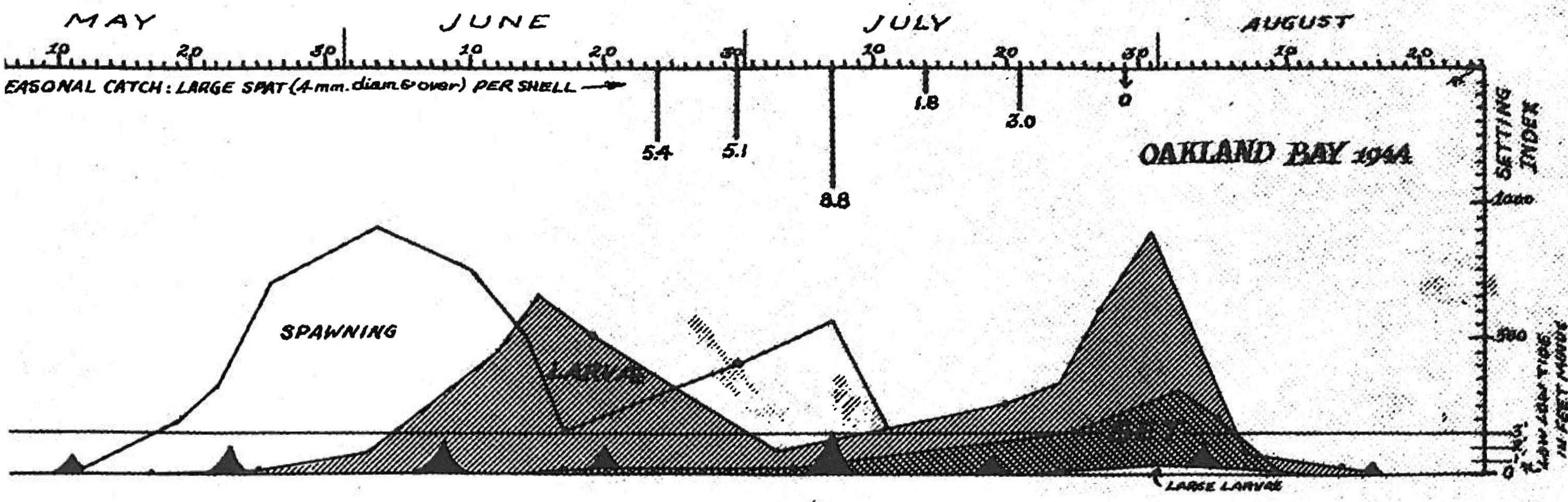
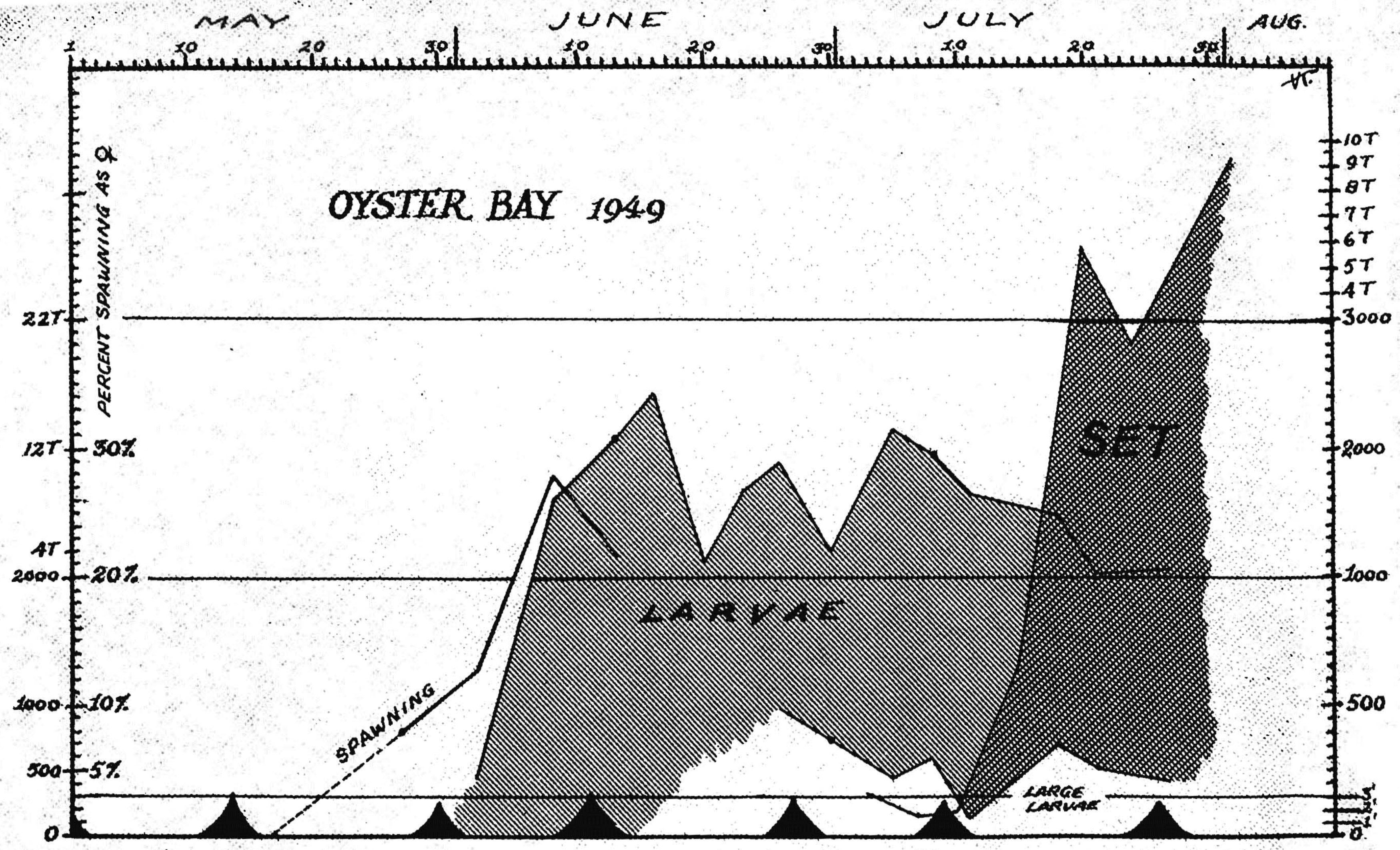


Figure 13 Oakland Bay Reproductive Season, 1944



Oyster Bay Reproductive Season, 1949.

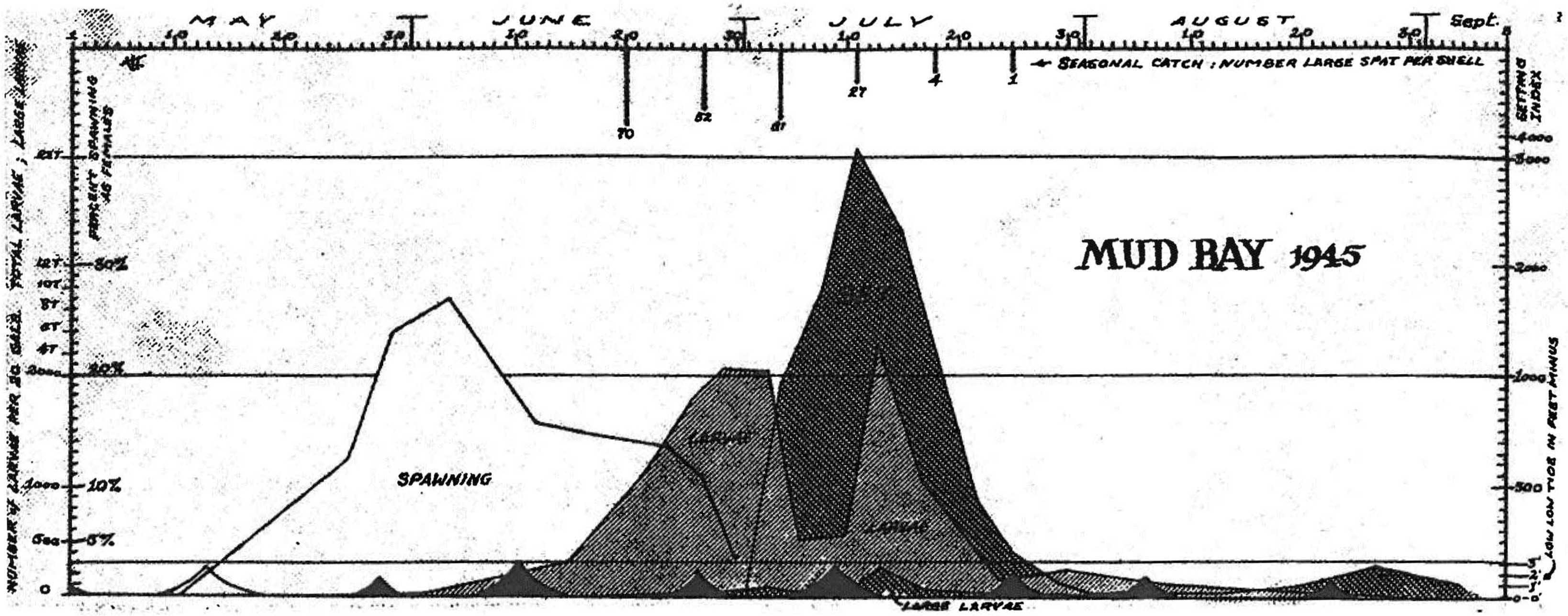


Figure 15 Mud Bay Reproductive Season, 1945

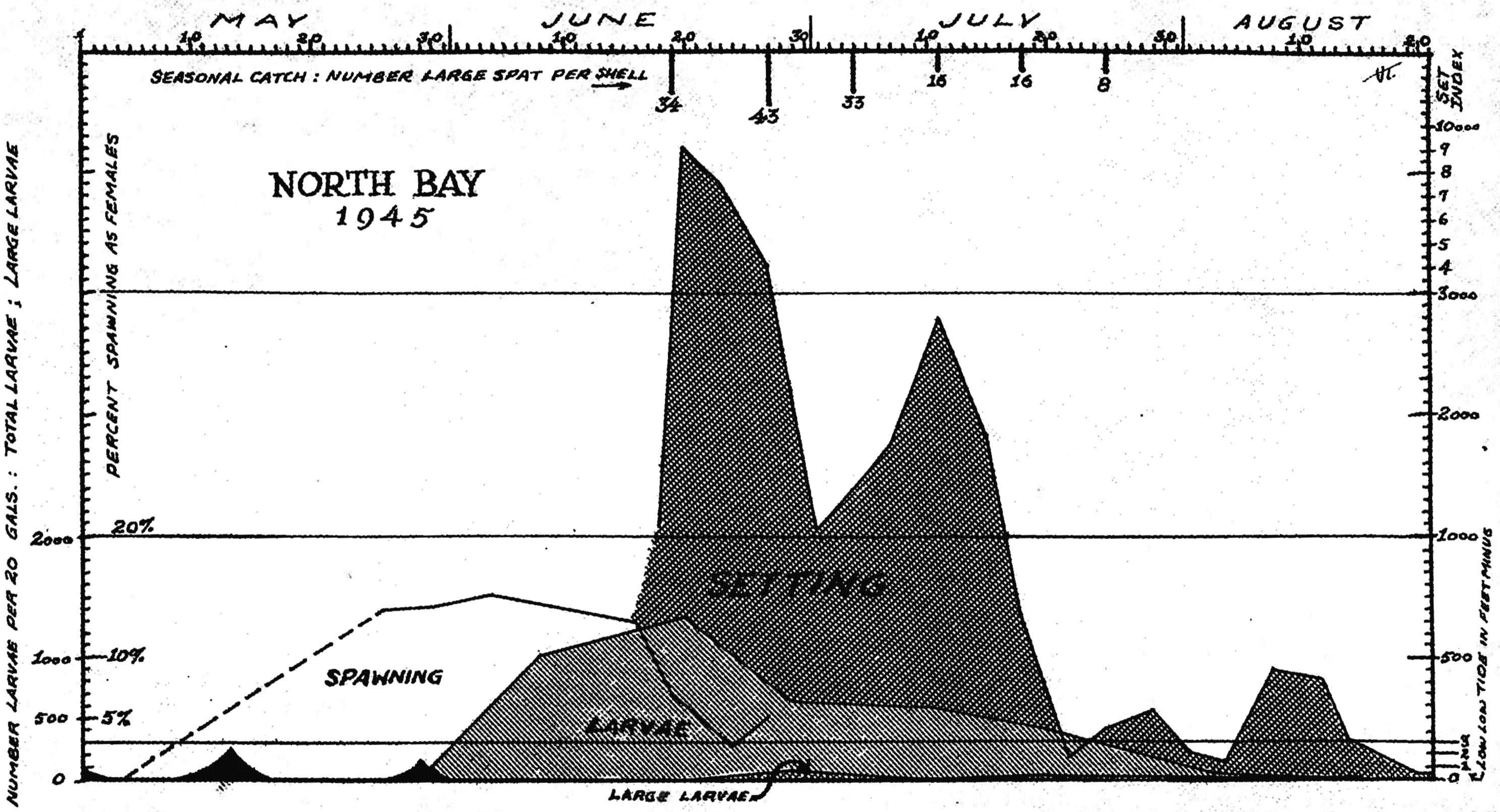


Figure 16 North Bay Reproductive Season, 1945.

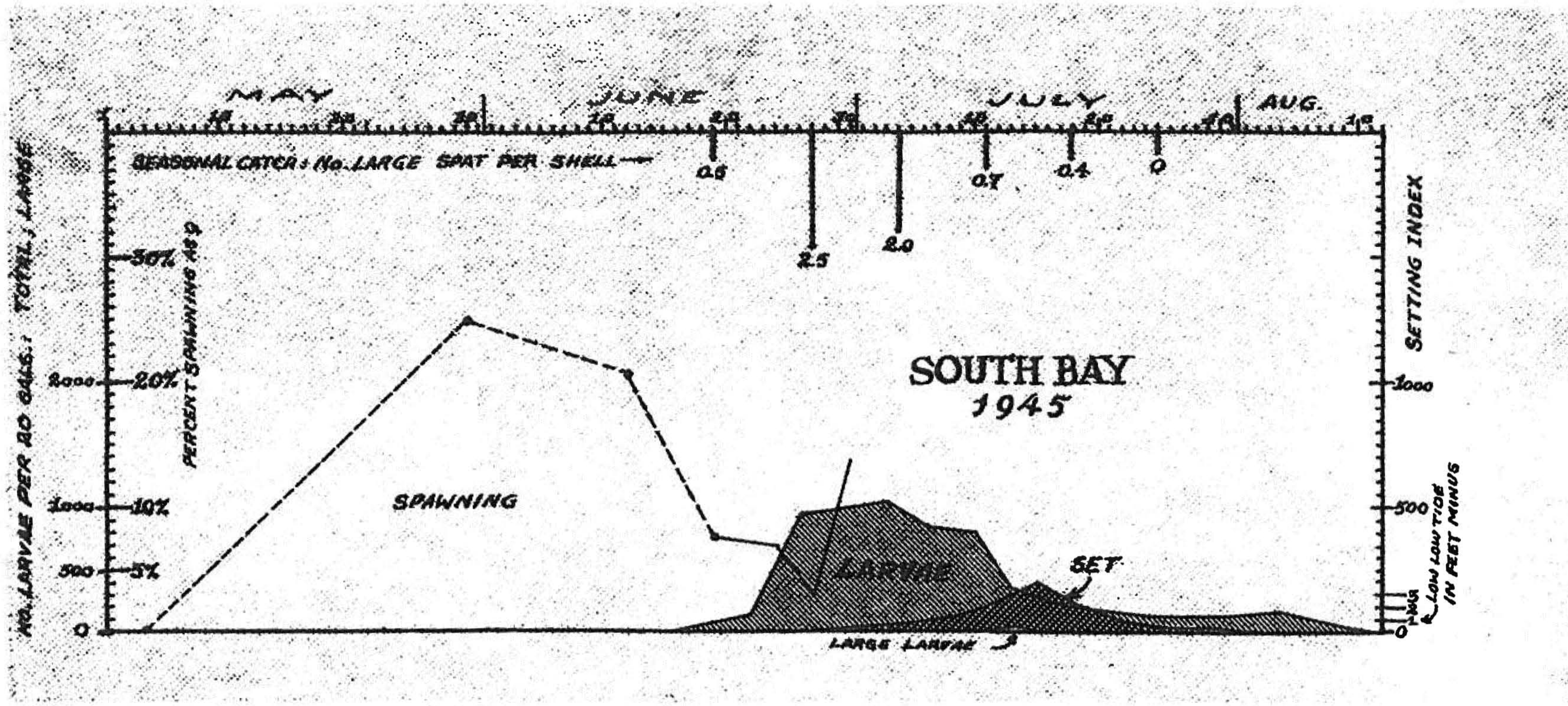


Figure 17 South Bay Reproductive Season, 1945.

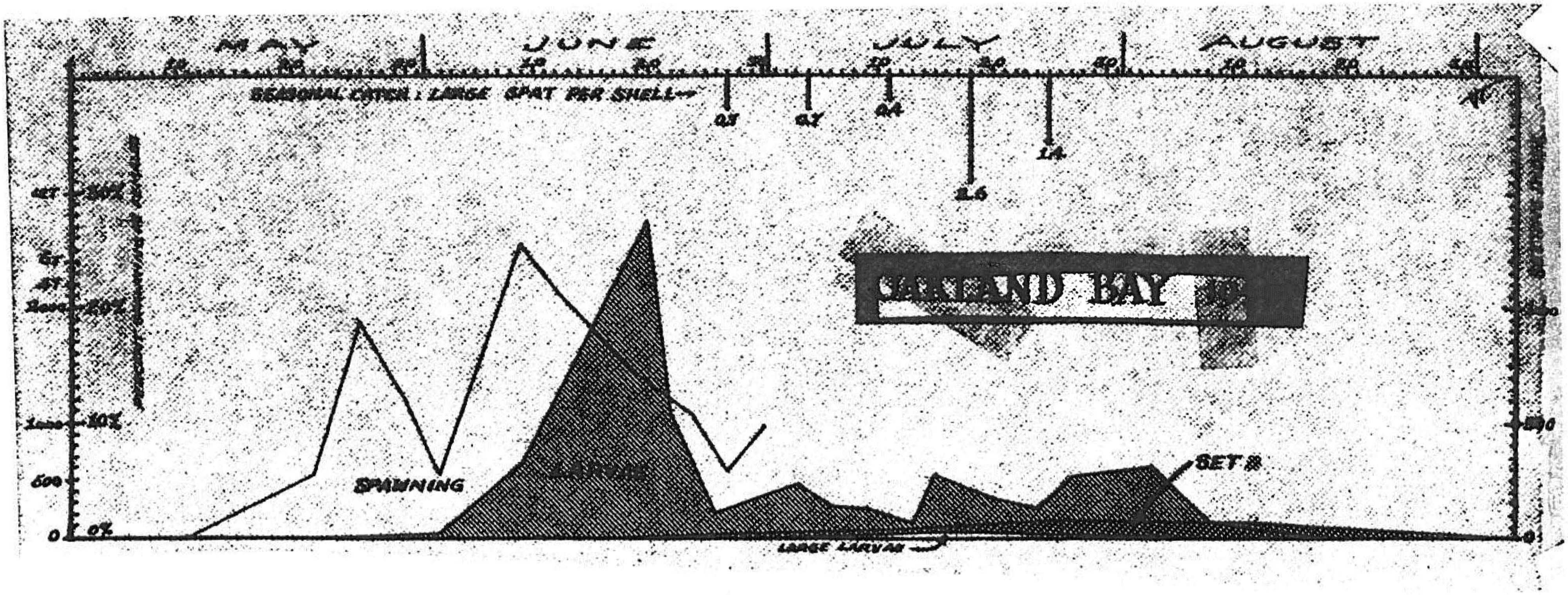


Figure 18 Oakland Bay Reproductive Season, 1945

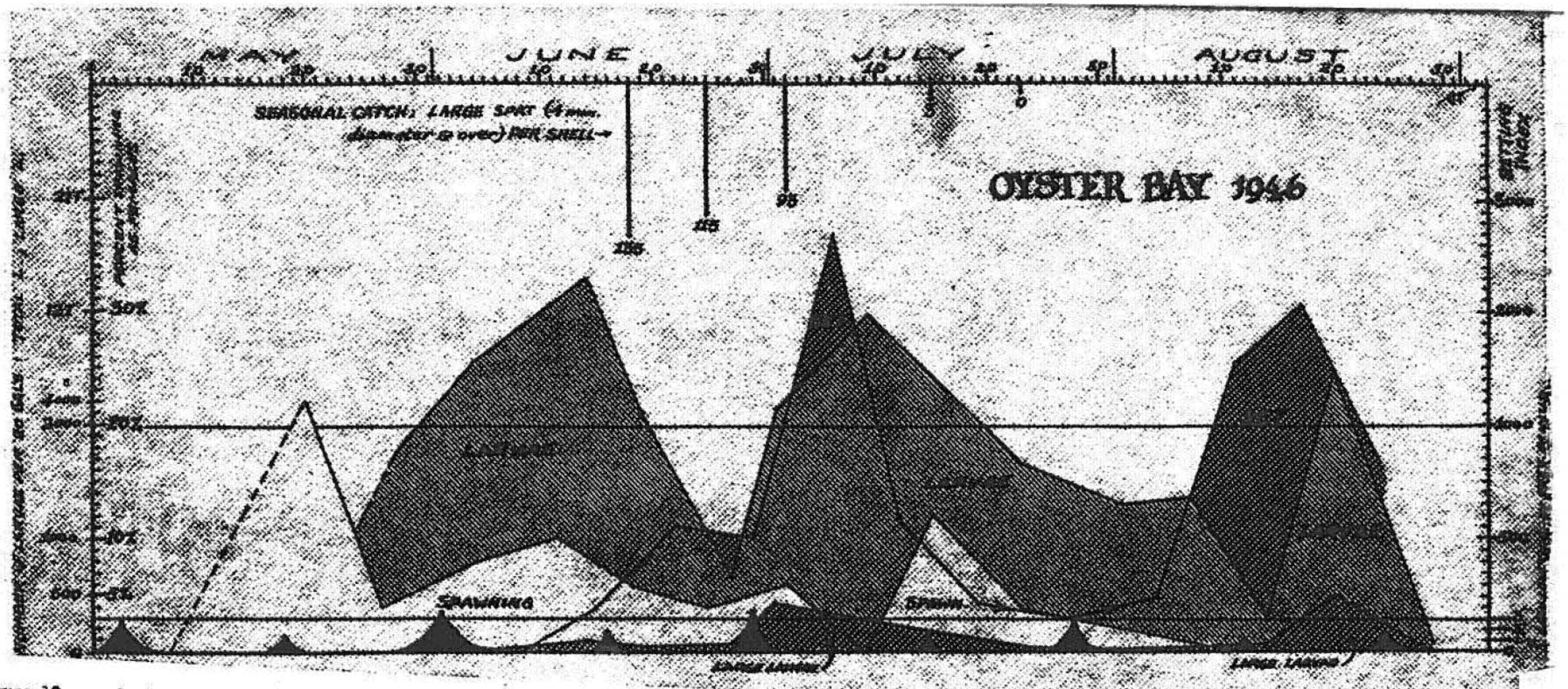


Figure 19 Oyster Bay Reproductive Season, 1946

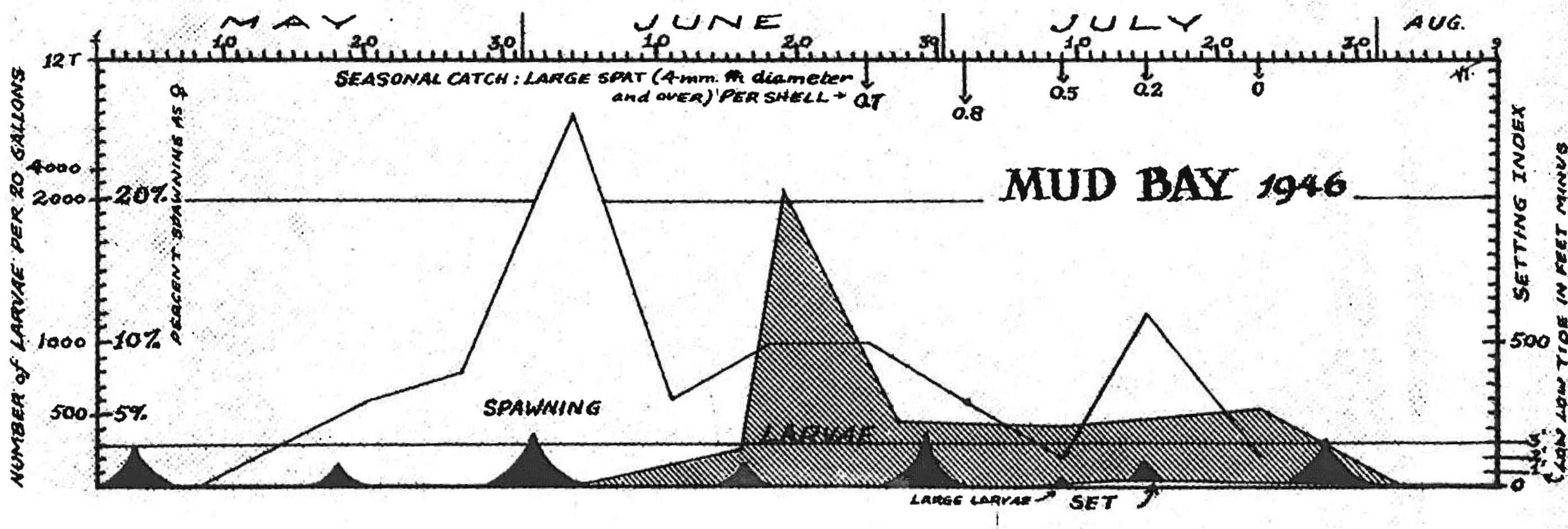


Figure 20 Mud Bay Reproductive Season, 1946.

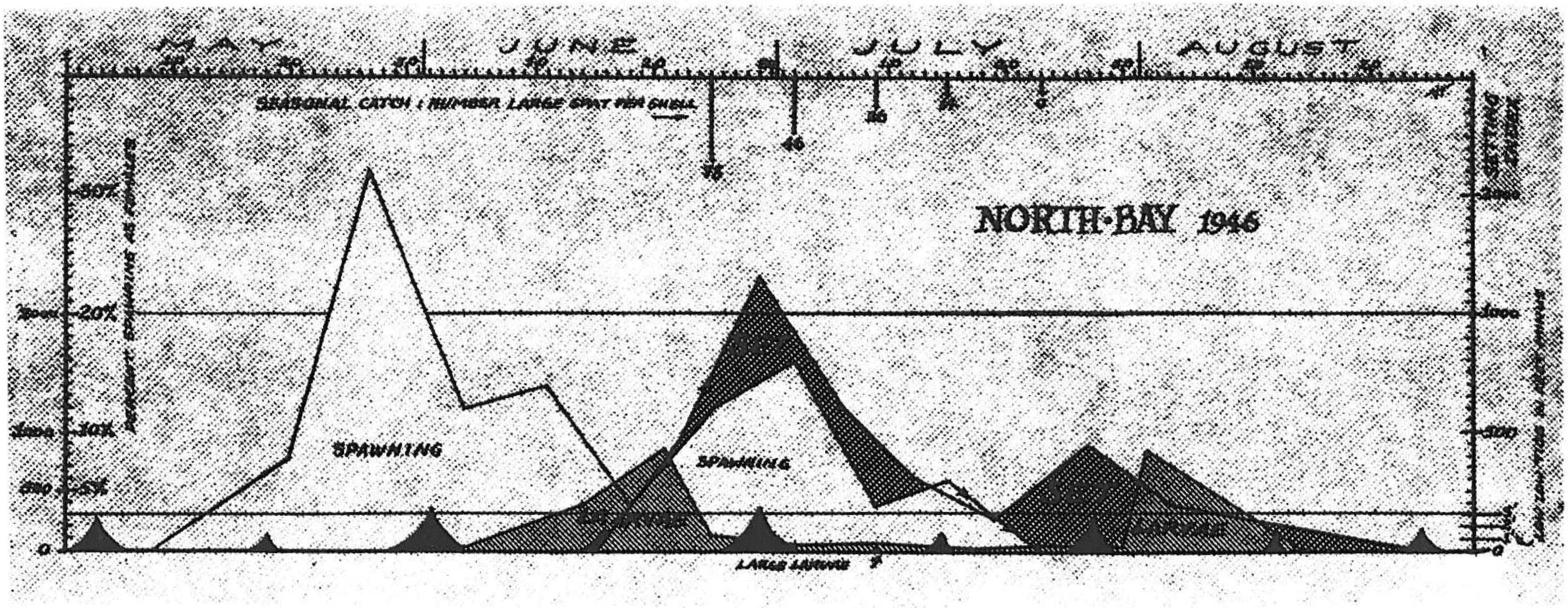


Figure 21 North Bay Reproductive Season, 1946

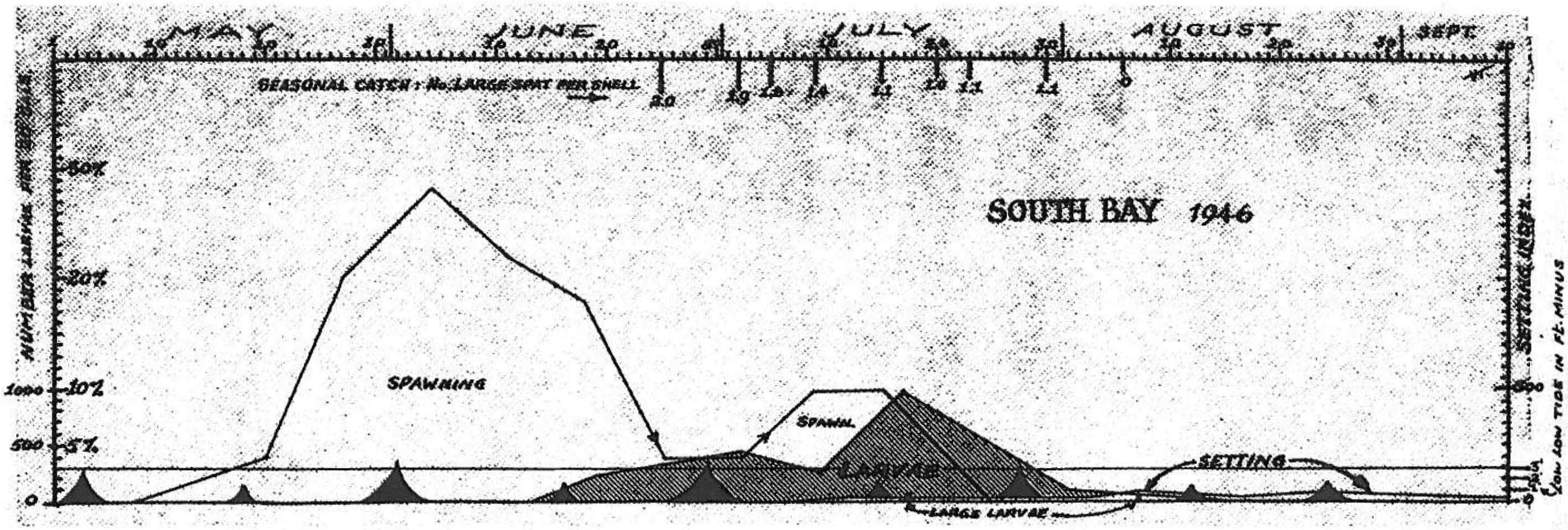
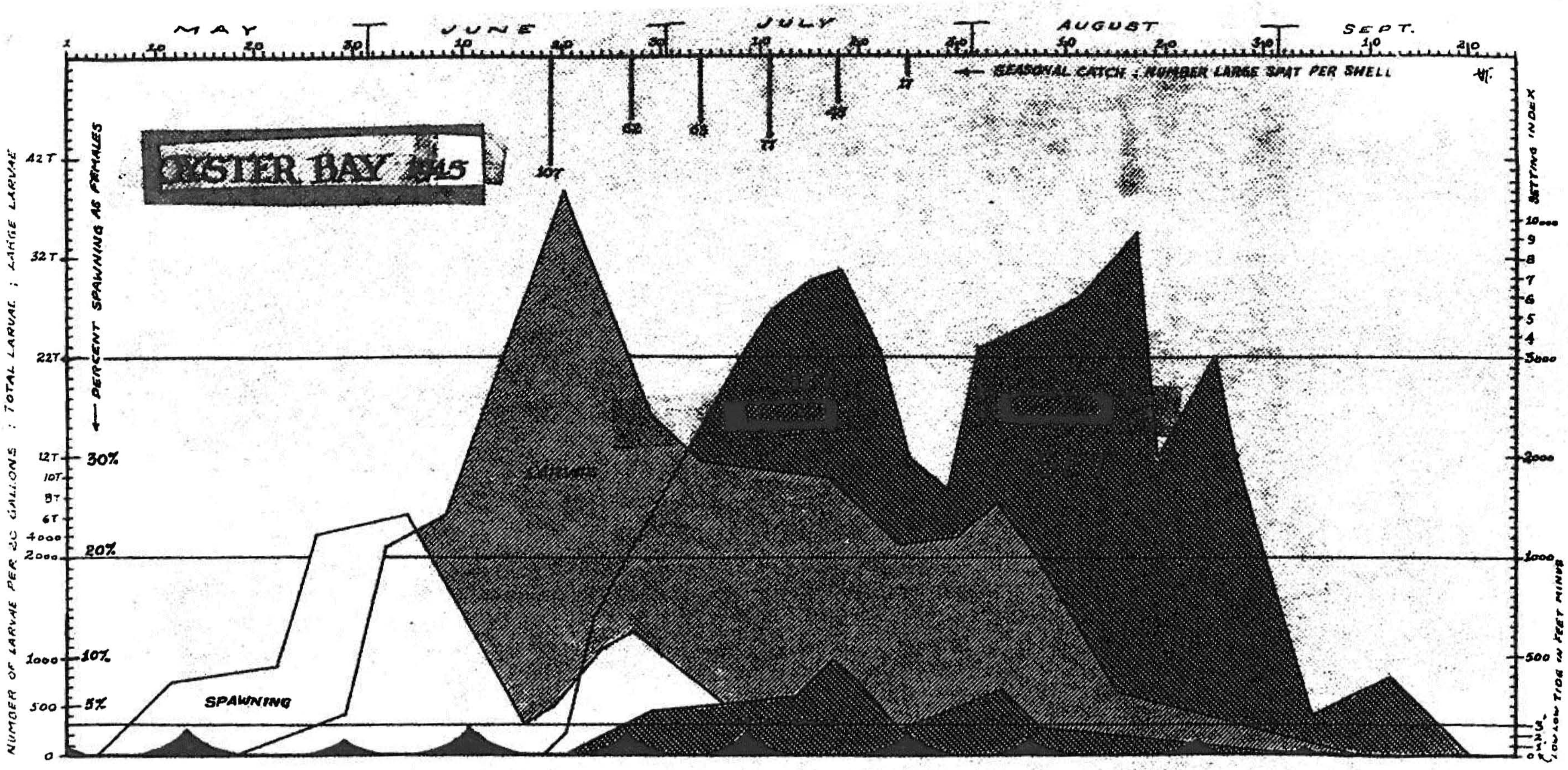


Figure 22 South Bay Reproductive Season, 1946


OYSTER BAY 1945
MAY
JUNE
JULY
AUGUST
SEPT.
← SEASONAL CATCH : NUMBER LARGE SPAT PER SHELL
← PERCENT SPAWNING AS FEMALES
SPAWNING
NUMBER OF LARVAE PER 20 GALLONS : TOTAL LARVAE ; LARGE LARVAE
SETTING INDEX
LOW TIDE IN FEET MINUS
30%
20%
10%
5%
42T
32T
22T
12T
10T
8T
6T
4000
2000
1000
500
0
10T
10000
3000
2000
1000
500

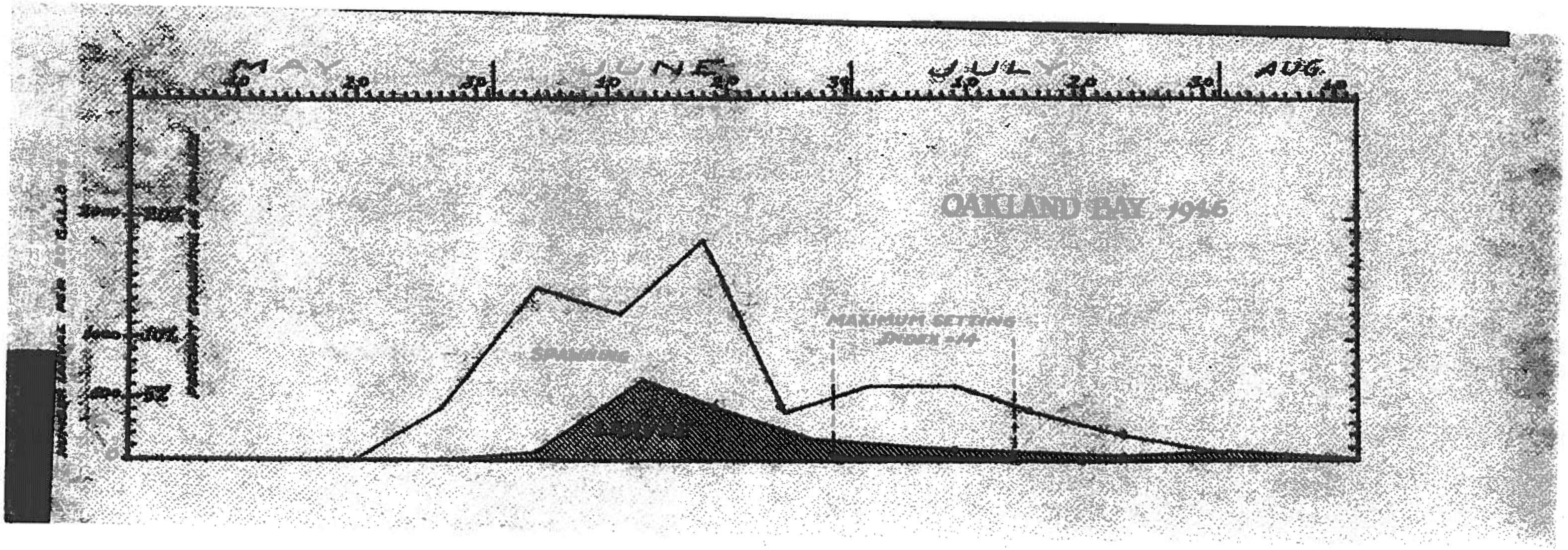


Figure 23 Oakland Bay Reproductive Season, 1946.

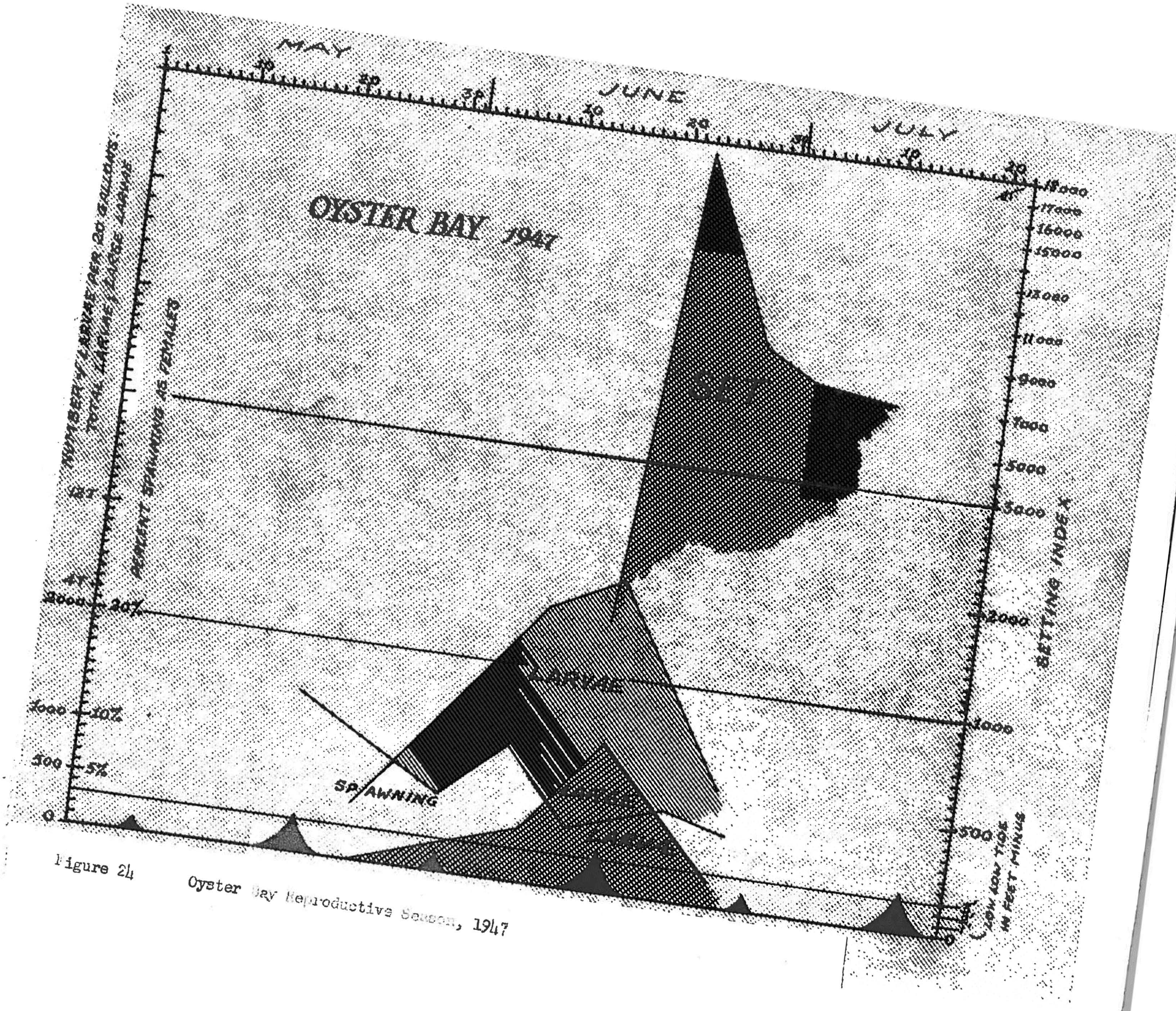


Figure 24 Oyster Bay Reproductive Season, 1947

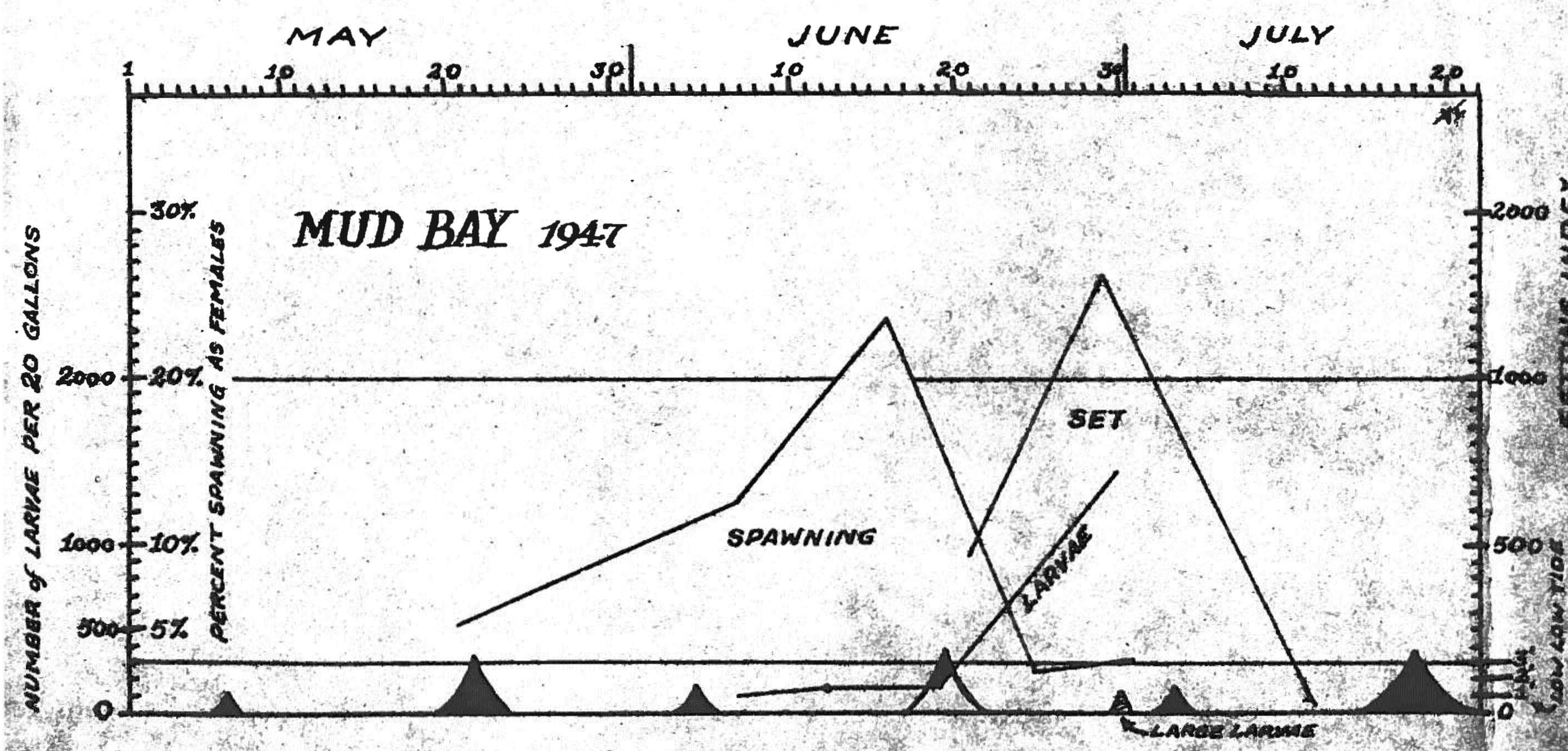
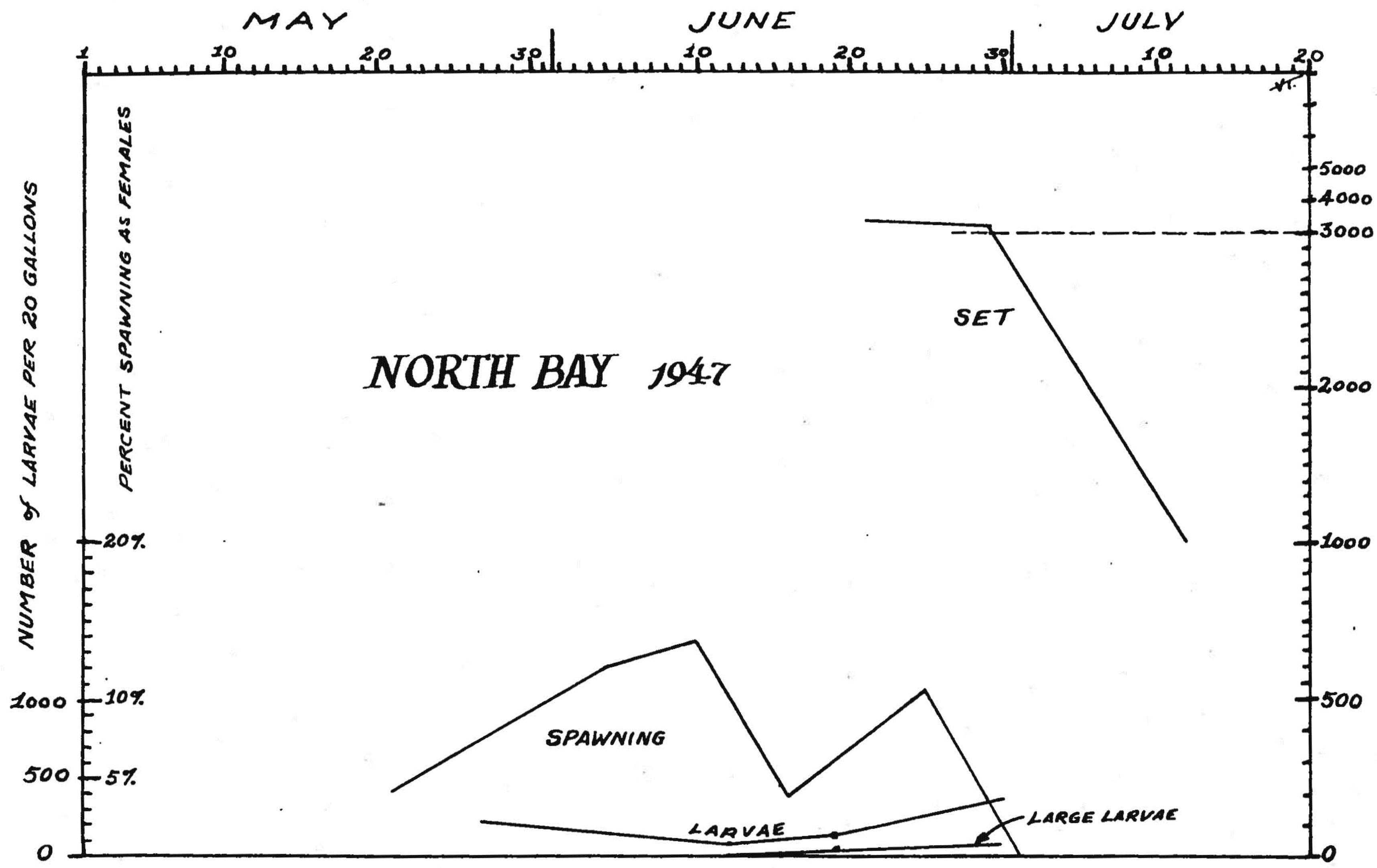


Figure 25 Mud Bay Reproductive Season, 1947.



igure 26 North Bay Reproductive Season, 1947.

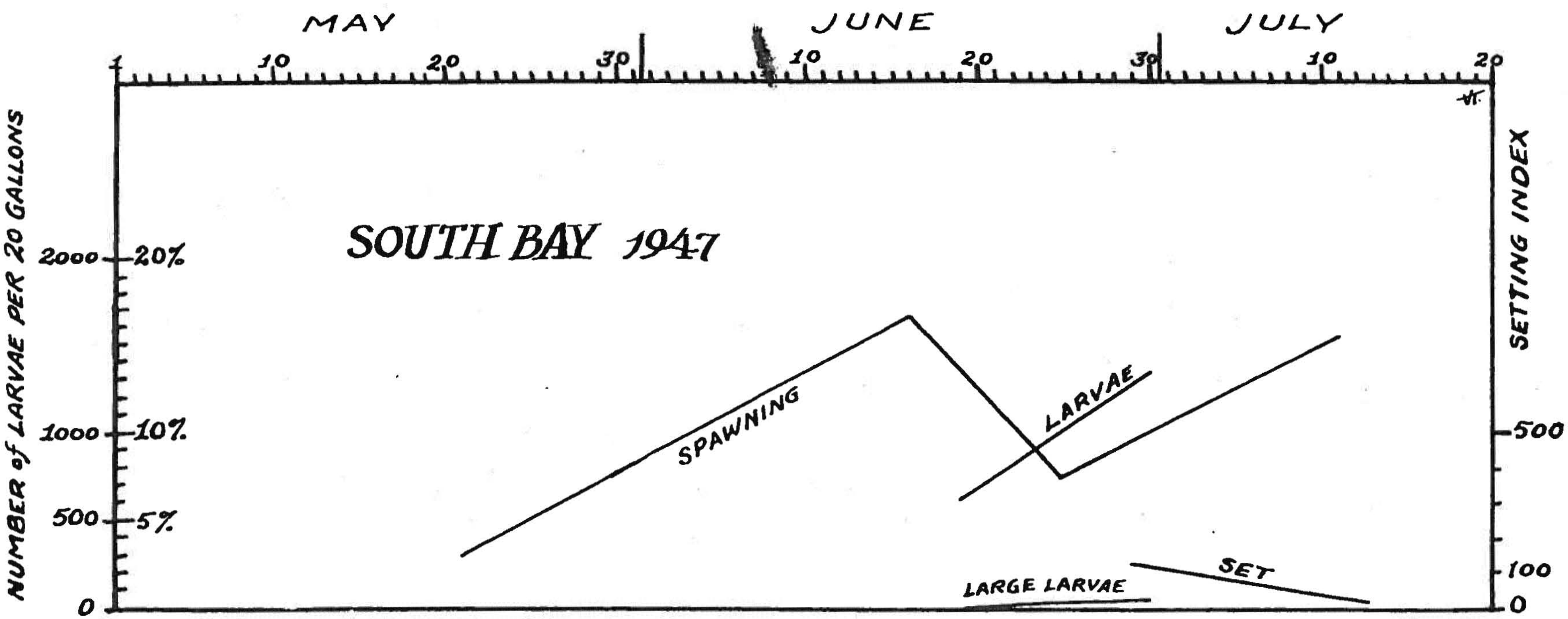
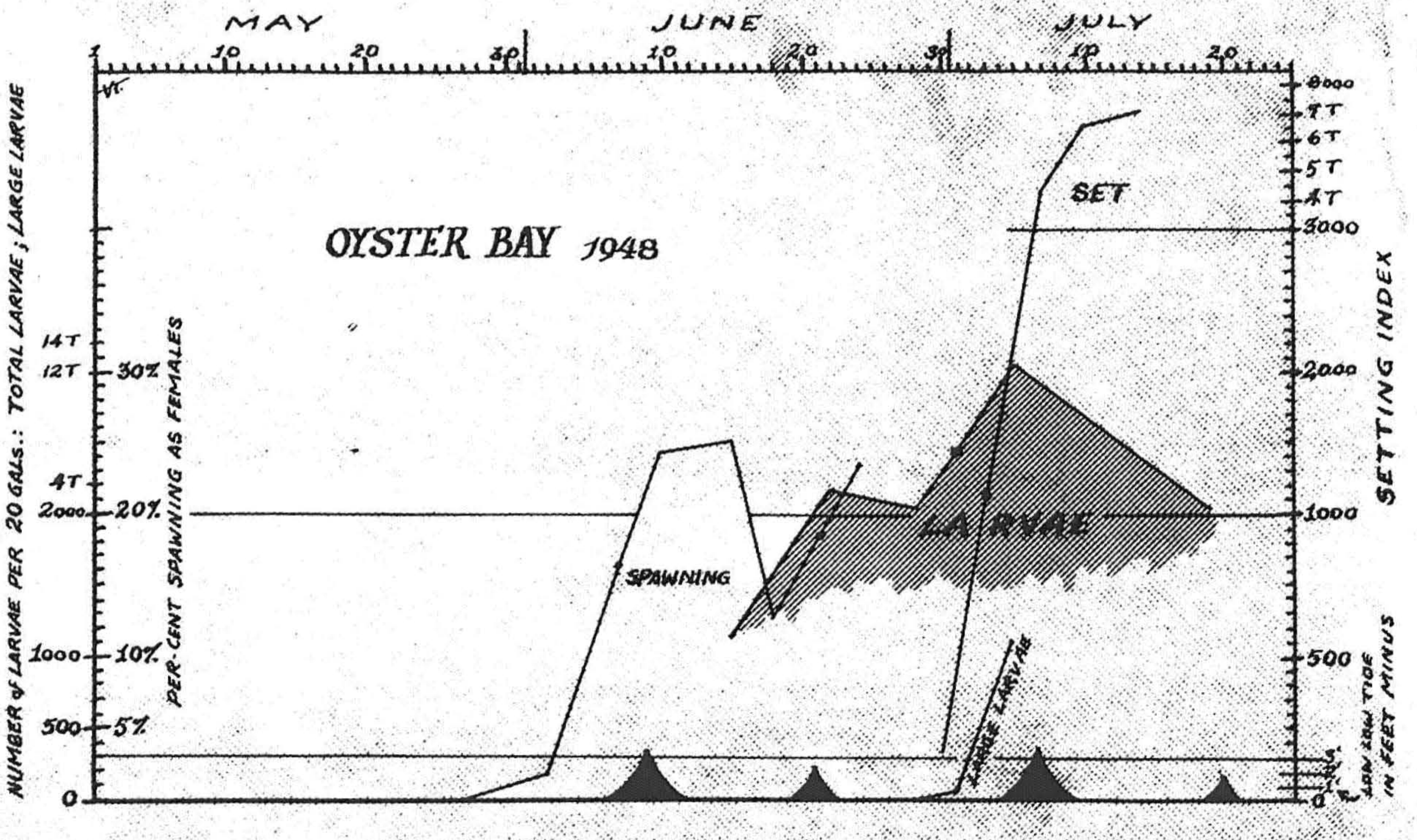


Figure 27 South Bay Reproductive Season, 1947.



grue 28 Oyster Bay Reproductive Season, 1948.

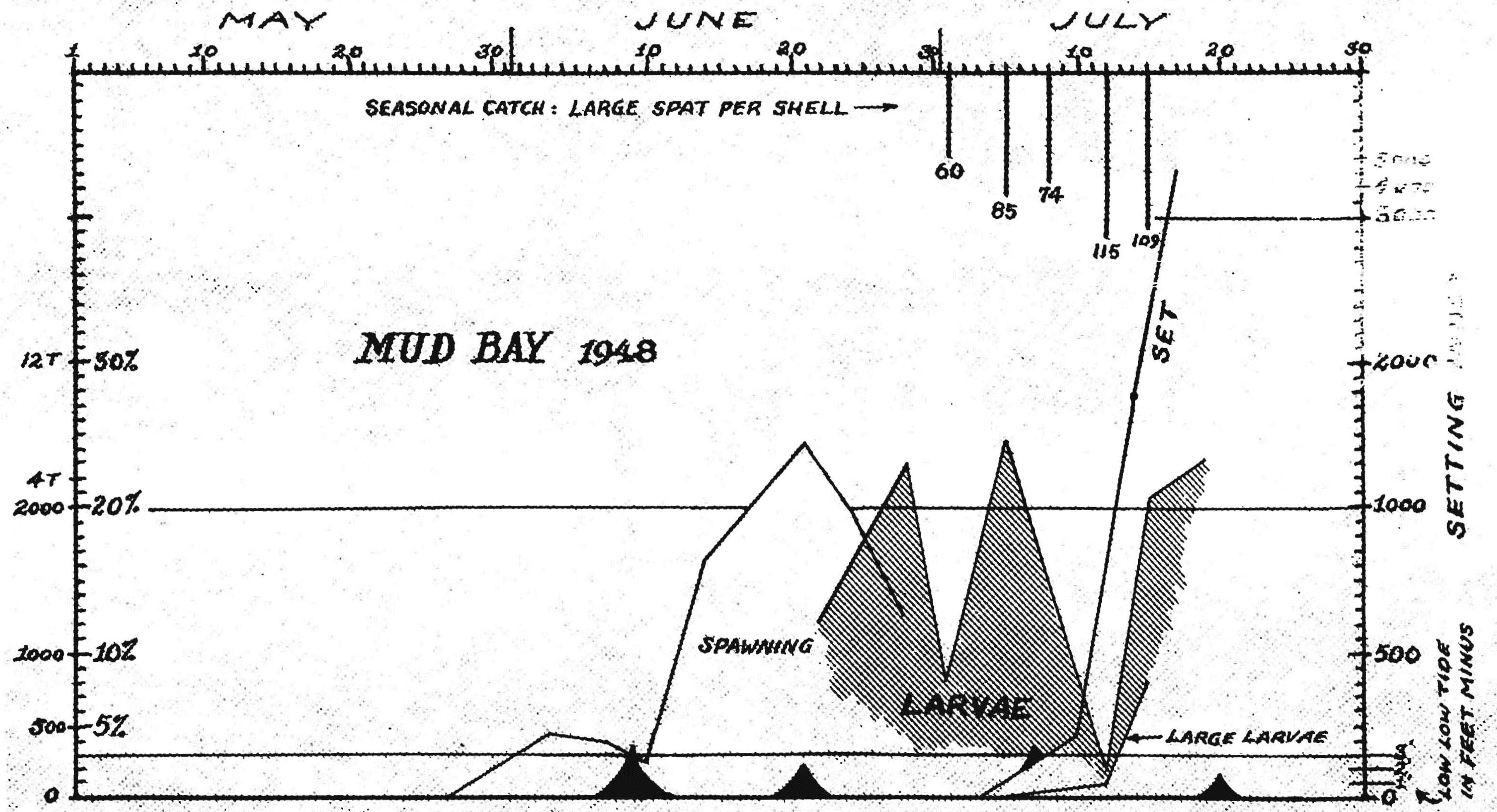


Figure 29 Mud Bay Reproductive Season, 1948.

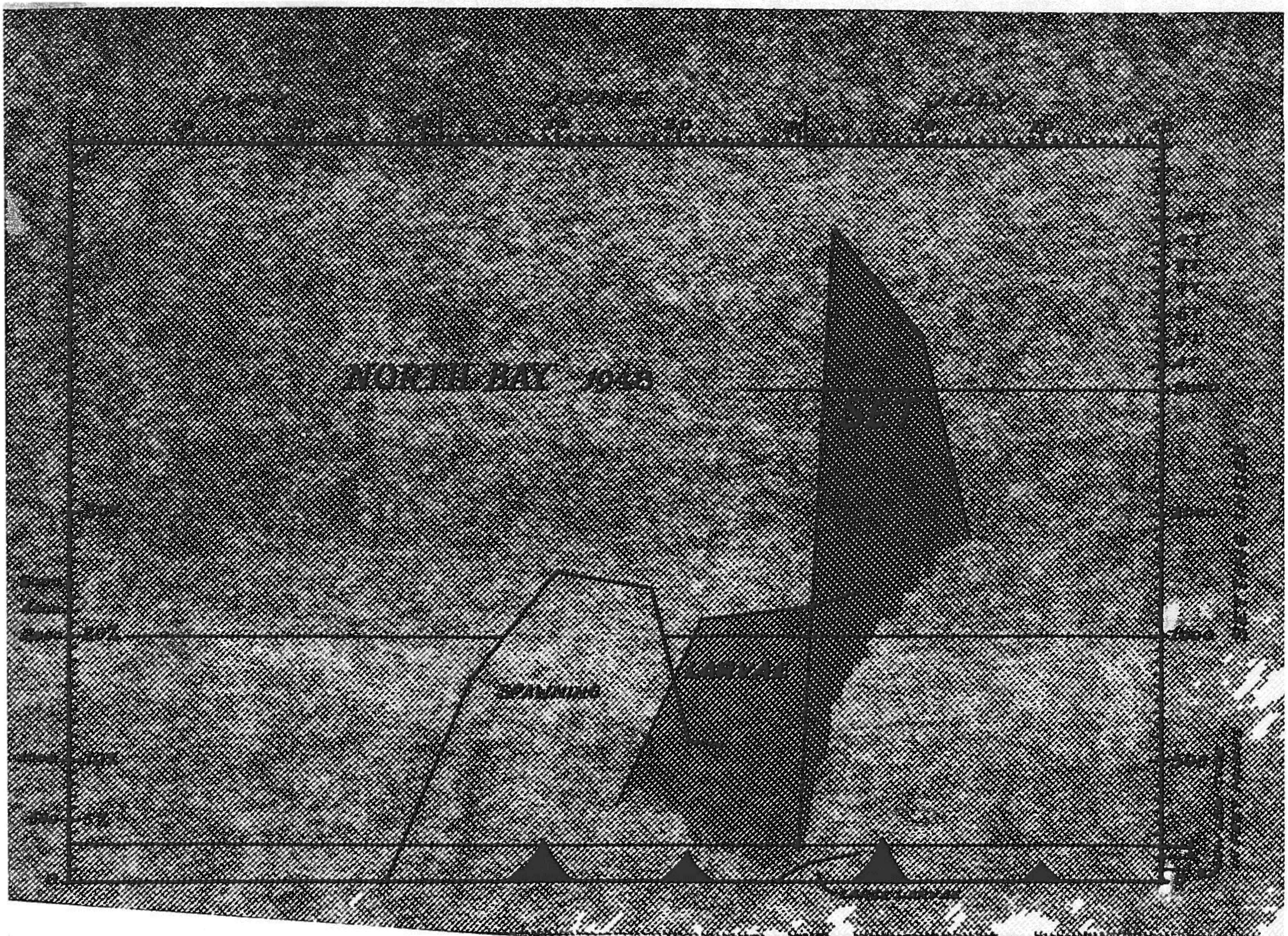


Figure 30 North Bay Reproductive Season, 1948.

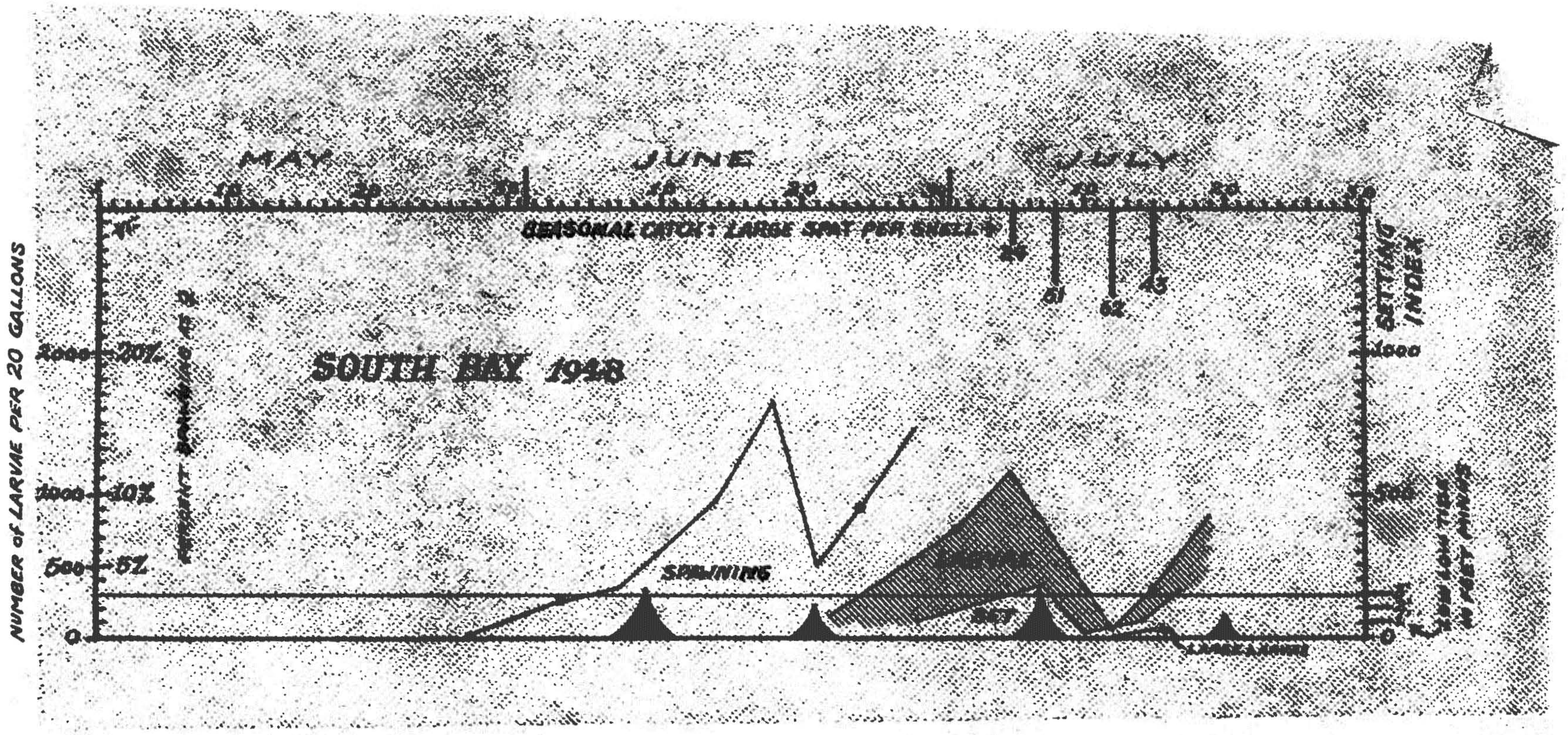


Figure 31 South Bay Reproductive Season, 1948

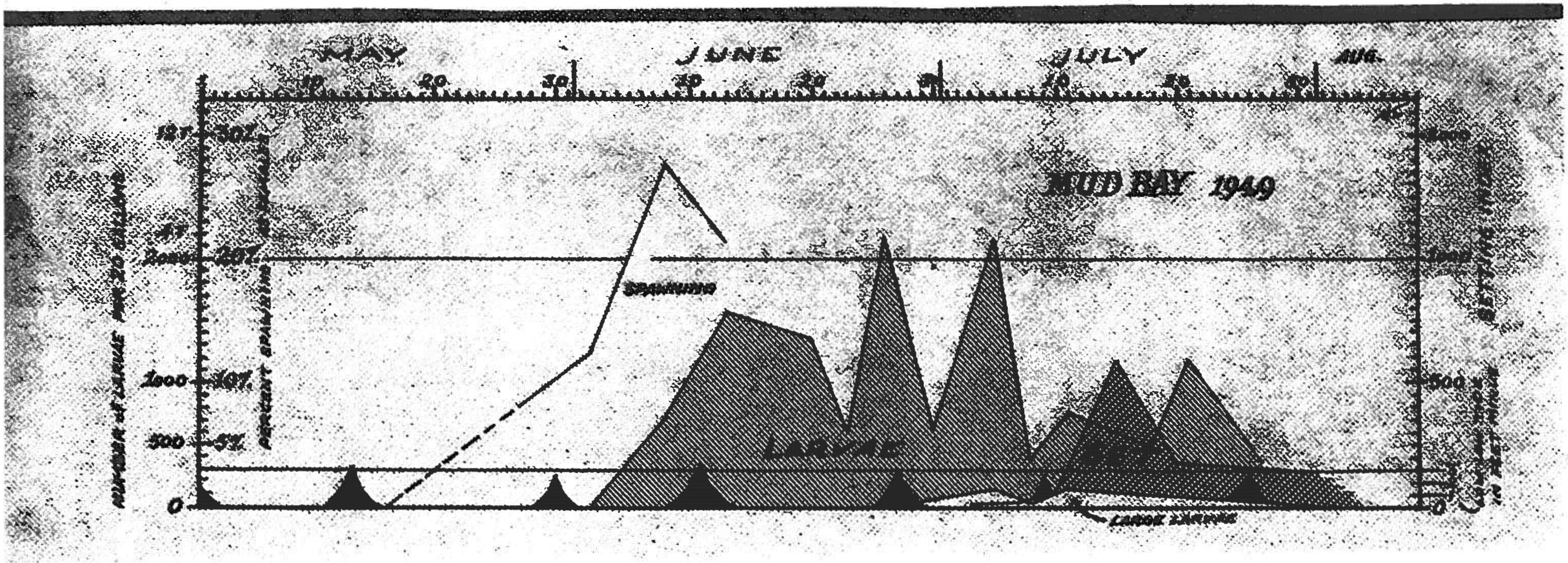
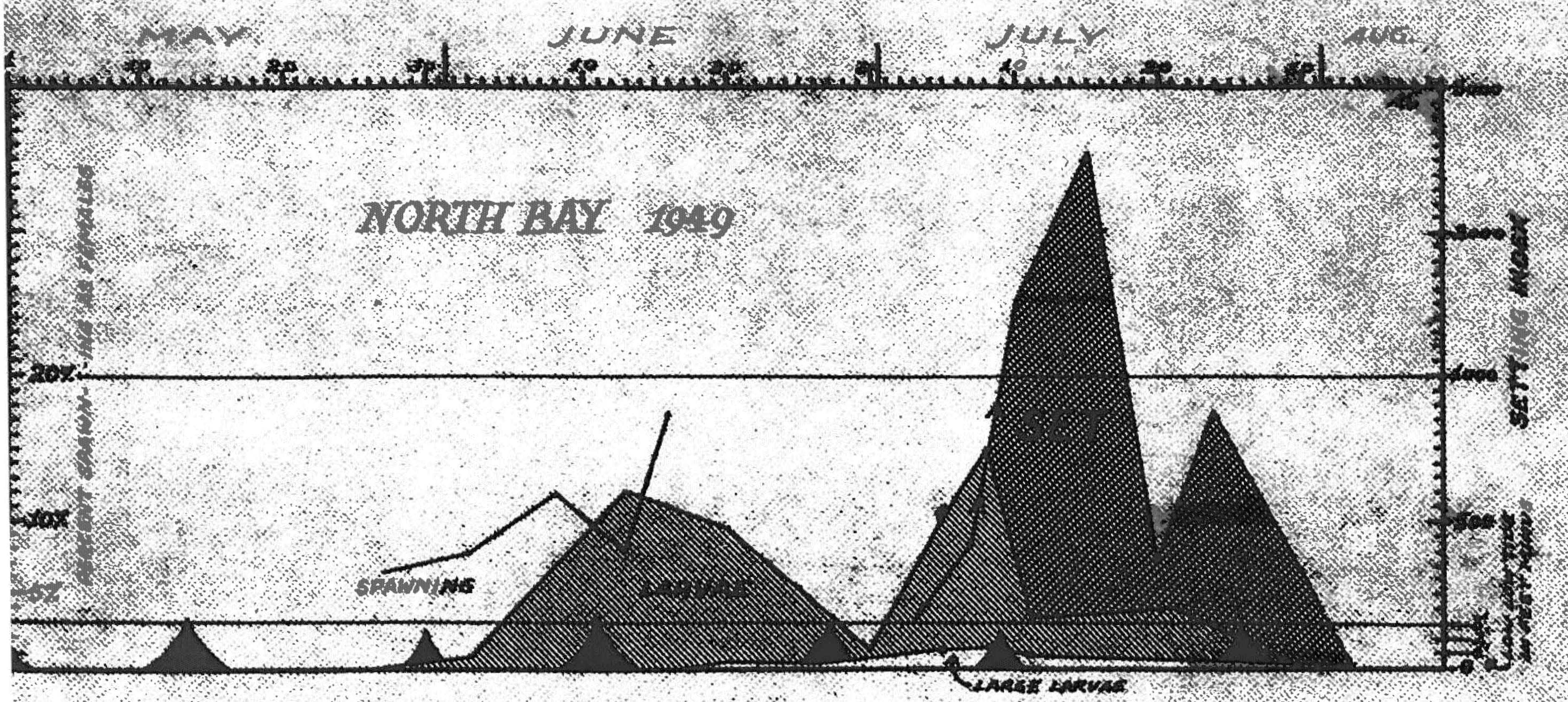


Figure 33 Mud Bay Reproductive Season, 1949



4 North Bay Reproductive Season, 1949

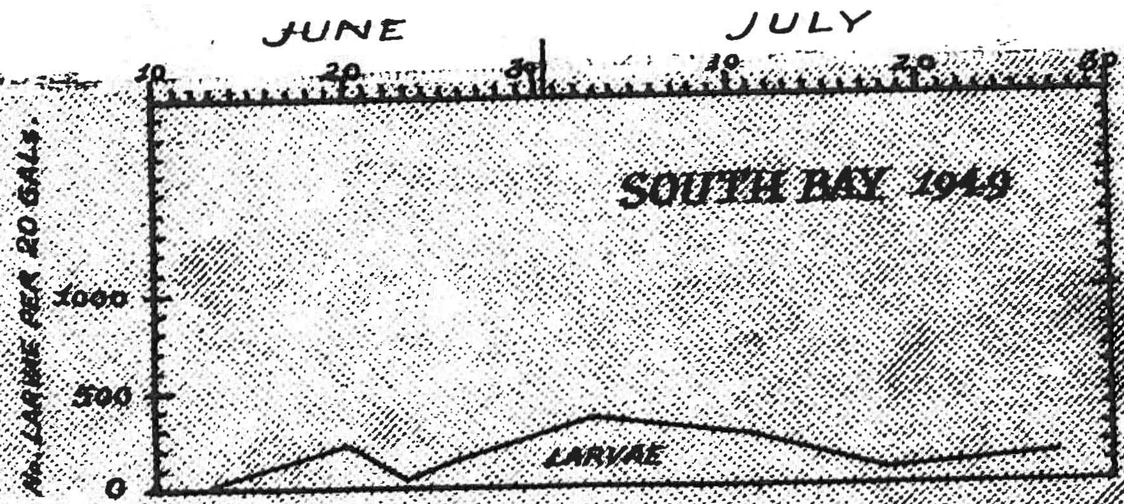


Figure 35 South Bay Reproductive Season, 1949

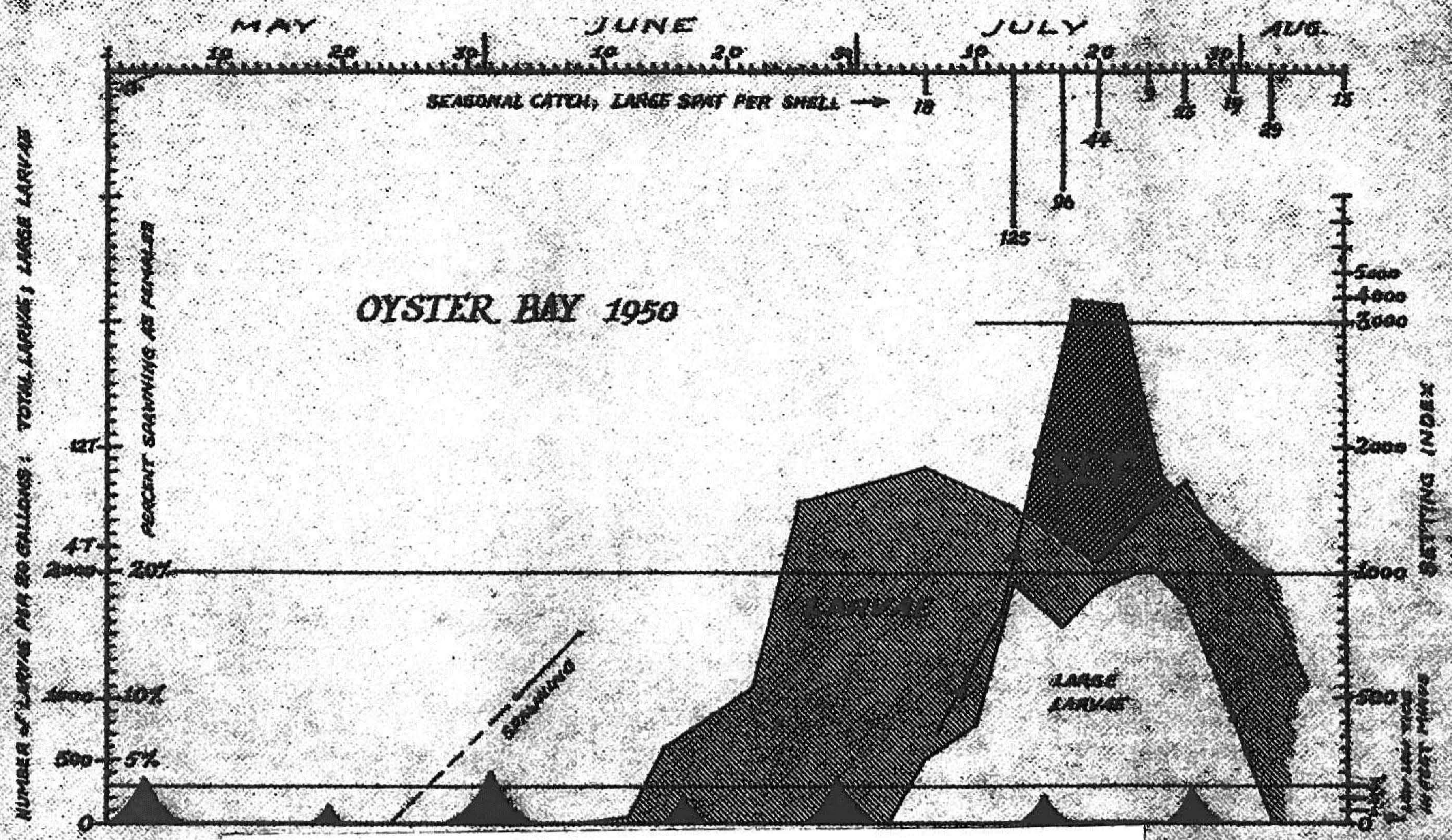


Figure 35A Oyster Bay Reproductive Season, 1950

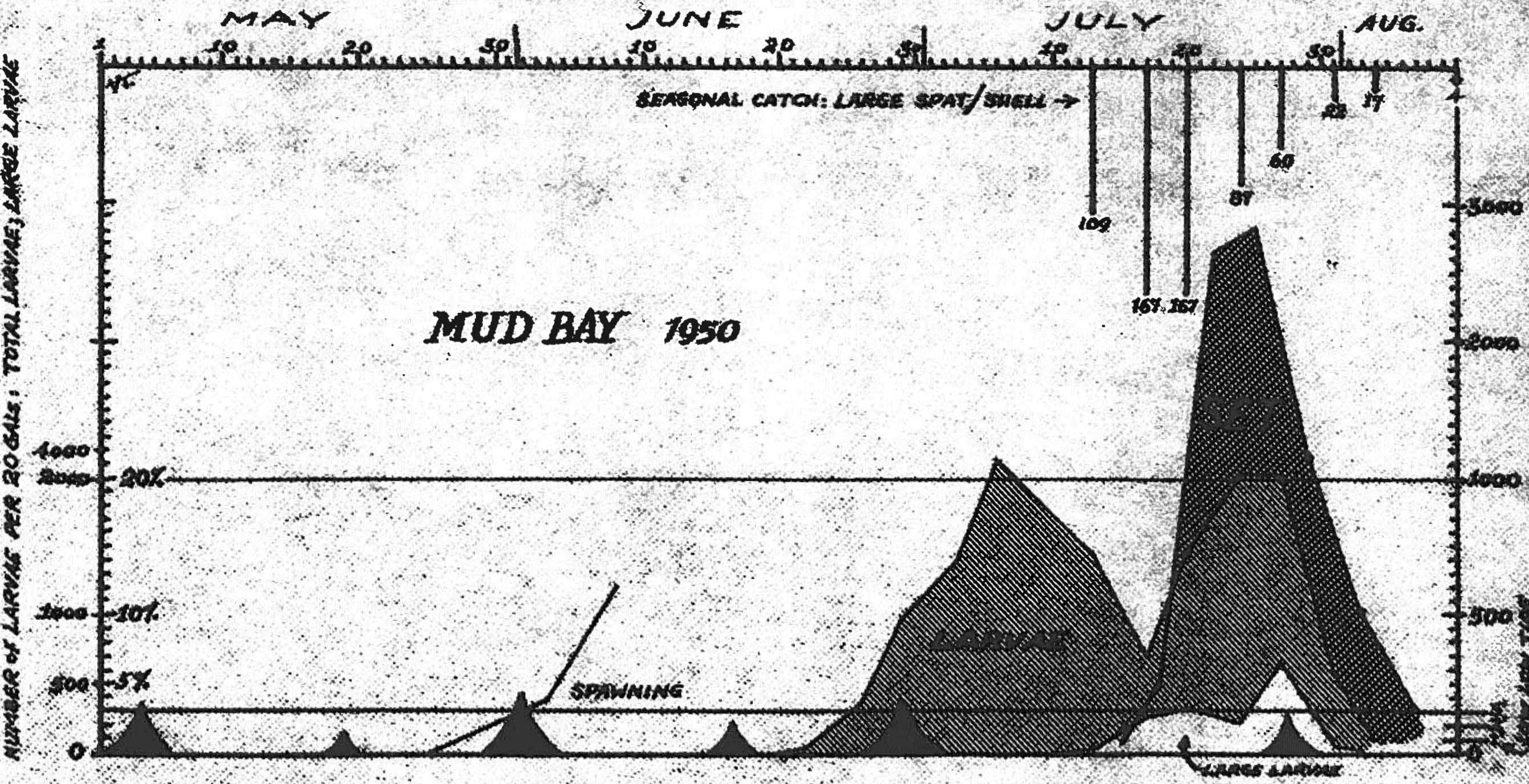


Figure 36 Mud Bay Reproductive Season, 1950

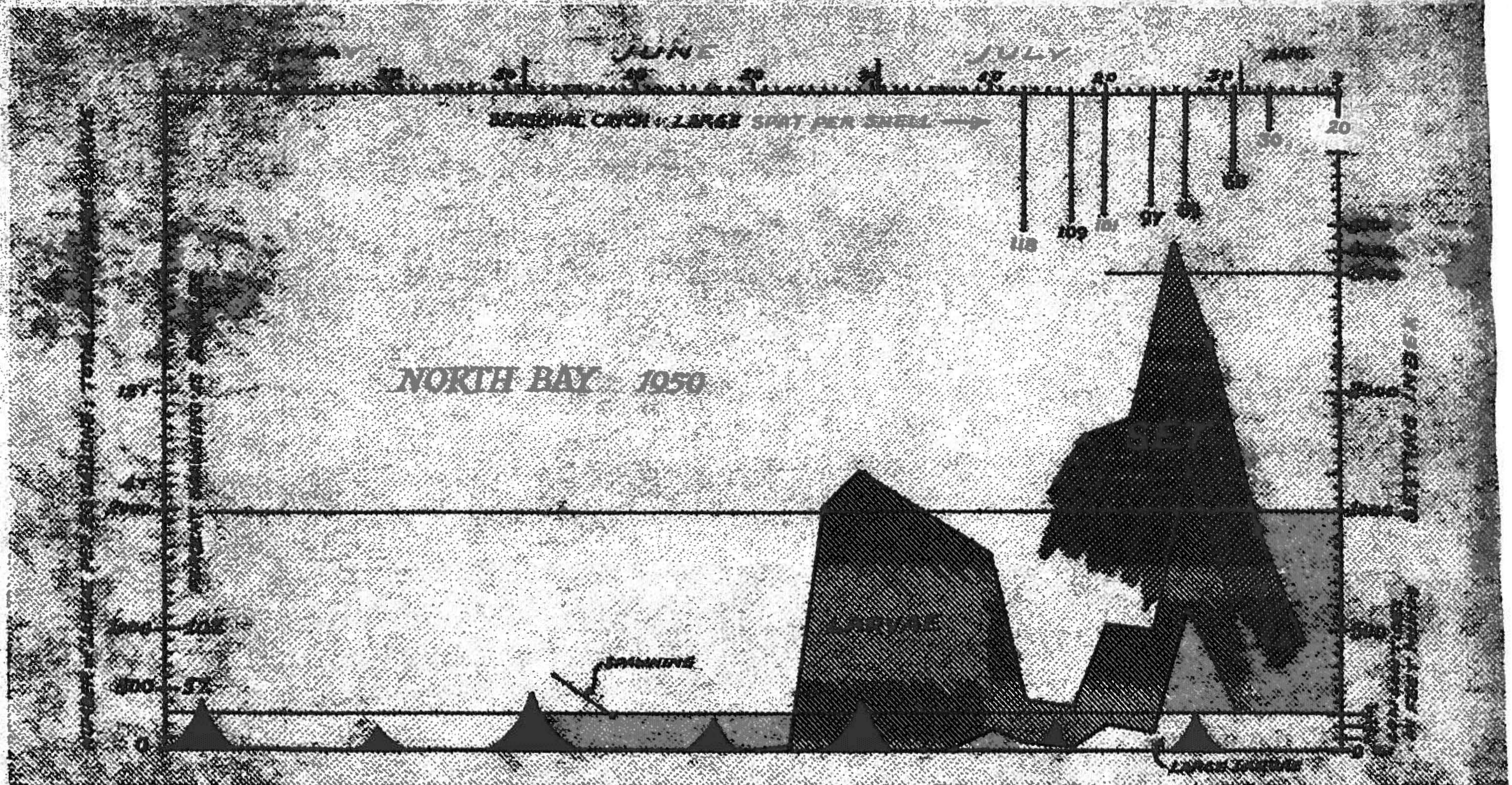


Figure 37 North Bay Reporductive Season, 1950.

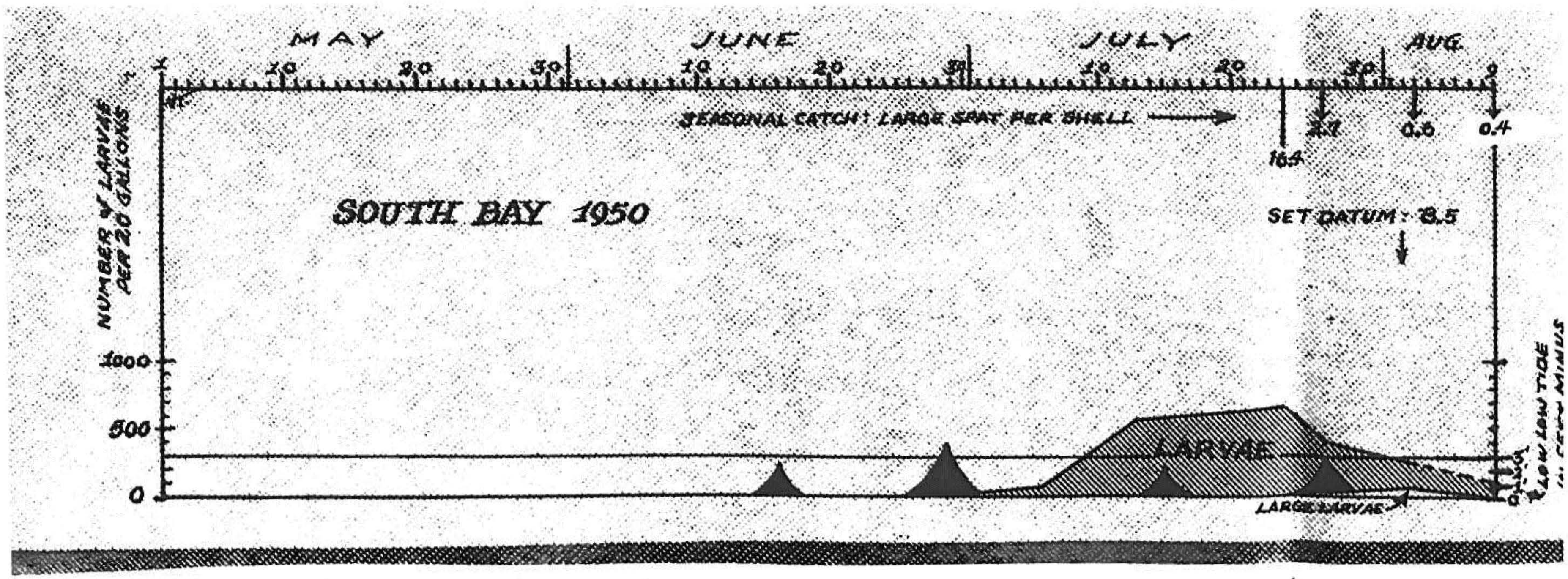


Figure 38 South Bay Reproductive Season, 1950

Figure 39 Oyster BAY Correlation between Time of Beginning Spatfall and Spring Thermal Trend (algebraic sum of deviations from normal of air temperatures at Priest Point Park, Olympia, January through April).

Figure

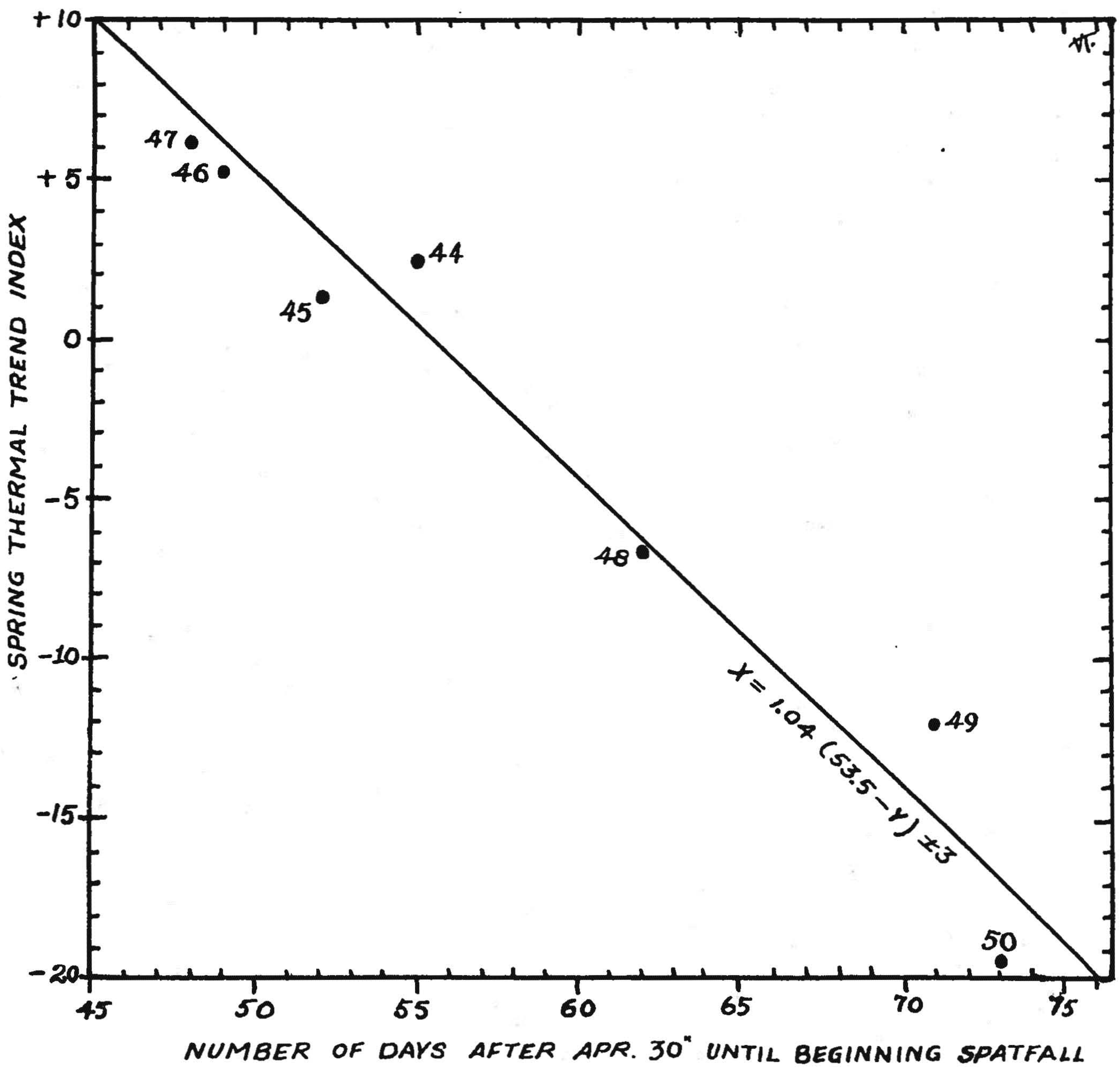
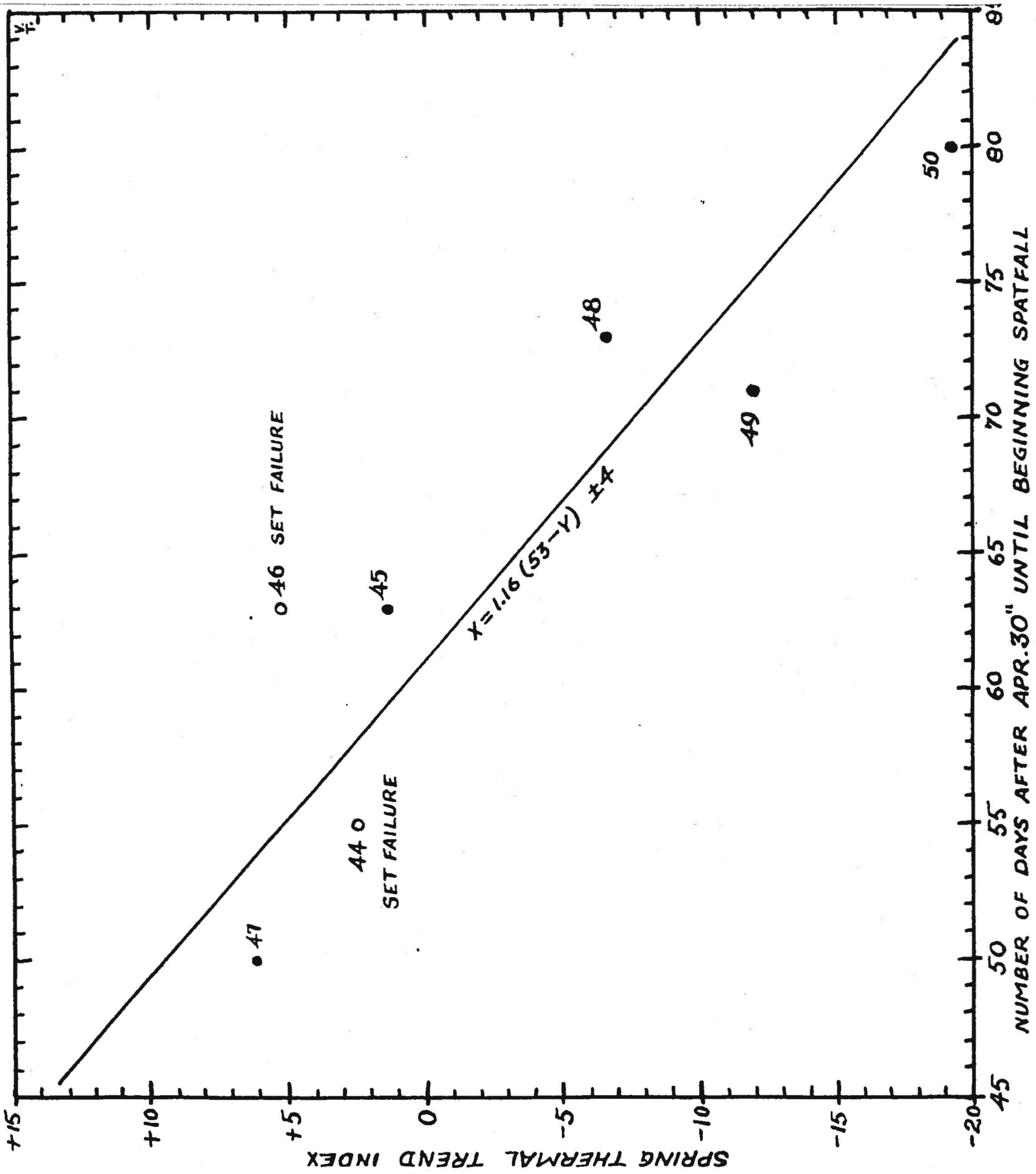


Figure 40 MUD BAY Correlation between time of beginning oyster set and Spring Thermal Trend (algebraic sum of the deviations from normal of air t/emperatures at Priest Point Park Olympia, January through April).



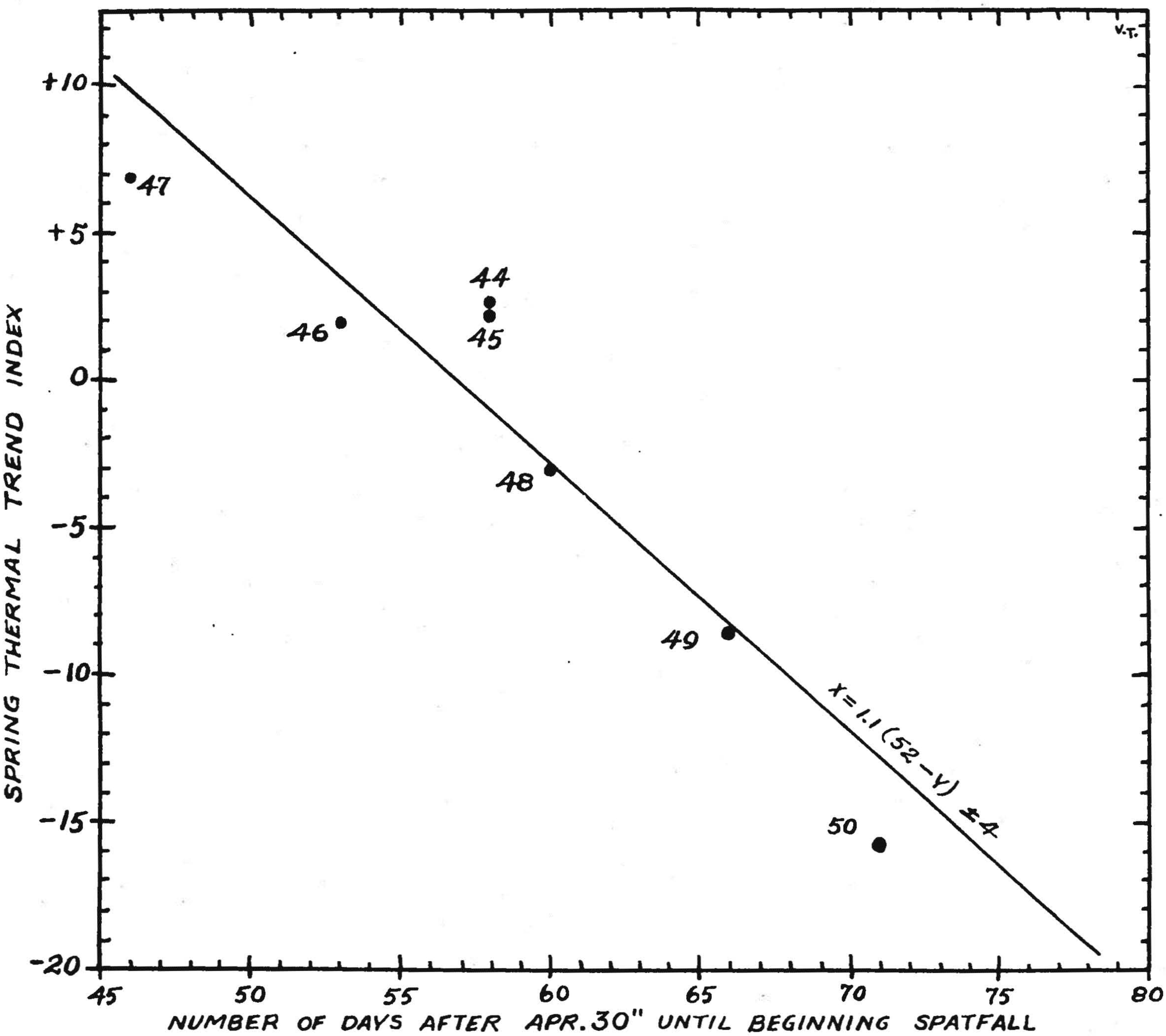


Figure 41 NORTH BAY Correlation between Time of Beginning Spatfall and Spring Thermal Trend (Algebraic sum of deviations from normal of air temperatures at Grapeview during January through April).

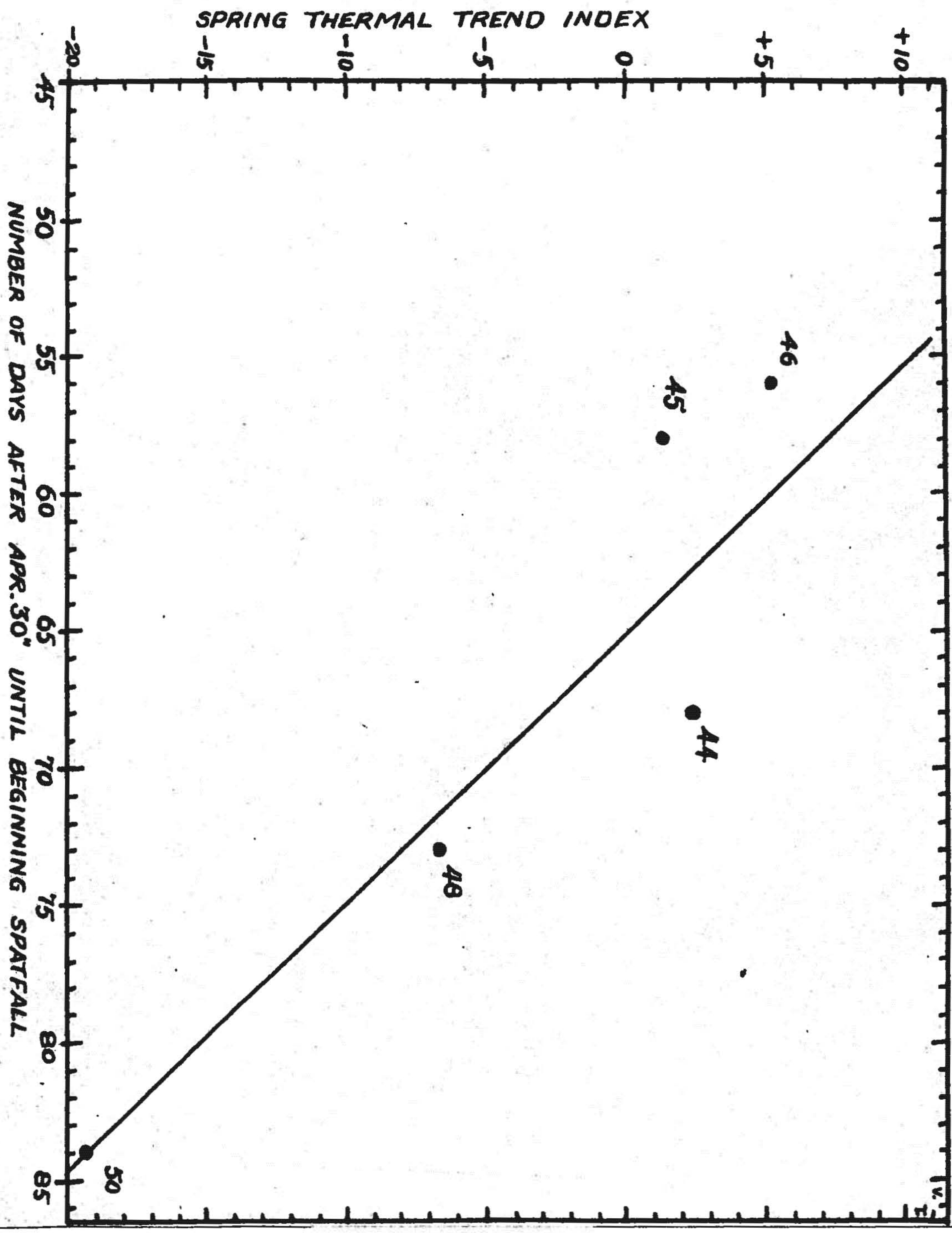
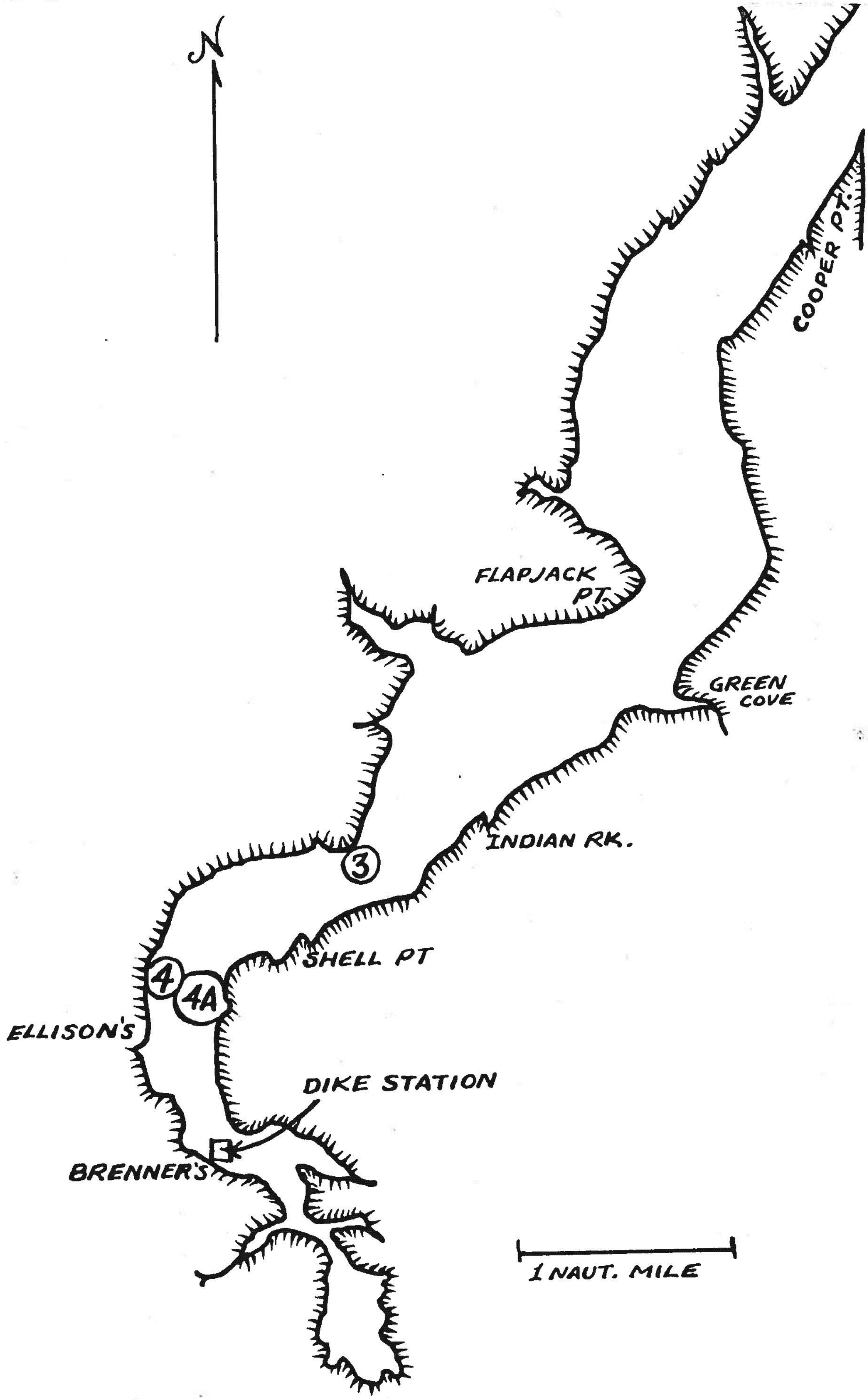


Figure 42 SOUTH BAY Correlation between Time of Beginning Spatfall and Spring Thermal Trend (Algebraic sum of deviations from normal of air temperatures at Priest Point Park, Olympia, January through April).

Figure 42A Map of Mud Bay Showing Dike Station (Spawning and Setting Samples and Areas of Sampling for Planktonic Larvae.



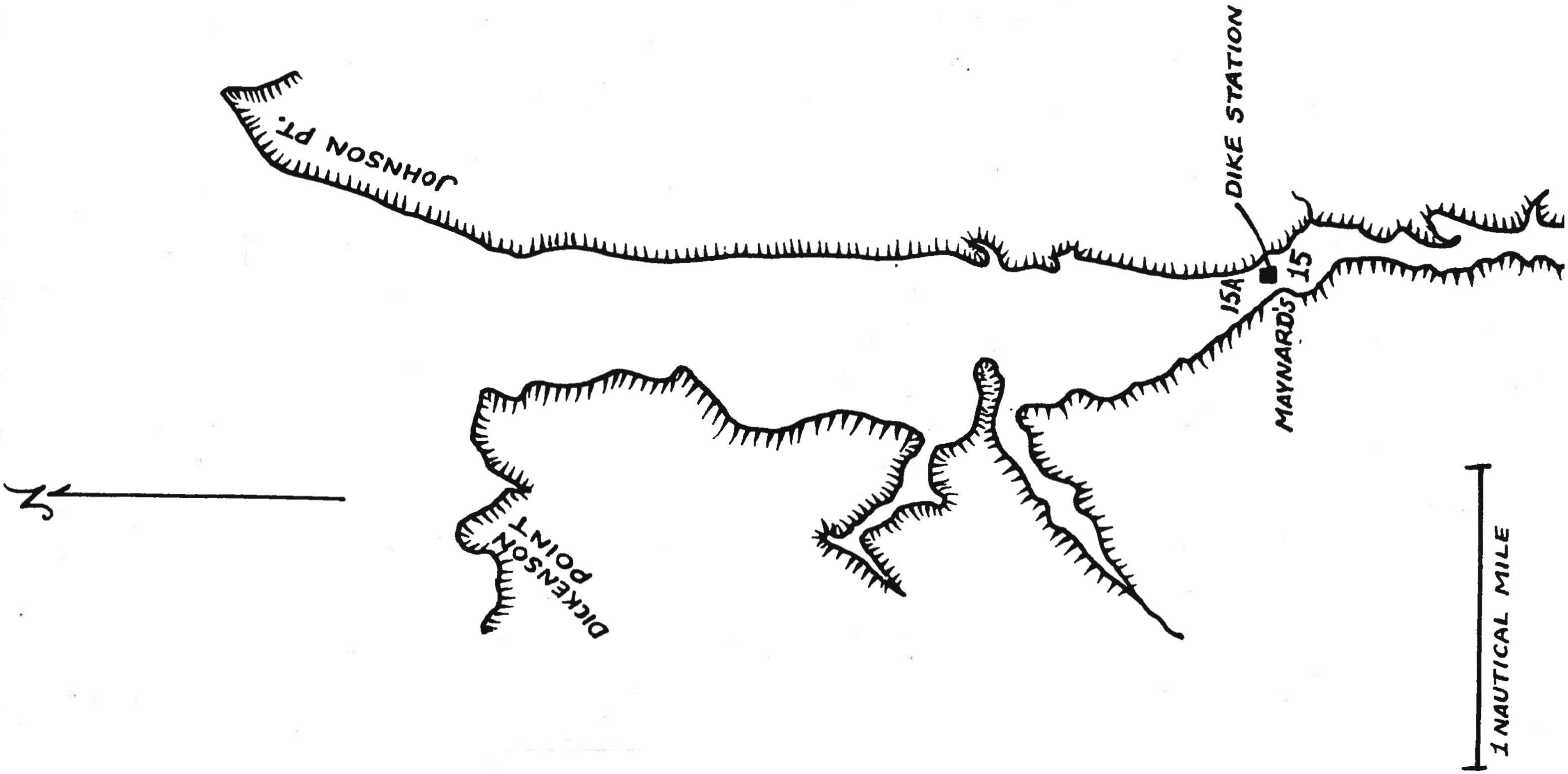


Figure 42B Map of SOUTH BAY Showing Dike Station (Spawning and Setting Samples) and Areas of Sampling for Planktonic Larvae.

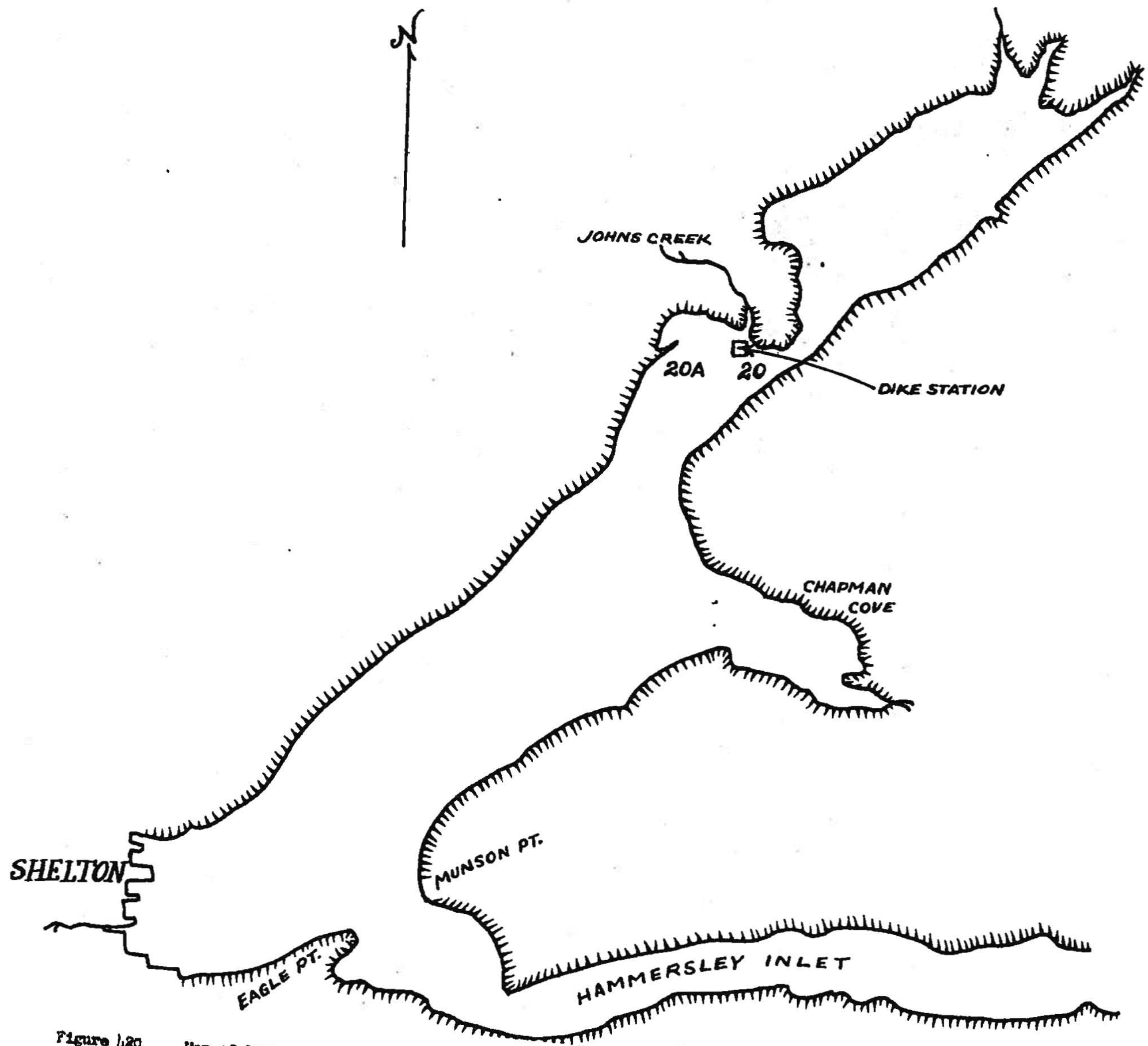


Figure 420 Map of OAKLAND BAY Showing Dike Station (Spawning and Setting Samples) and Areas of Sampling for Planktonic Larvae.

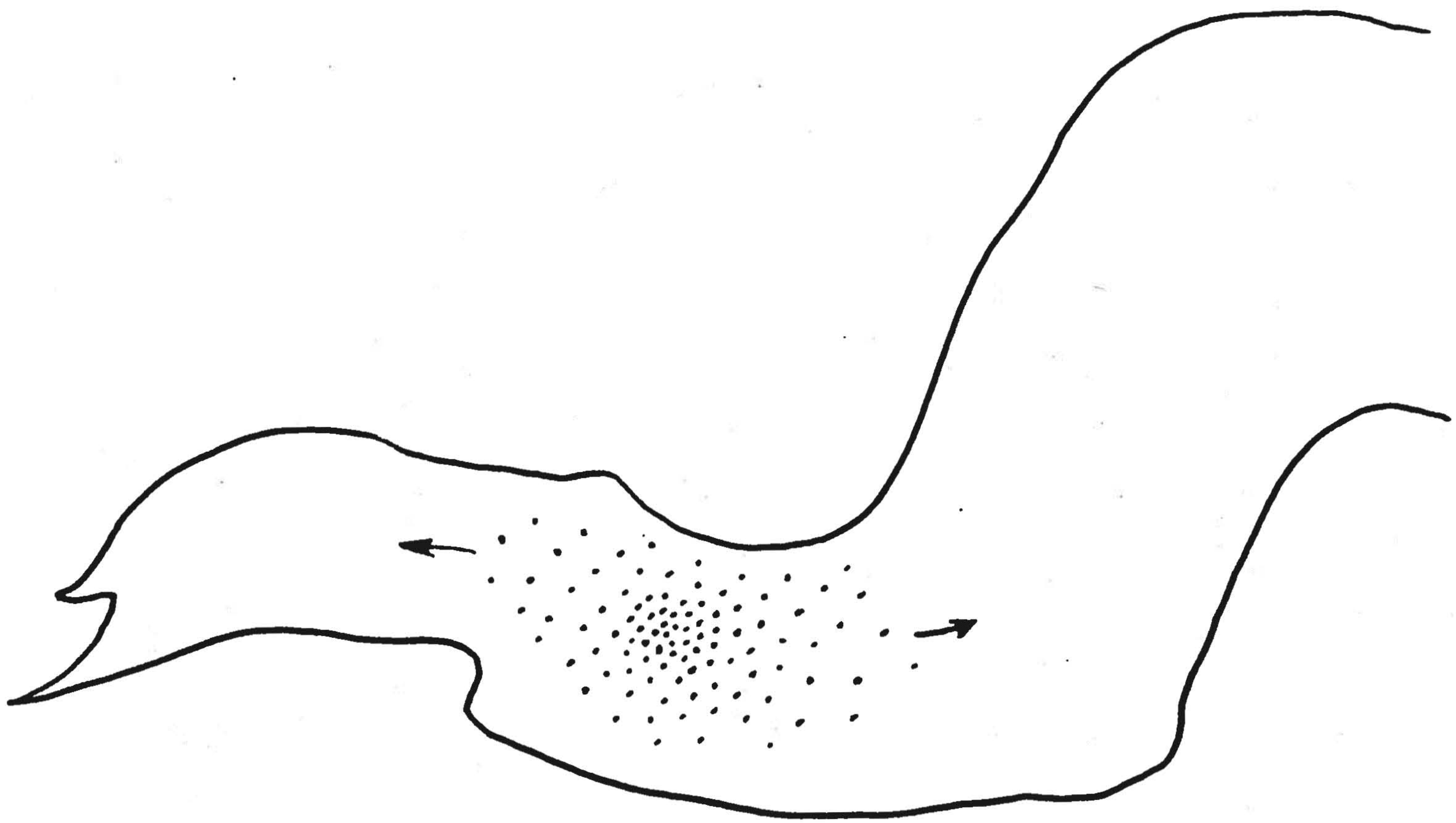


Figure 43 Conception of Larvae Mass moving Up and Down Bay with the tide.

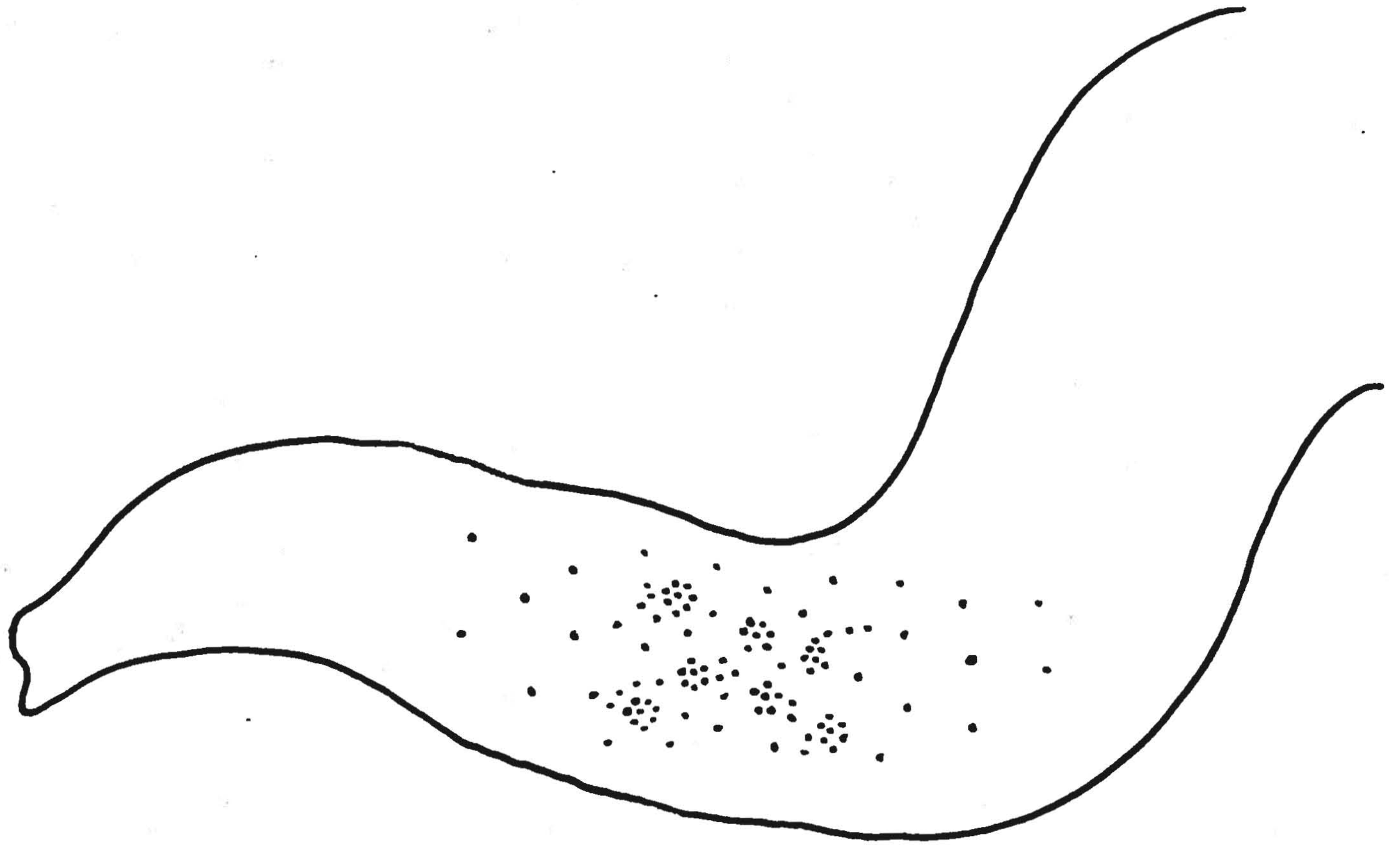
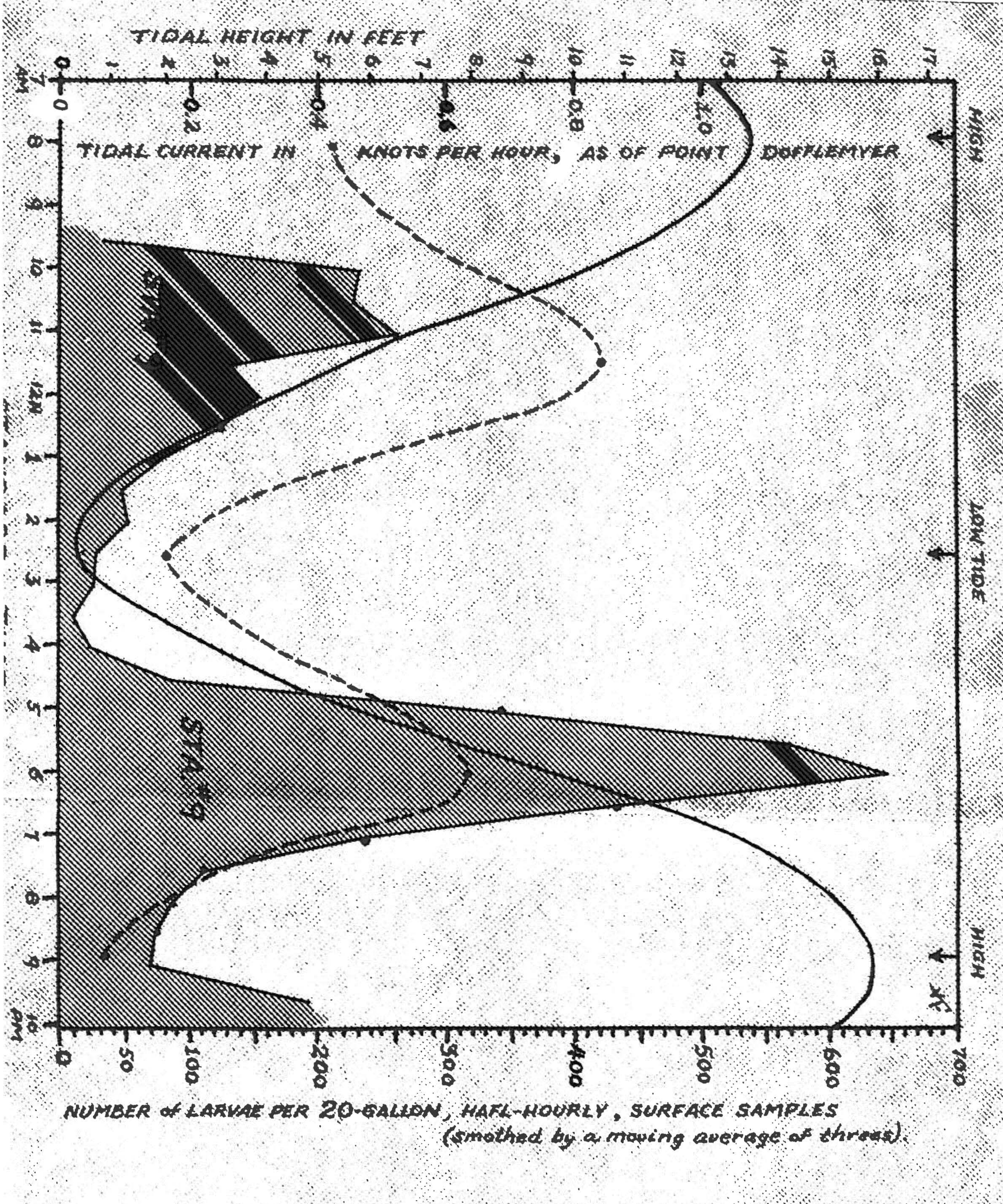


Figure 44 Conception of Spotty Concentrations of Larvae within the Larvae Mass.

Figure 45 Tidal Plankton Cycle at one Station in Oyster Bay on August 8, 1944.



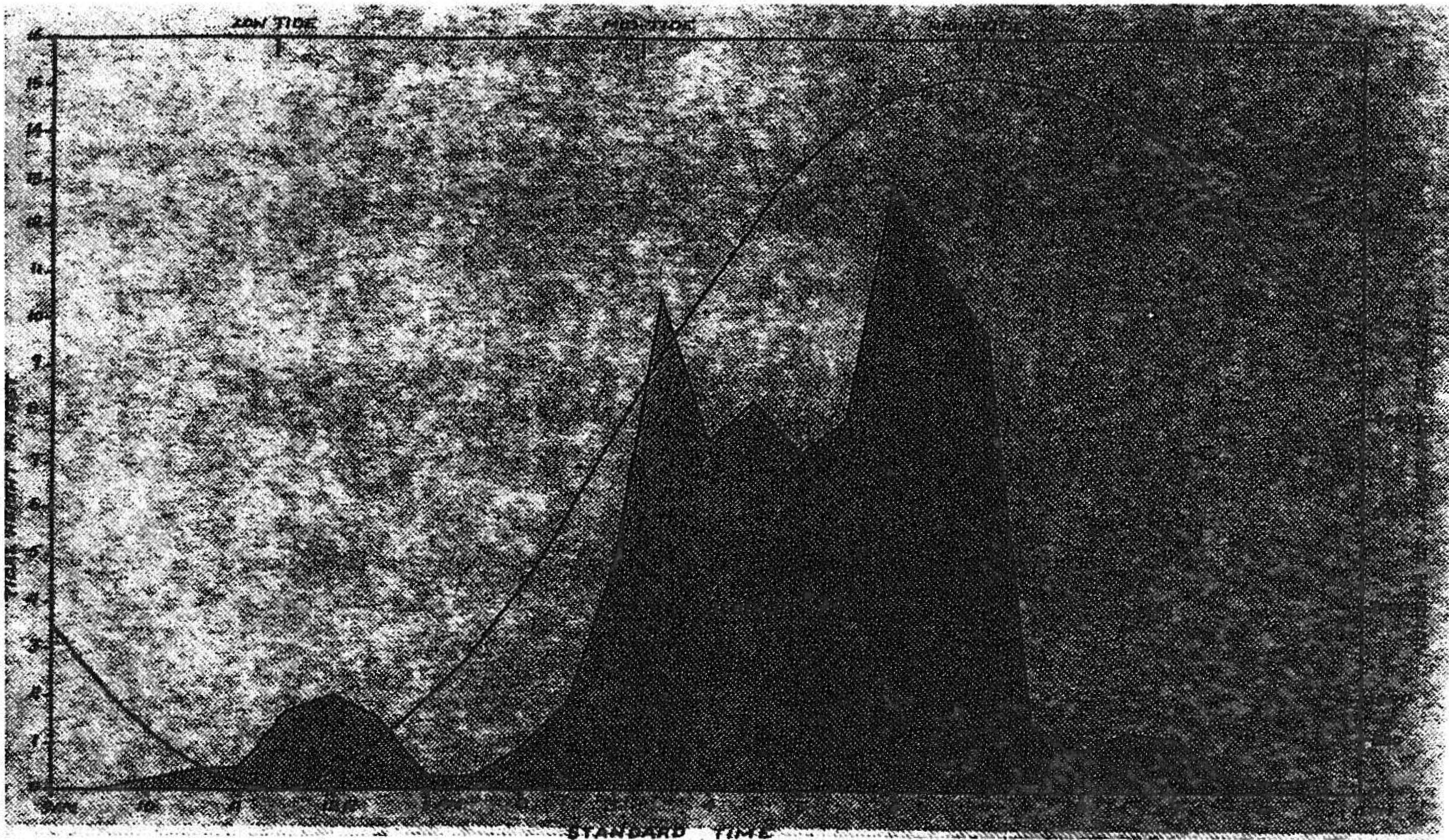


Figure 46 Tidal Plankton Cycle at one station in Oyster Bay on July 9, 1955. (Average of samples at all depths, grouped to nearest half hour.

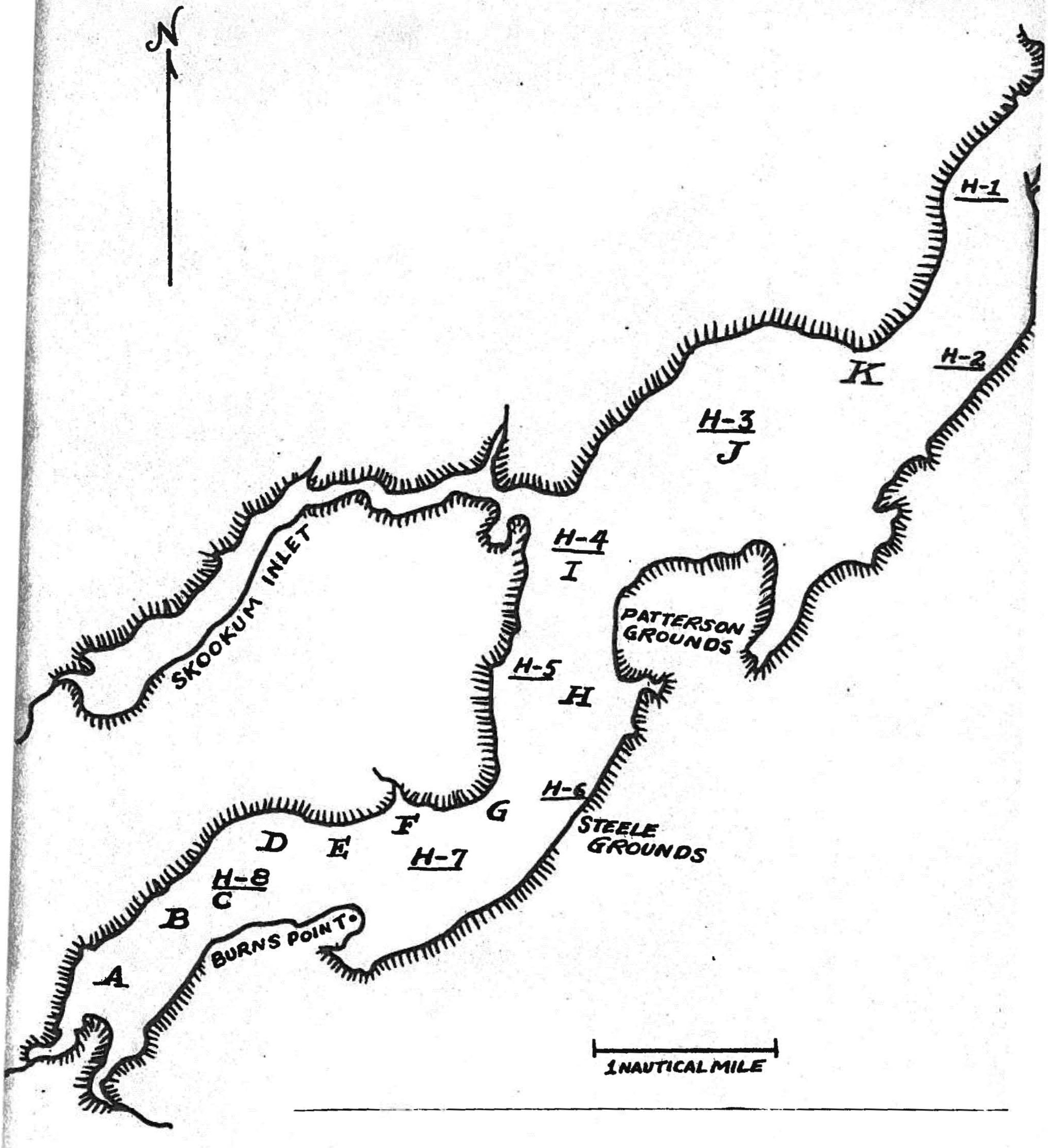


Figure 47 Map of Oyster Bay Showing Stations of Plankton Ti-
Cycle Studies of July 24 and Aug. 23, 1945, and J
1st, 1946.

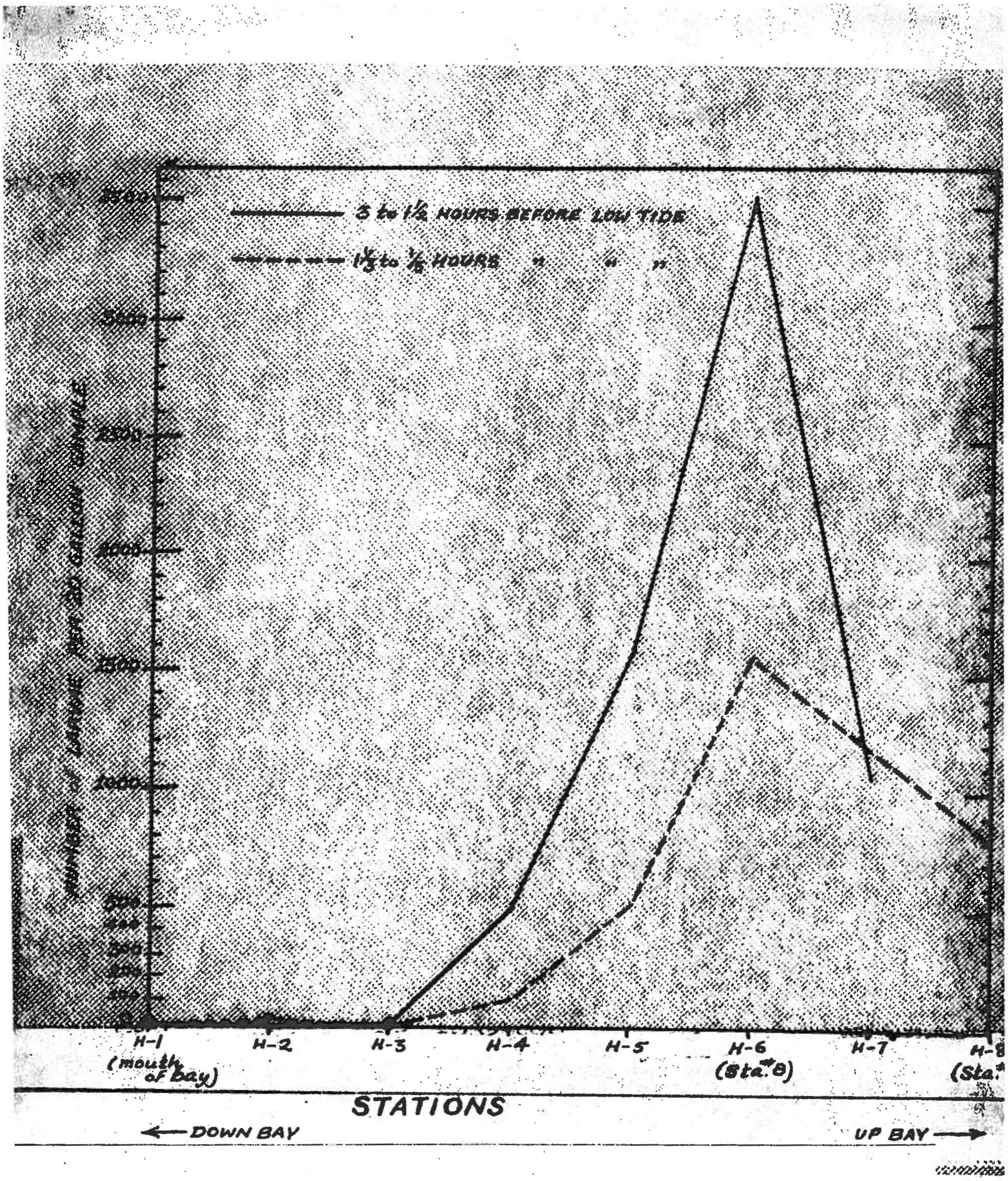


Figure 48 Tidal Plankton Study of Eight Stations in Oyster Bay on July 24, 1945. (For location of stations see

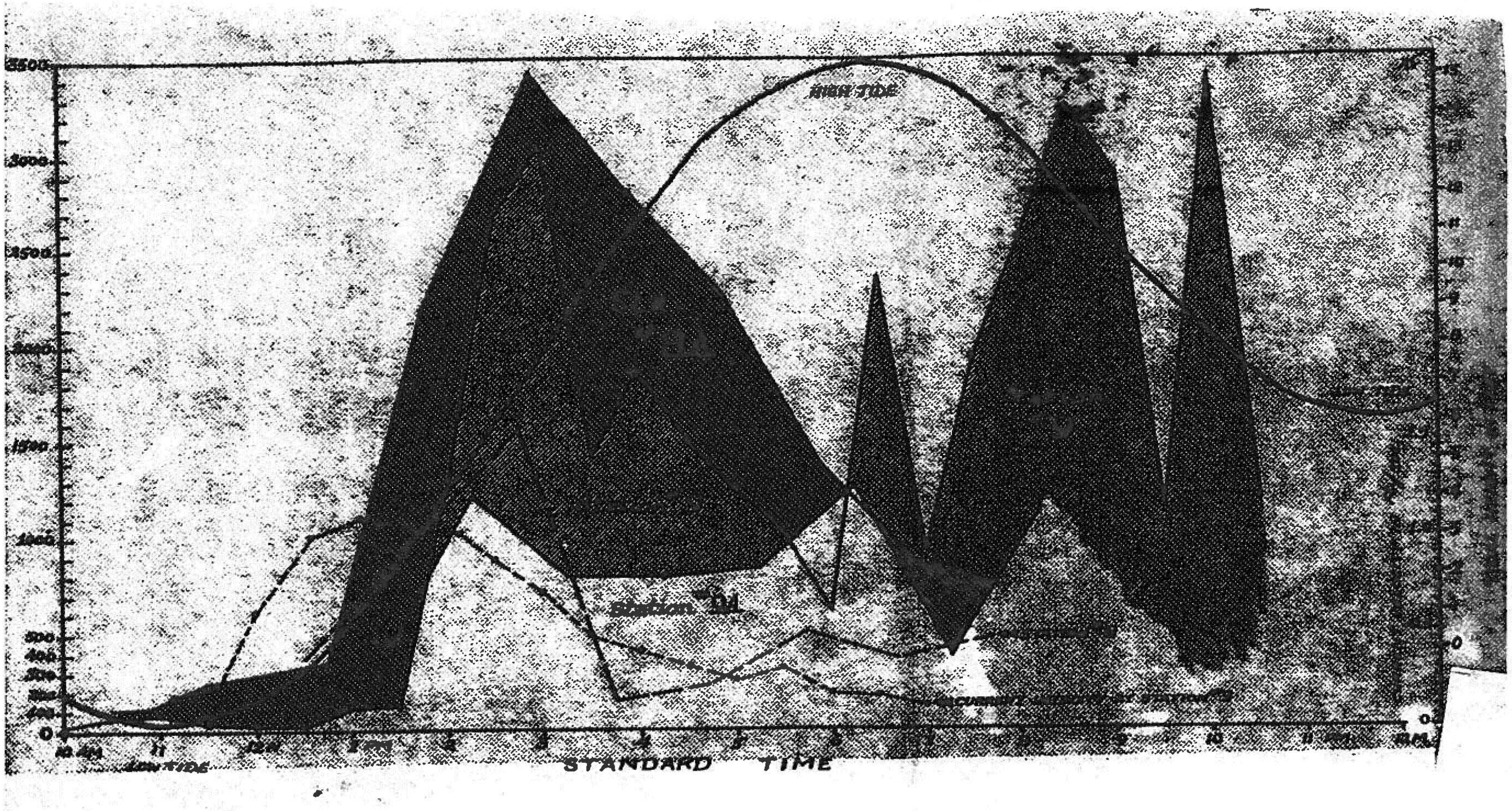


Figure 49 Tidal Plankton Cycle at Four Stations in Oyster bay on August 7, 1945. (For location of Stations see

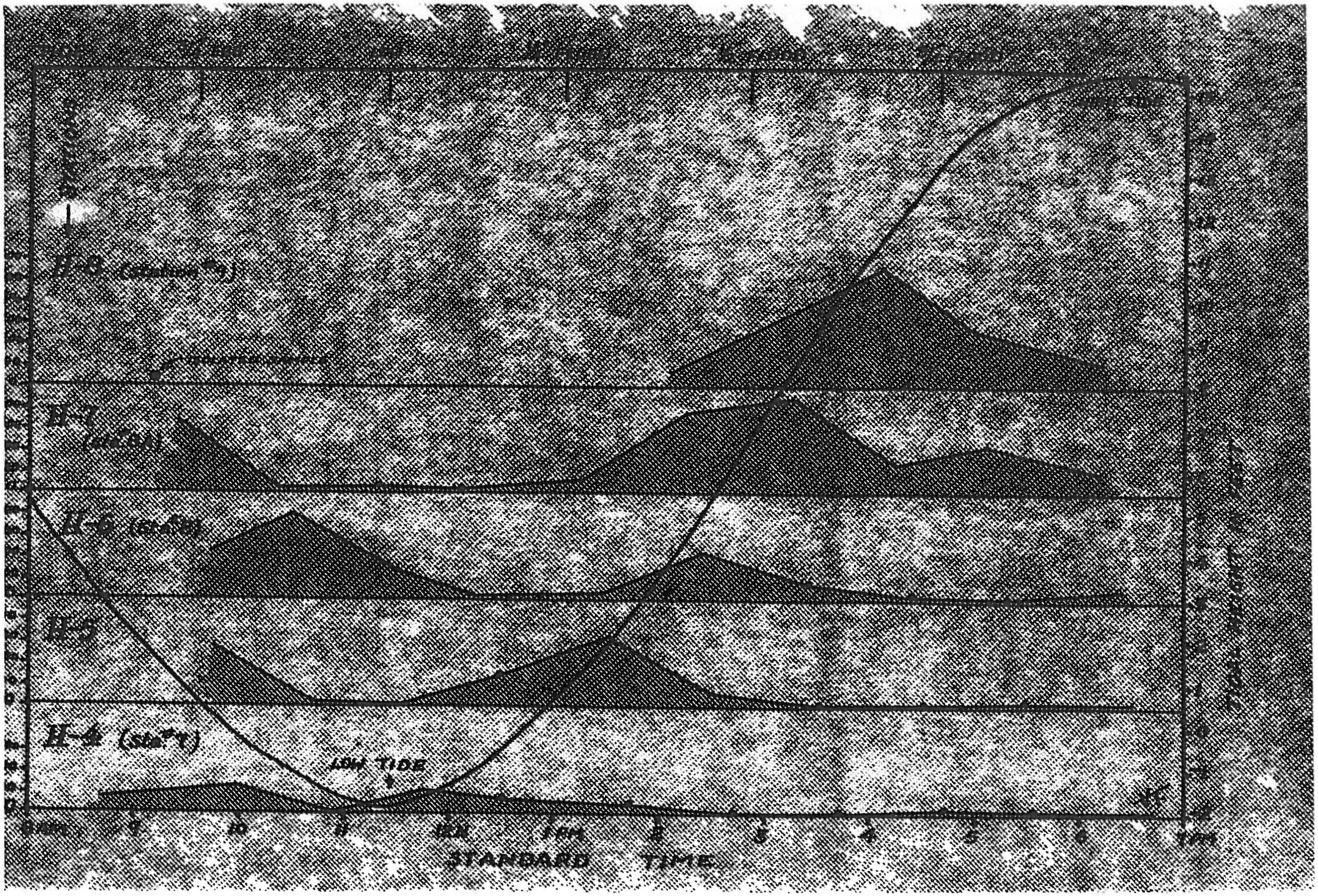
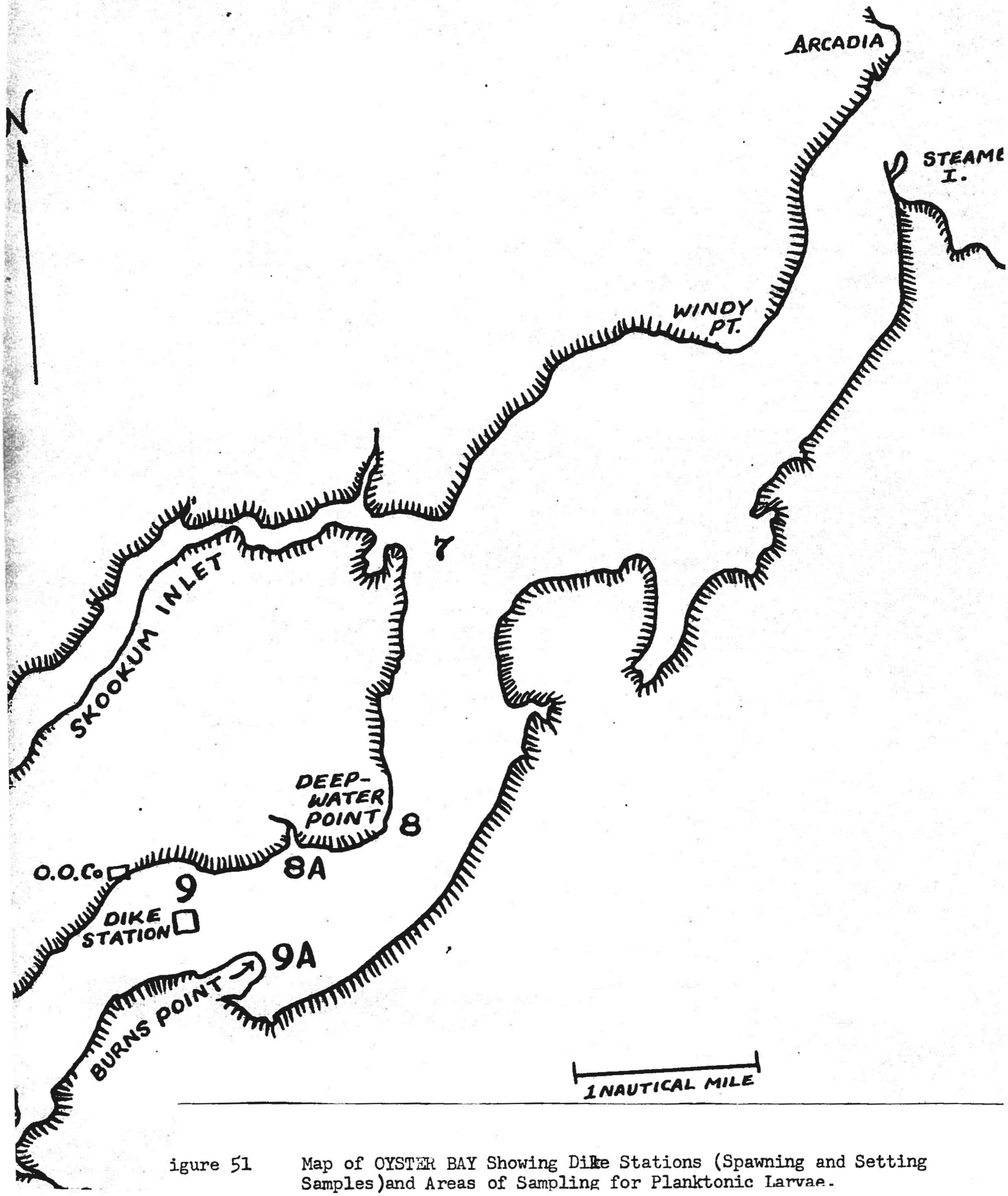


Figure 5? Tidal Plankton Cycle at Five Stations in Oyster Bay on August 23, 1945. (For location of Stations see



igure 51 Map of OYSTER BAY Showing Dike Stations (Spawning and Setting Samples) and Areas of Sampling for Planktonic Larvae.

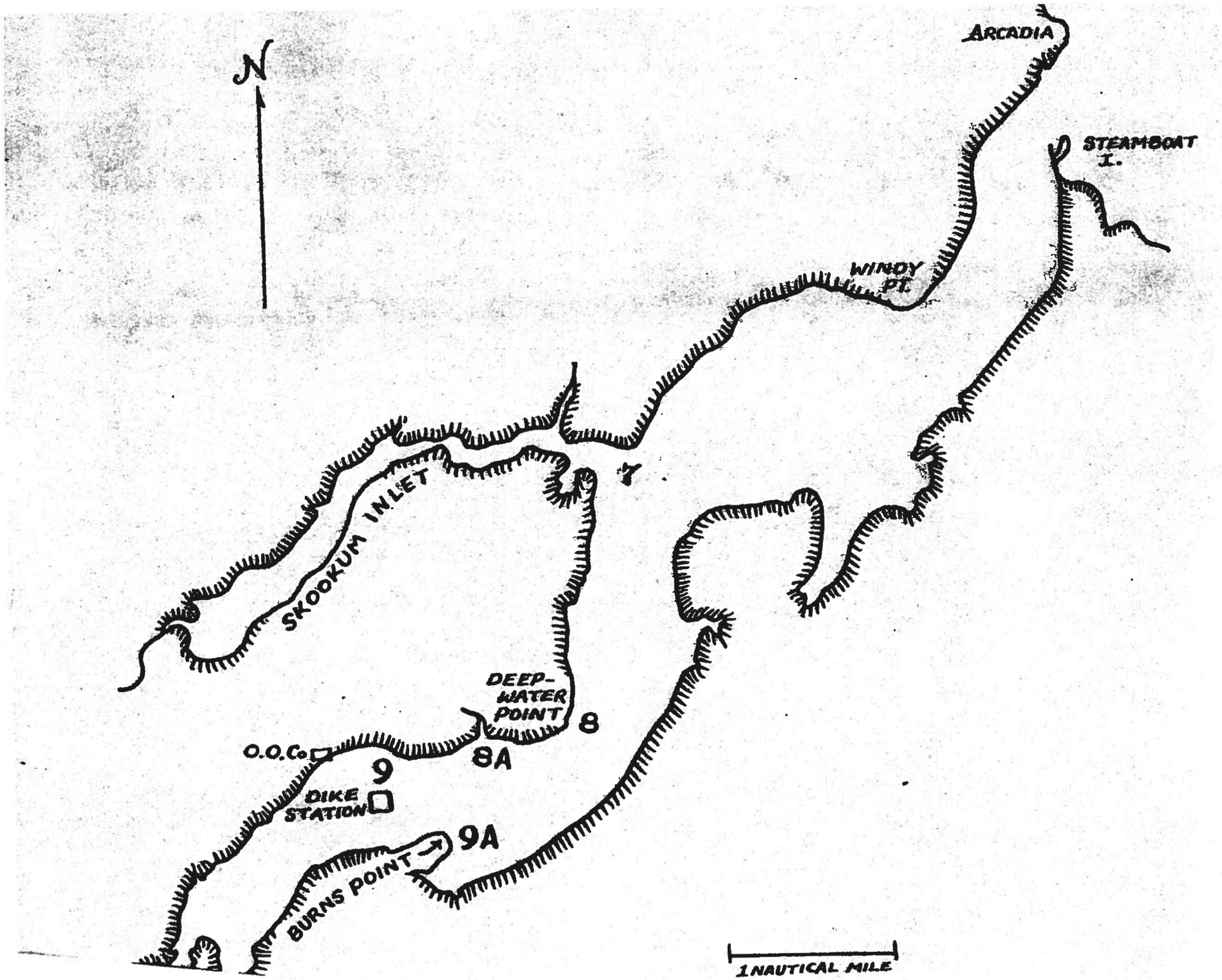
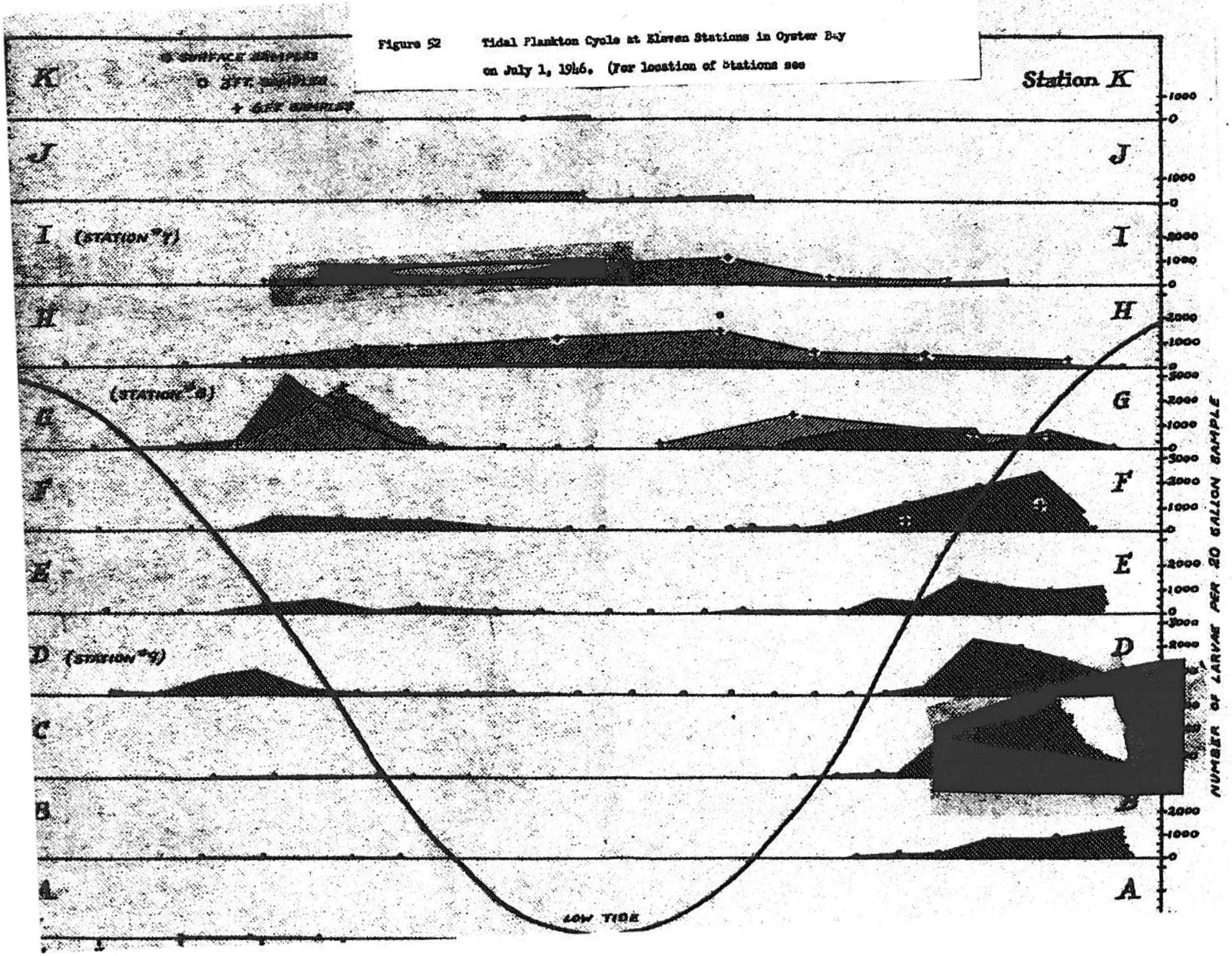


Figure 51 Map of OYSTER BAY Showing Dike Stations (Spawning and Setting Samples) and Areas of Sampling for Planktonic Larvae.

Figure 52 Tidal Plankton Cycle at Eleven Stations in Oyster Bay on July 1, 1946. (For location of stations see



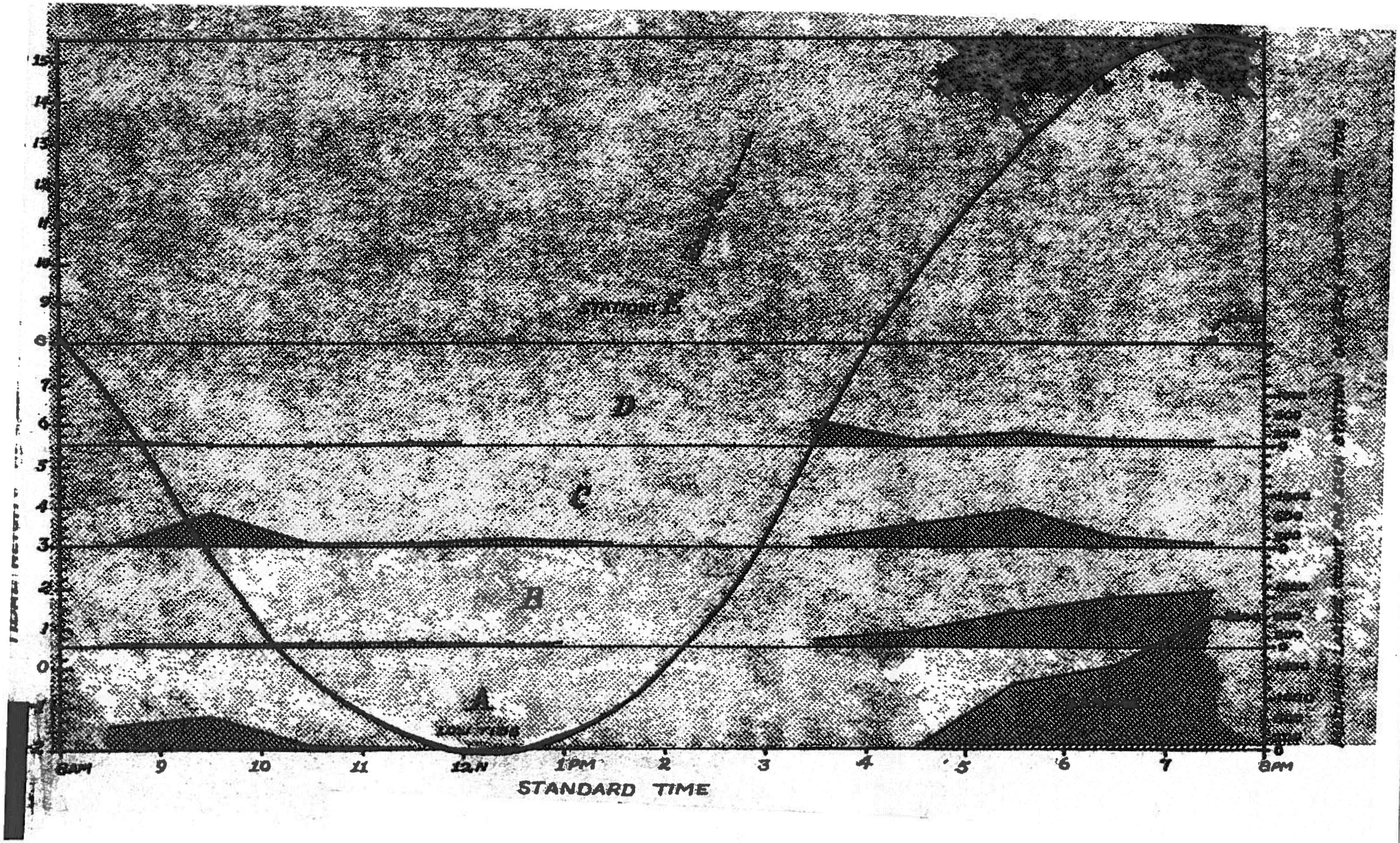


Figure 53 Tidal Plankton Cycle at five Areas in Mud Bay on July 30, 1950

(For location of Stations see Figure 54.)

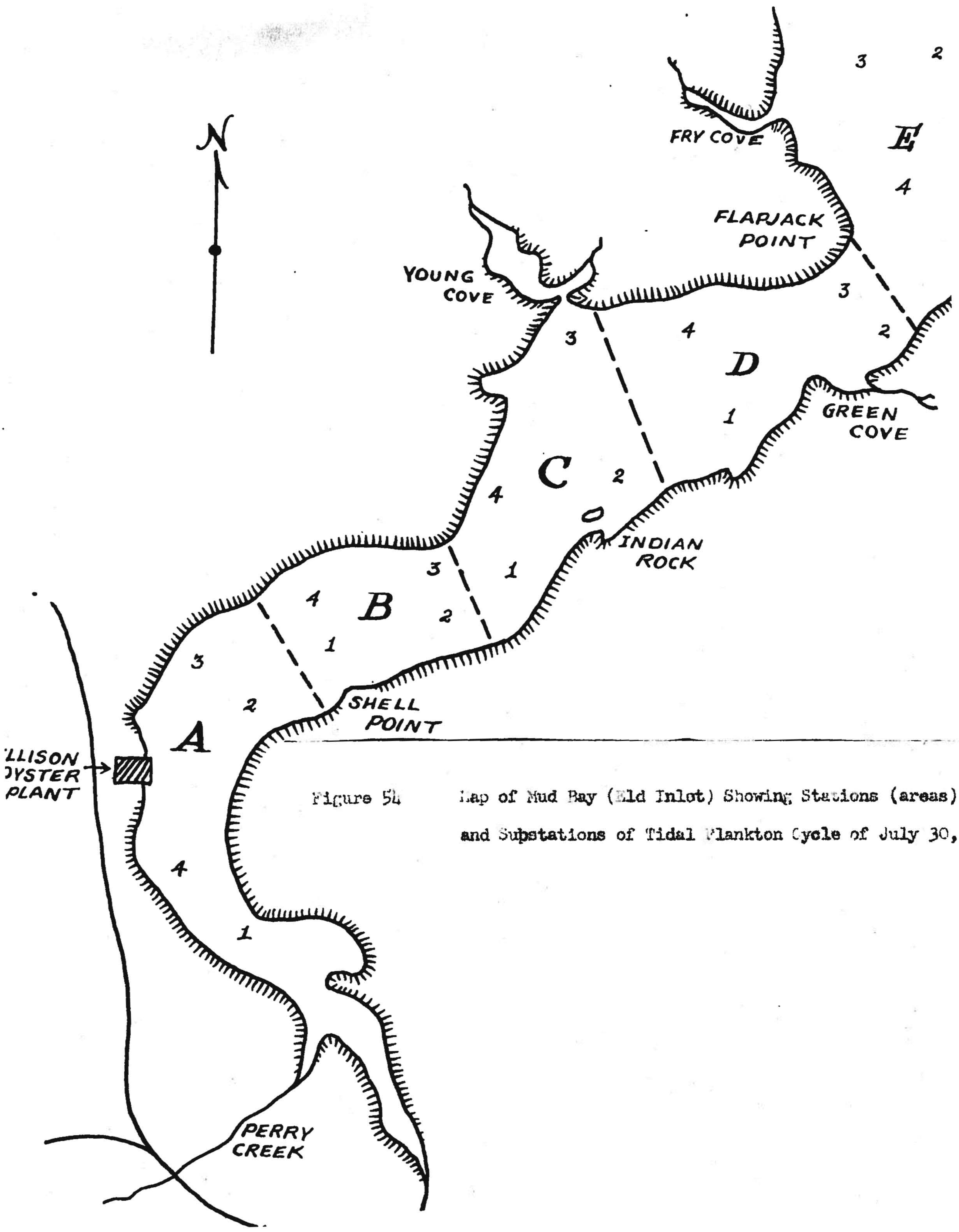
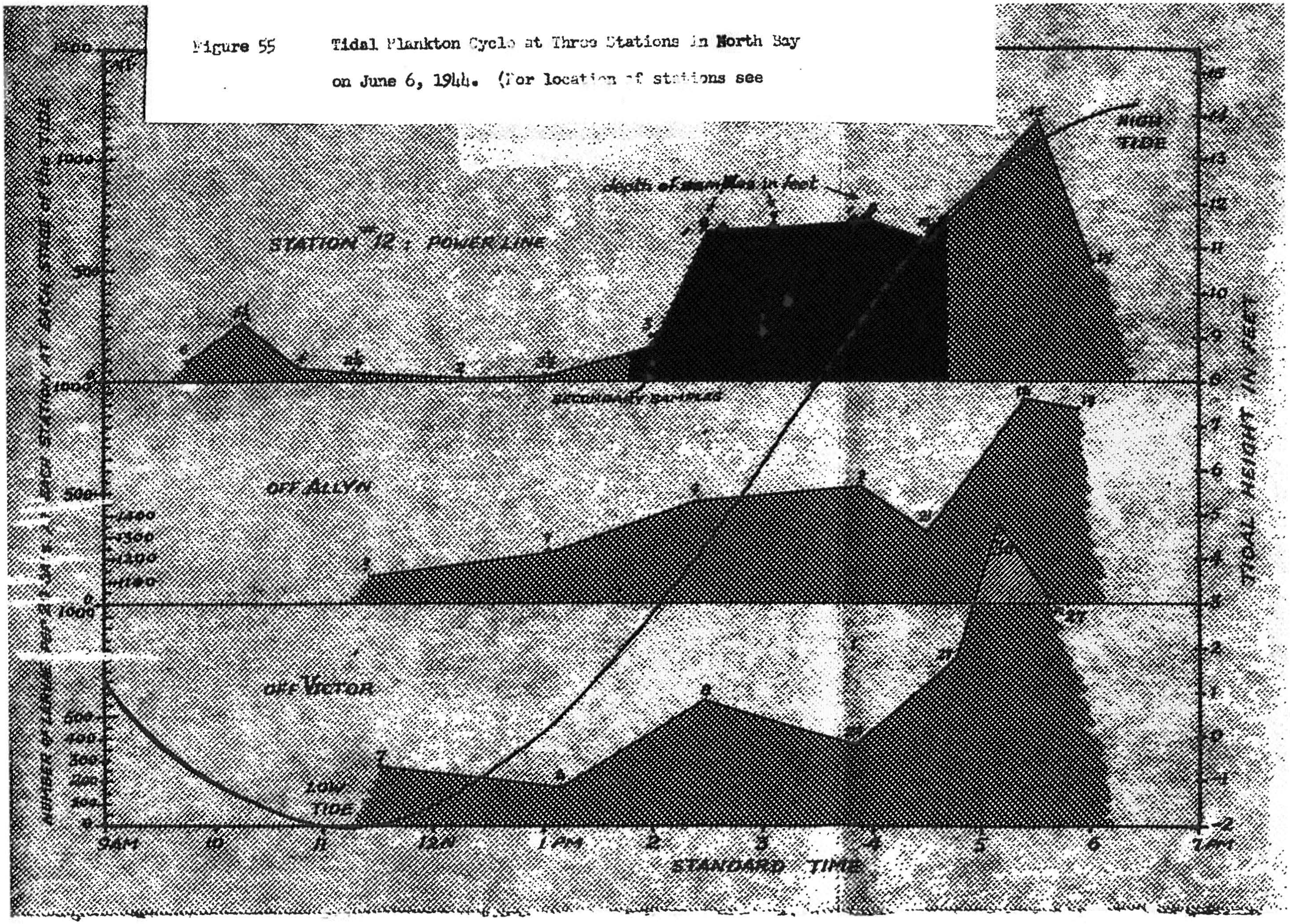


Figure 54 Map of Mud Bay (Eld Inlet) Showing Stations (areas) and Substations of Tidal Plankton Cycle of July 30,

Figure 55 Tidal Plankton Cycle at Three Stations in North Bay on June 6, 1944. (For location of stations see



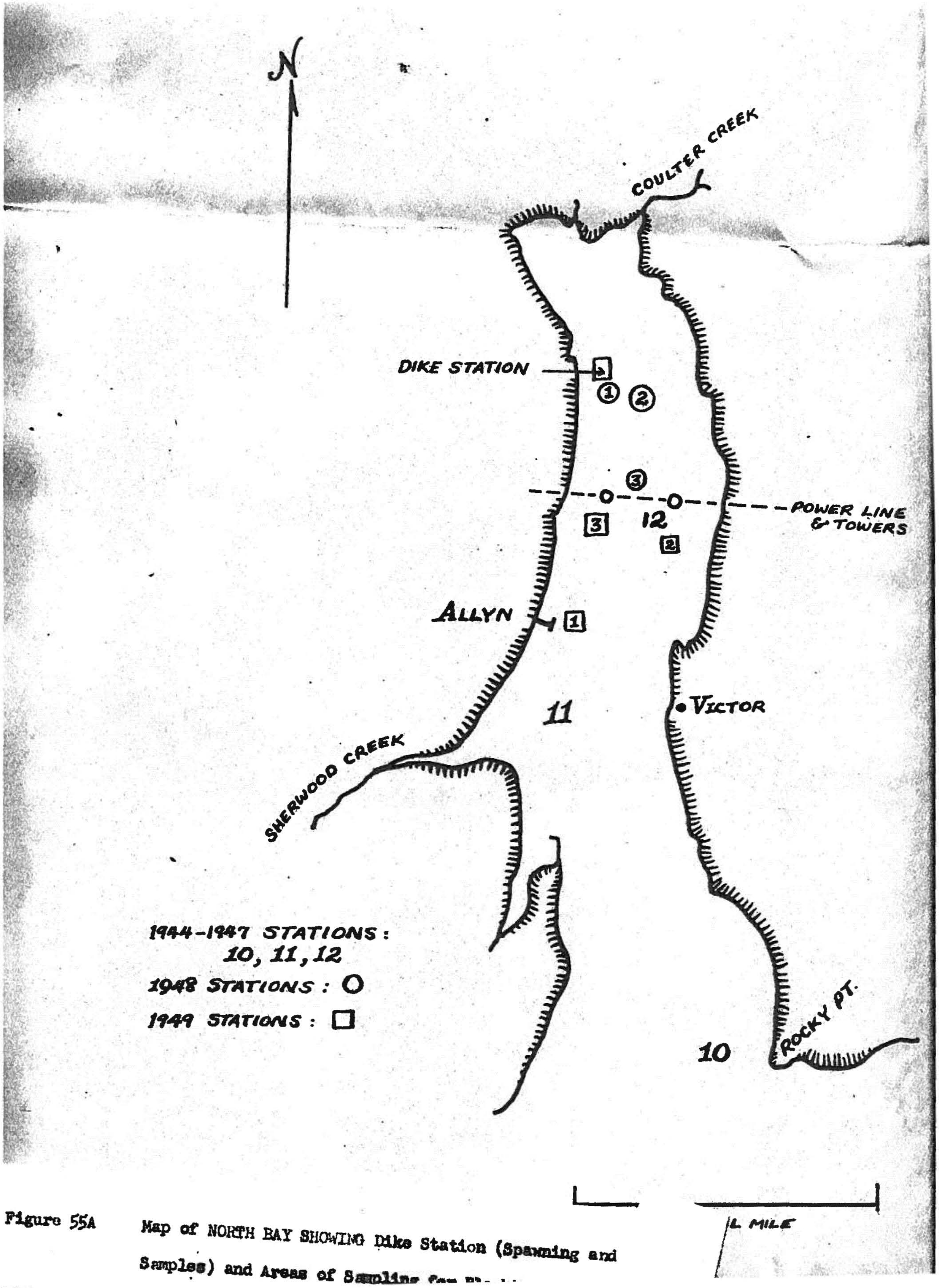
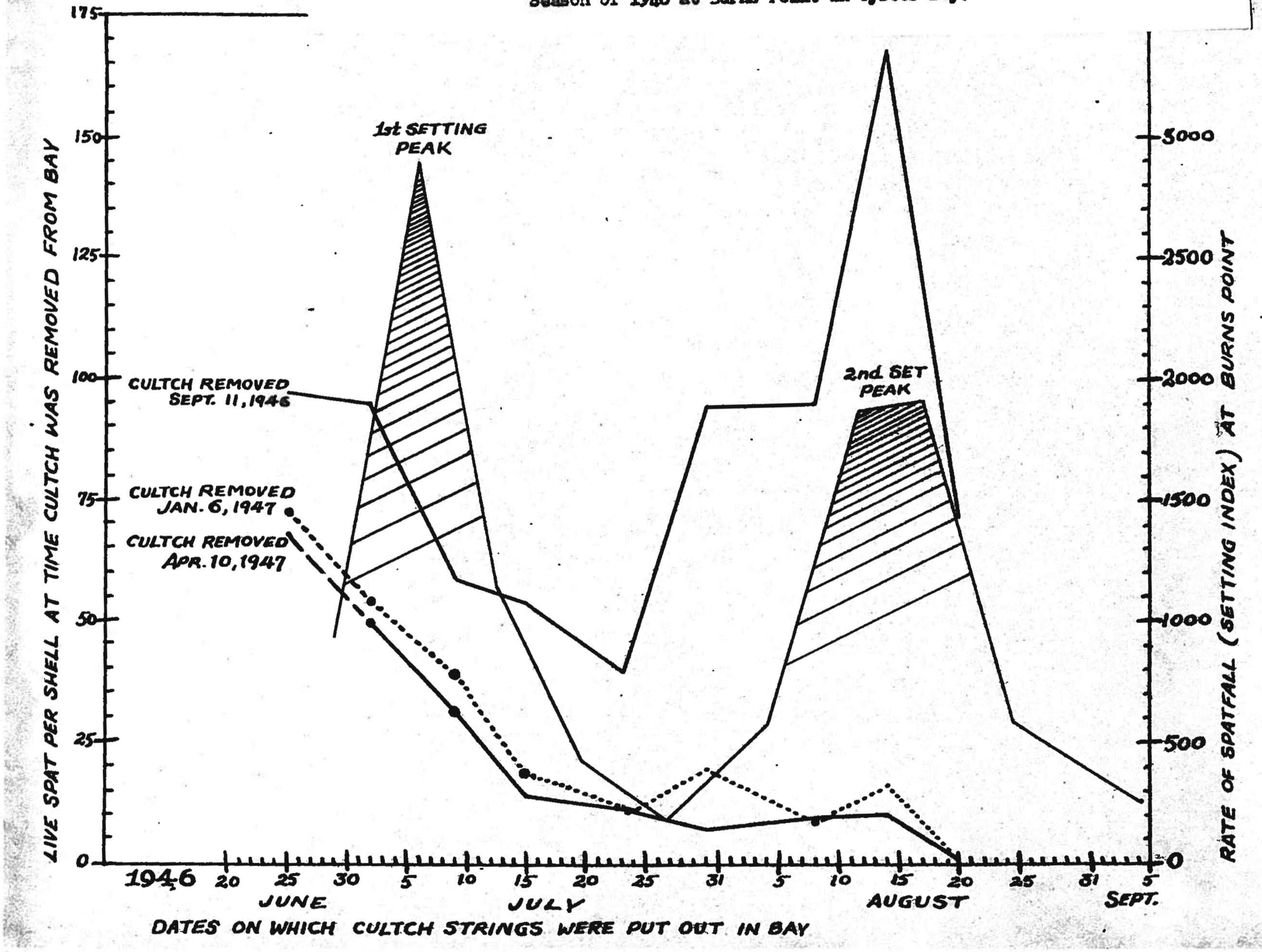


Figure 55A Map of NORTH BAY SHOWING Dike Station (Spawning and Samples) and Areas of Sampling ...

Figure 56 Survival of Spat in Relation to Time of Setting during the Season of 1946 at Burns Point in Oyster Bay.



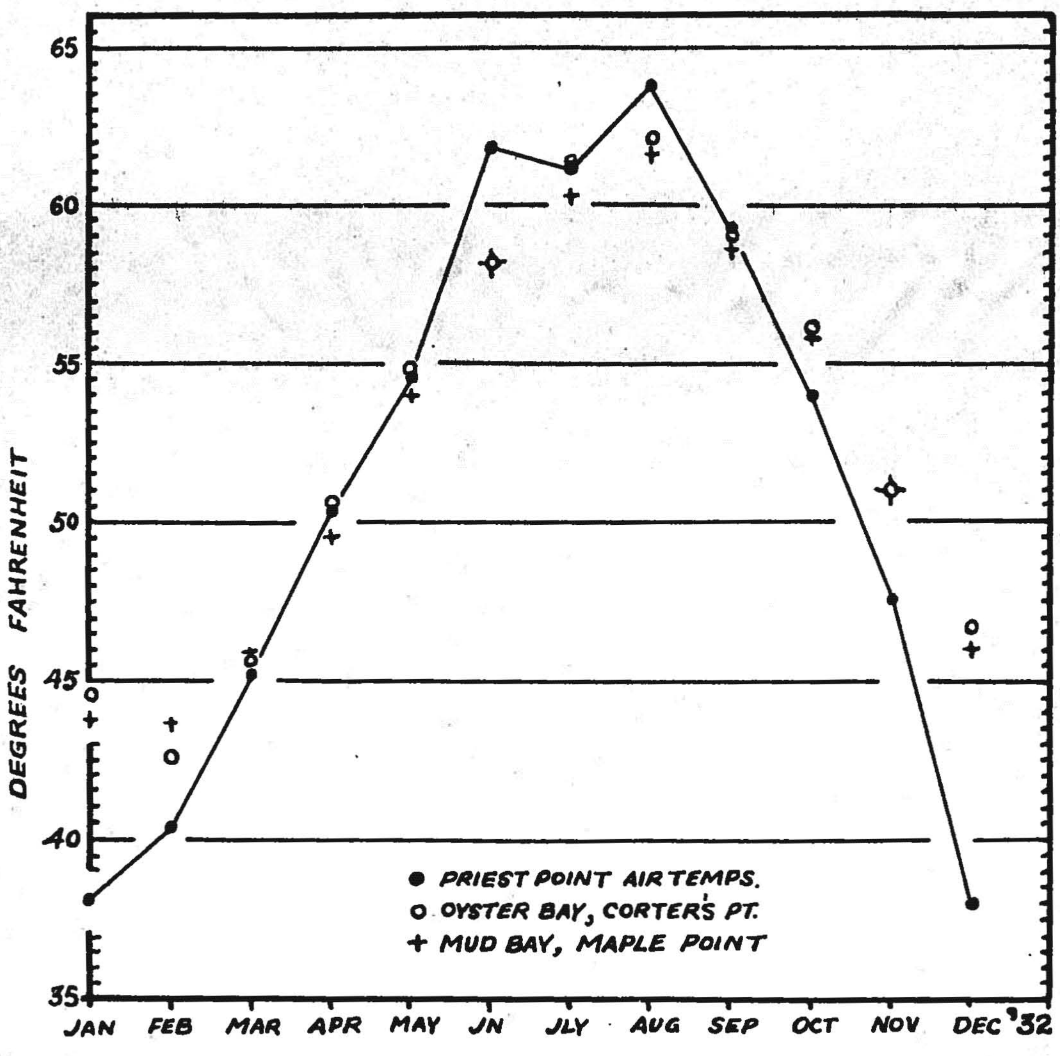


Figure 57 Correlation between Average Monthly Air and Water Temperatures, Olympia and Two Bays (data of Hopkins, 1937).

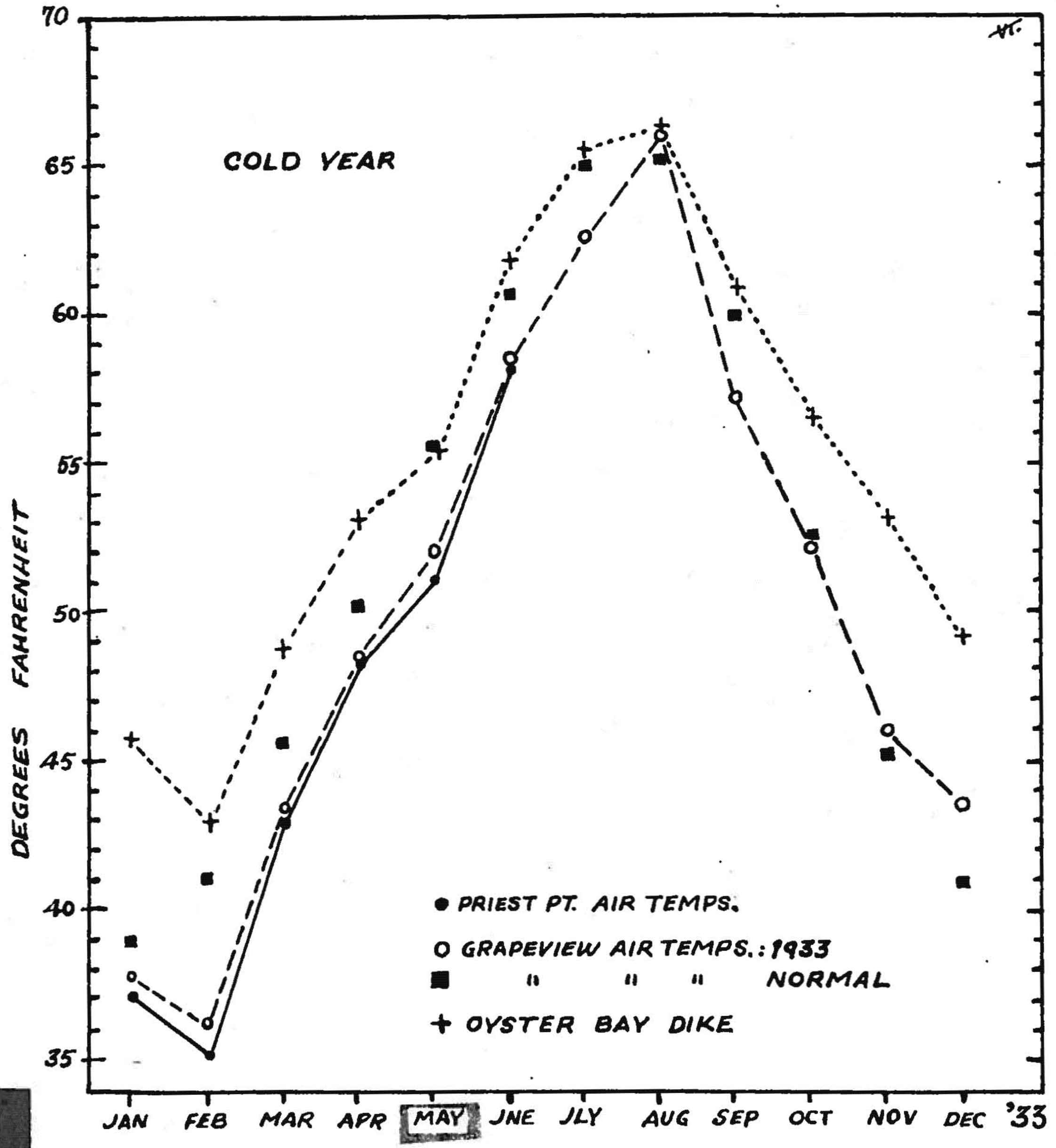


Figure 58 Average Monthly Temperatures during the Cold Year of 1933.
Water at an Oyster Bay Dike (data of Hopkins, 1937)

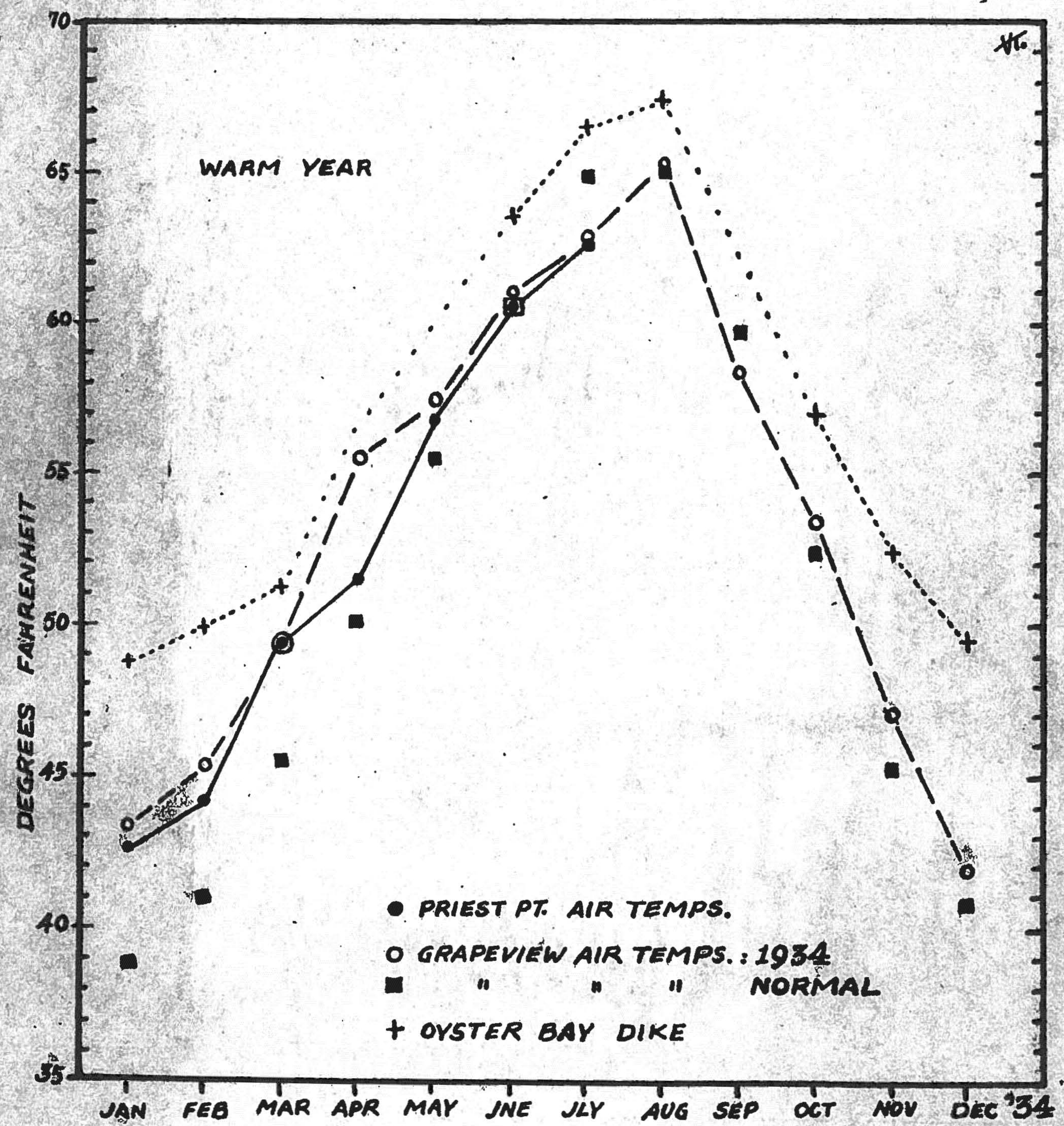


Figure 59 Average Monthly Temperatures during the Warm Year of 1934

Water at an Oyster Bay Dike (data of Hopkins, 1937)

Compared with Air Temperatures at Two Weather Bureau Stations.

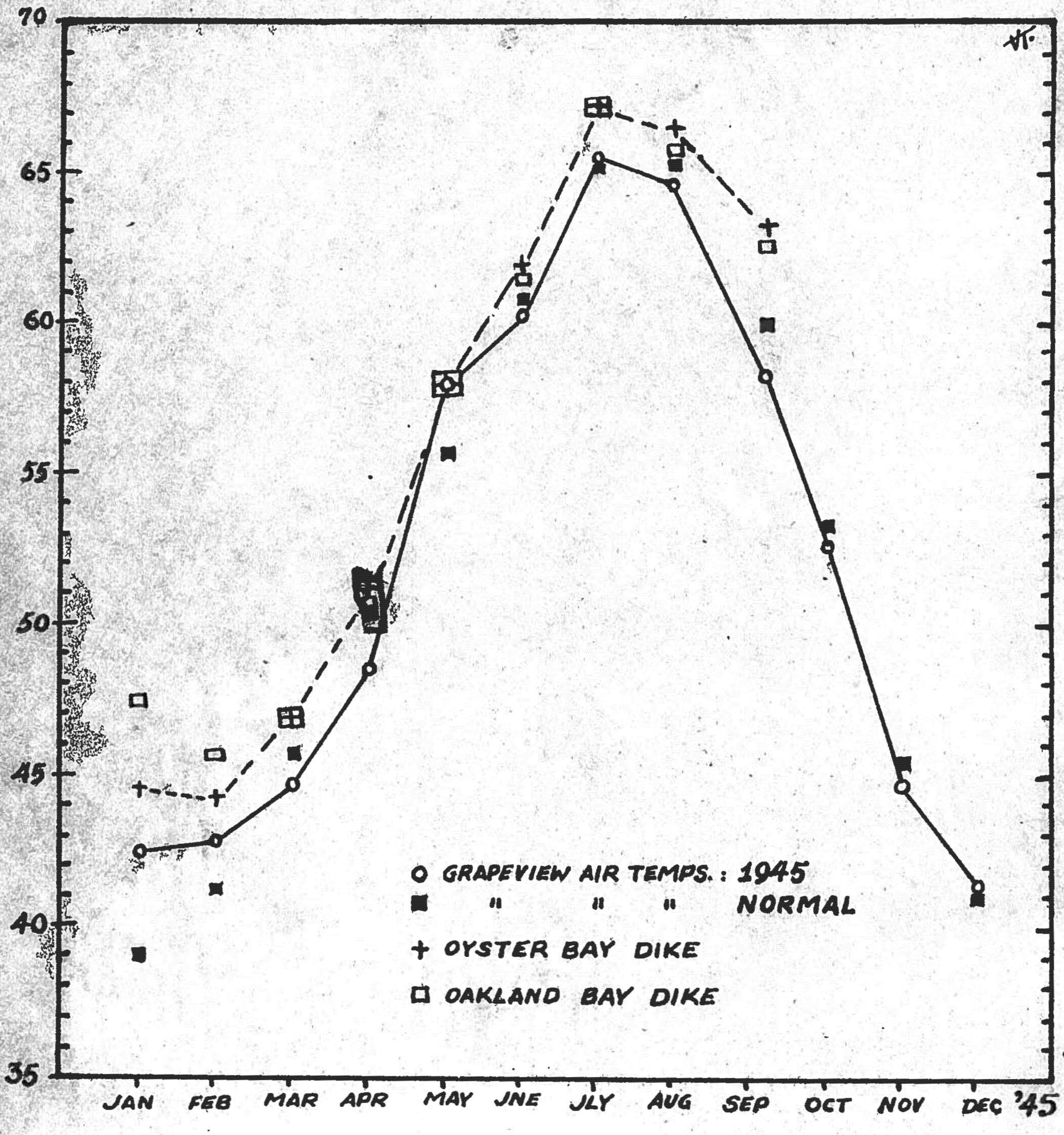
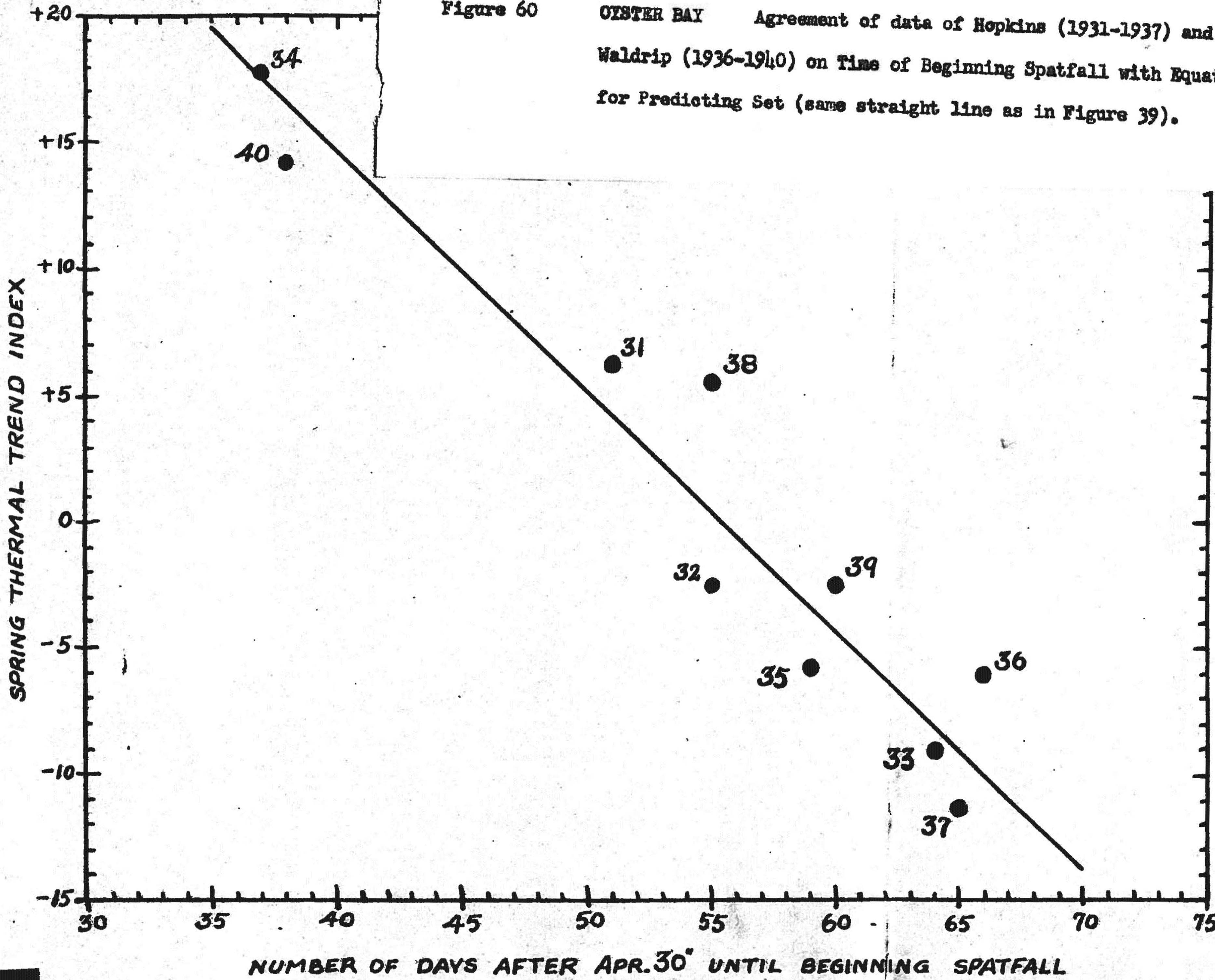


Figure 59A Average Monthly Temperatures During 1945. Waters at Dikes in Oyster Bay and Oakland Bay Compared with Grapeview Air Temperatures.

Figure 60 OYSTER BAY Agreement of data of Hopkins (1931-1937) and of Waldrip (1936-1940) on Time of Beginning Spatfall with Equation for Predicting Set (same straight line as in Figure 39).



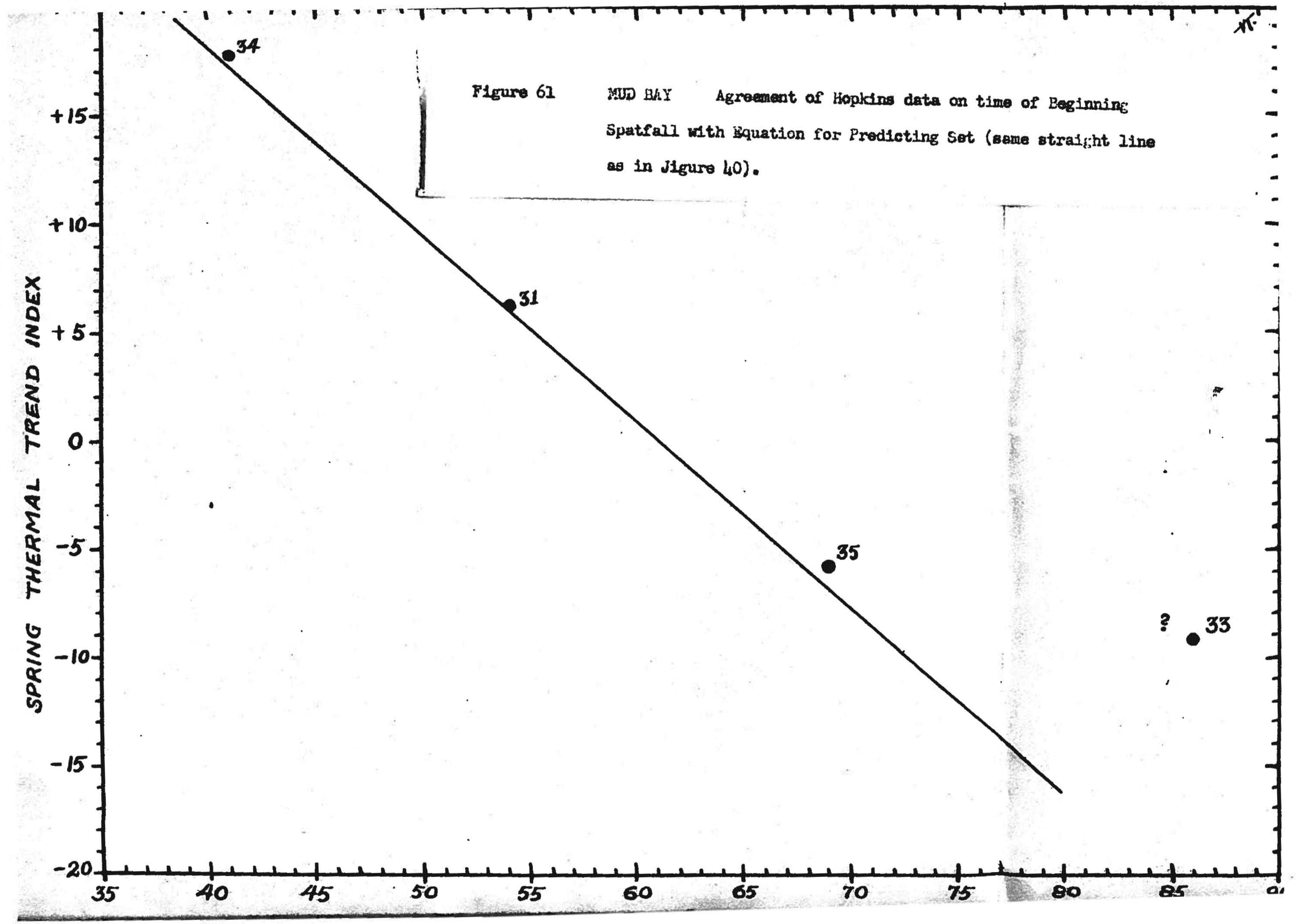


Figure 61 MUD BAY Agreement of Hopkins data on time of Beginning Spatfall with Equation for Predicting Set (same straight line as in Jigure 40).
SPRING THERMAL TREND INDEX
+15
+10
+5
0
-5
-10
-15
-20
35
40
45
50
55
60
65
70
75
80
85
34
31
35
33
?

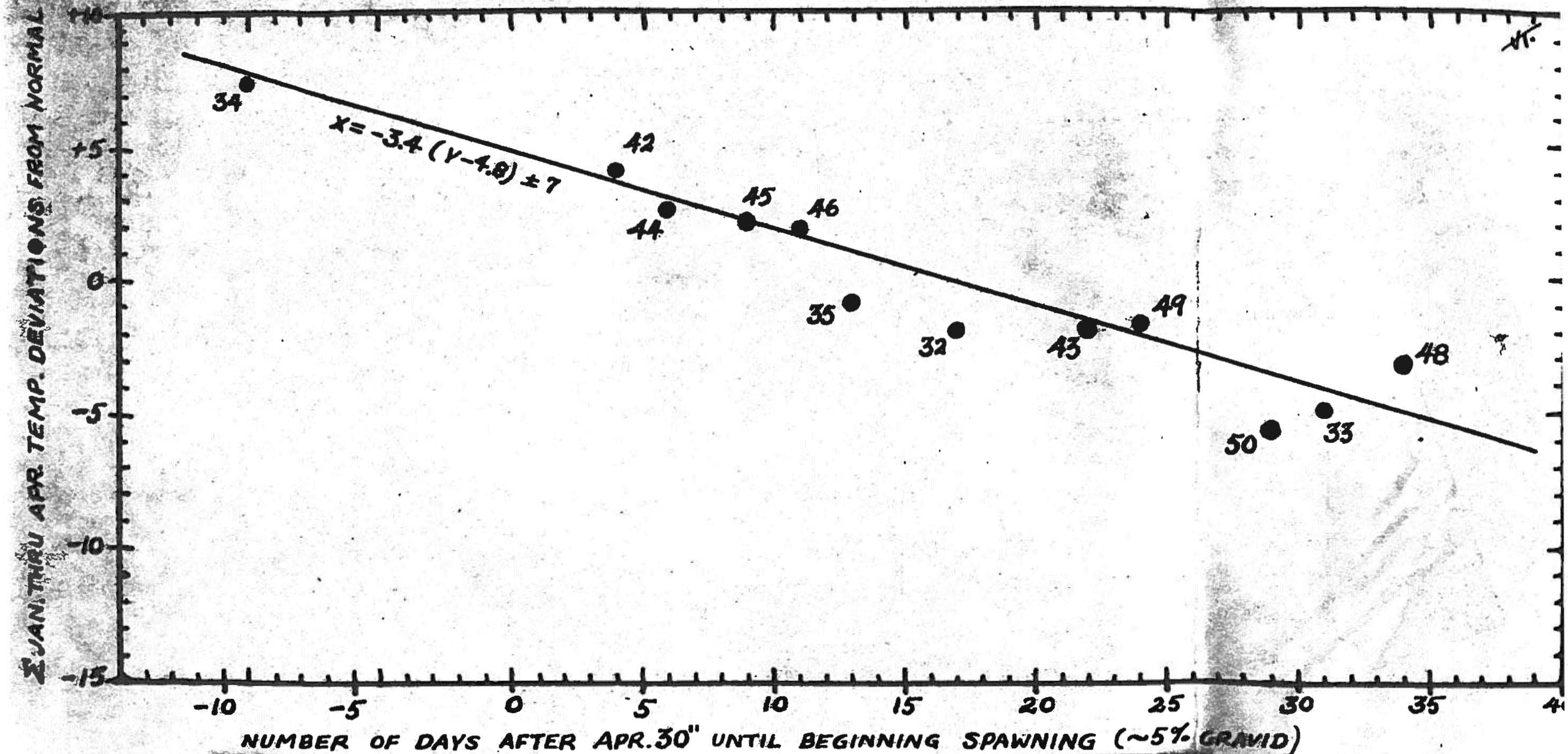
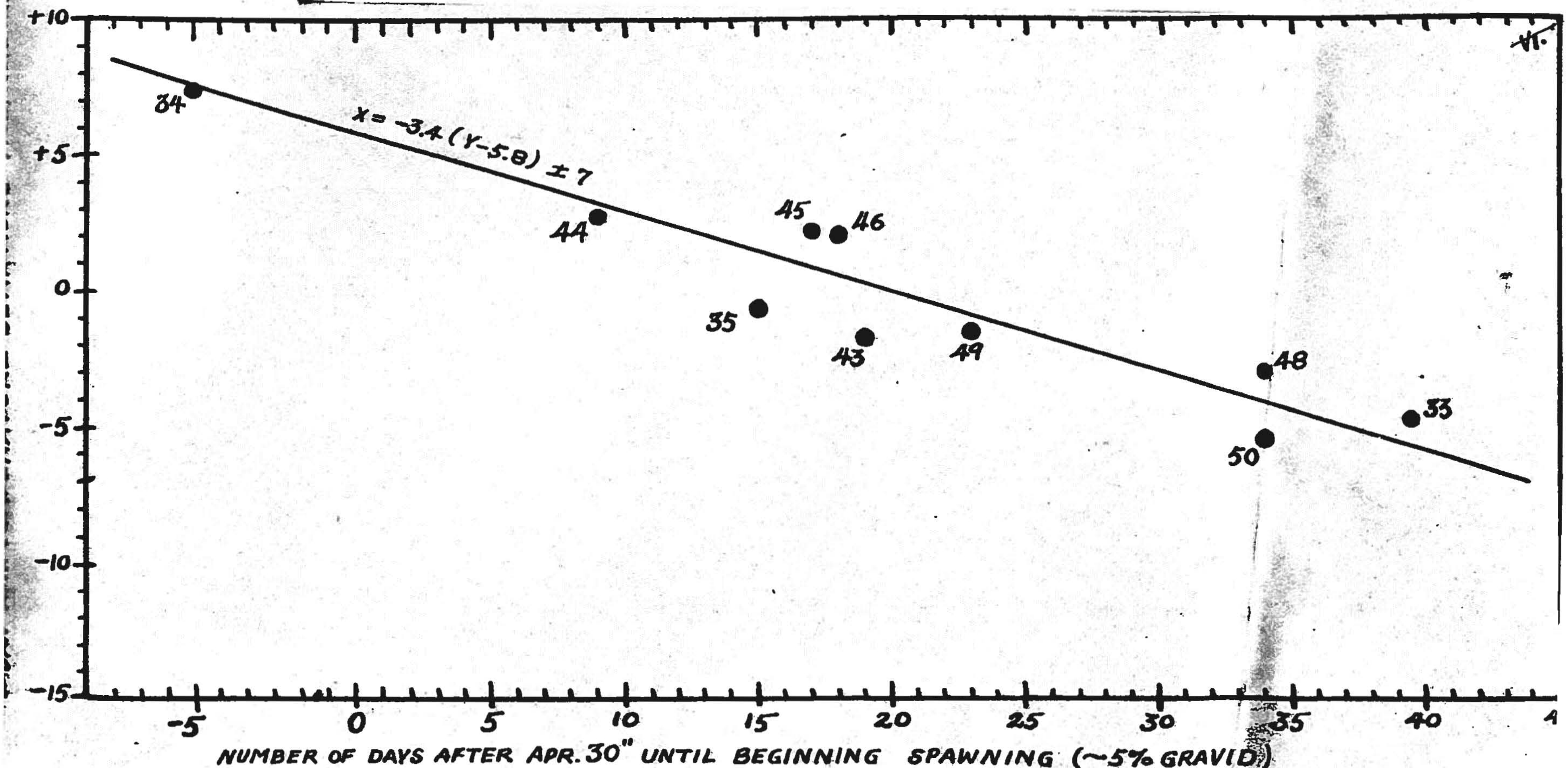


Figure 62 OYSTER BAY Correlation between Time of Beginning Spawning and Algebraic Sum of Deviations from Normal of Air Temperatures at Grapeview, January through April (omitting lowest January Deviations, see text).

Figure 63 MUD BAY Correlation between Time of Beginning Spawning and Algebraic Sum of Deviations from Normal of Air Temperatures at Grapeview, January through April (omitting lowest January Deviations, see text).



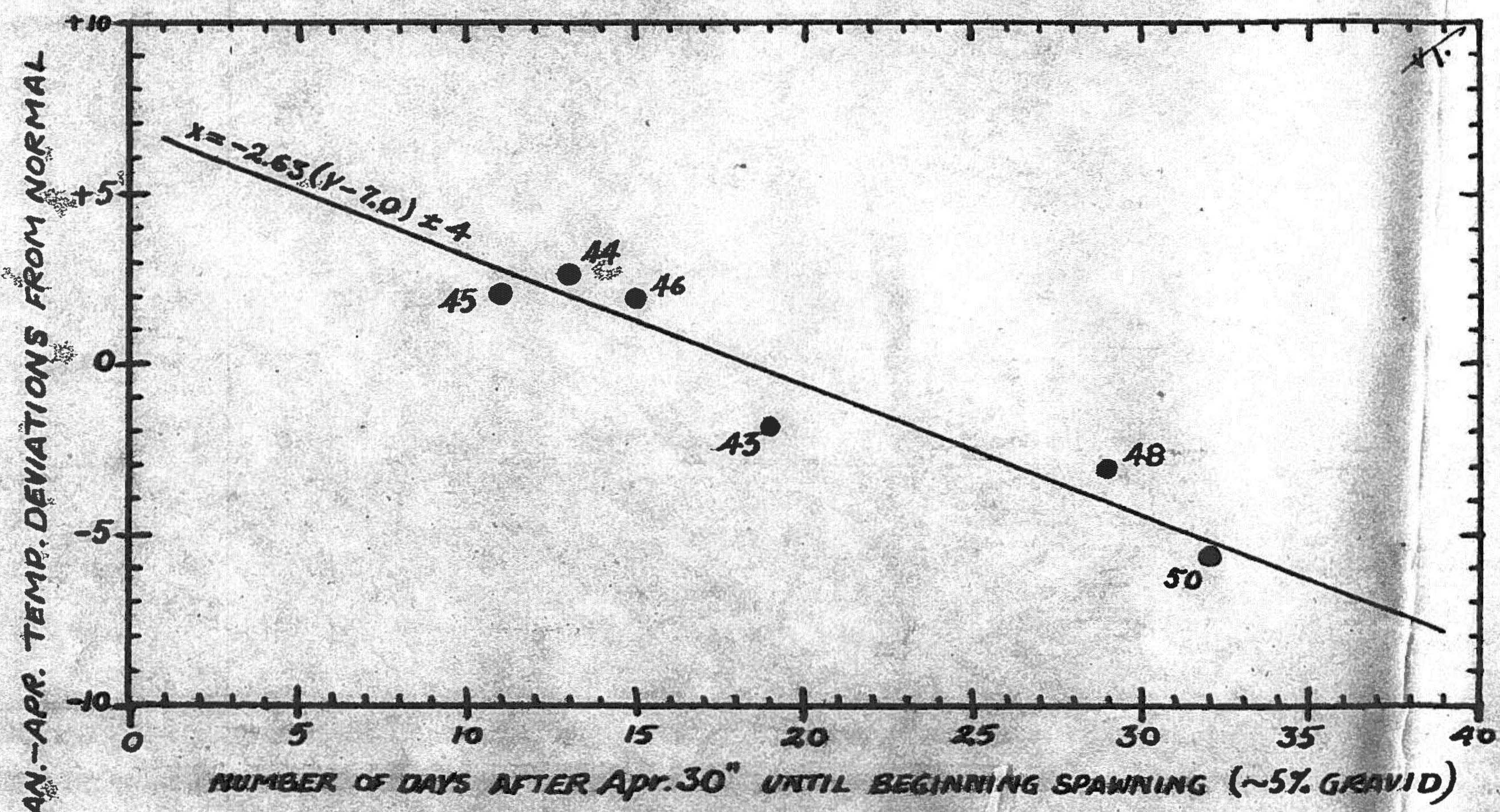


Figure 64 NORTH BAY Correlation between Time of Beginning Spawning and Algebraic Sum of Deviations from Normal of Air Temperatures at Grapeview, January through April (omitting lowest January Deviations, see text).

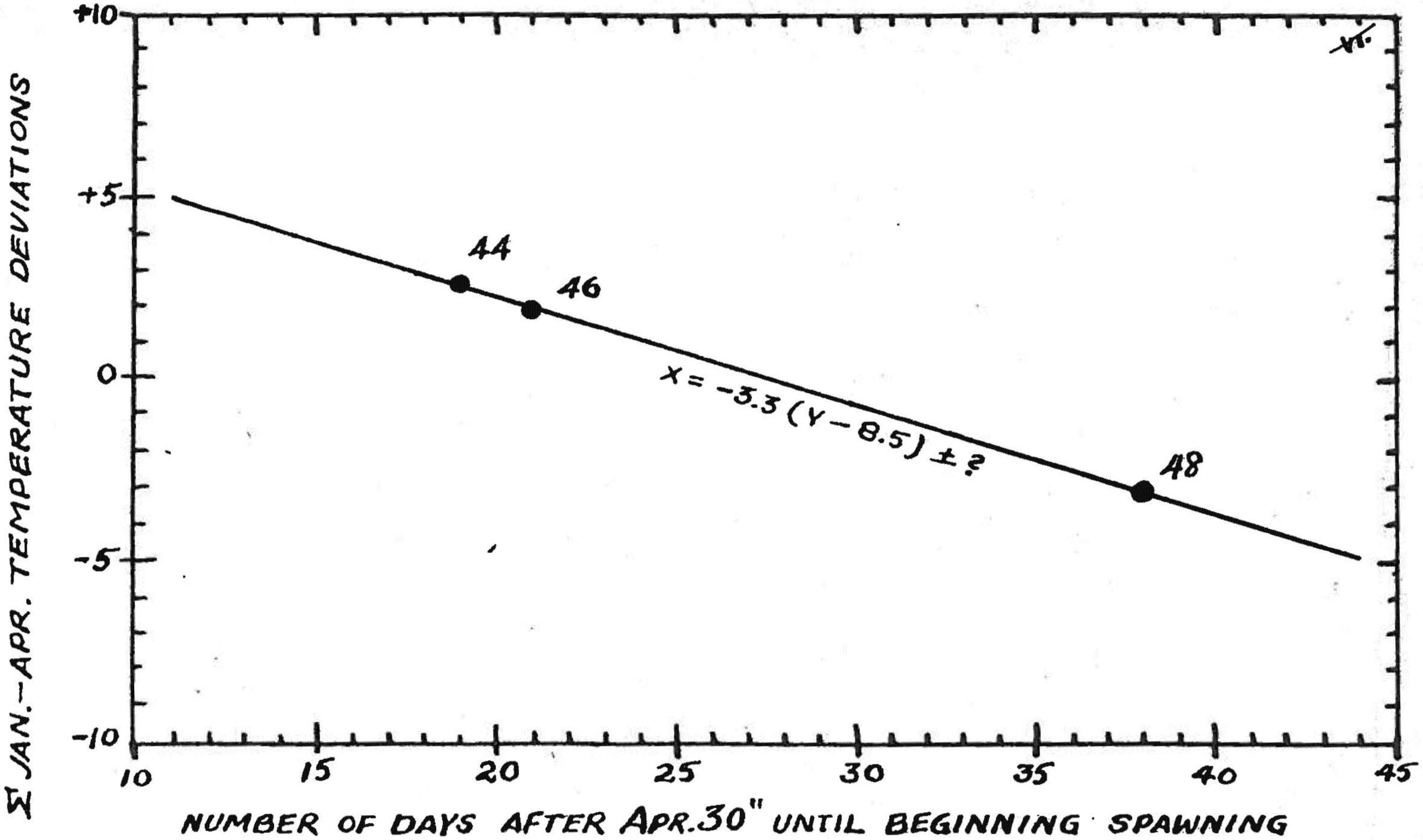


Figure 65 **SOUTH BAY** **Correlation between Time of Beginning Spawning and Algebraic Sum of Deviations from Normal of Air Temperatures** at Grapeview, January through April (omitting lowest Jan. Dev. see text)

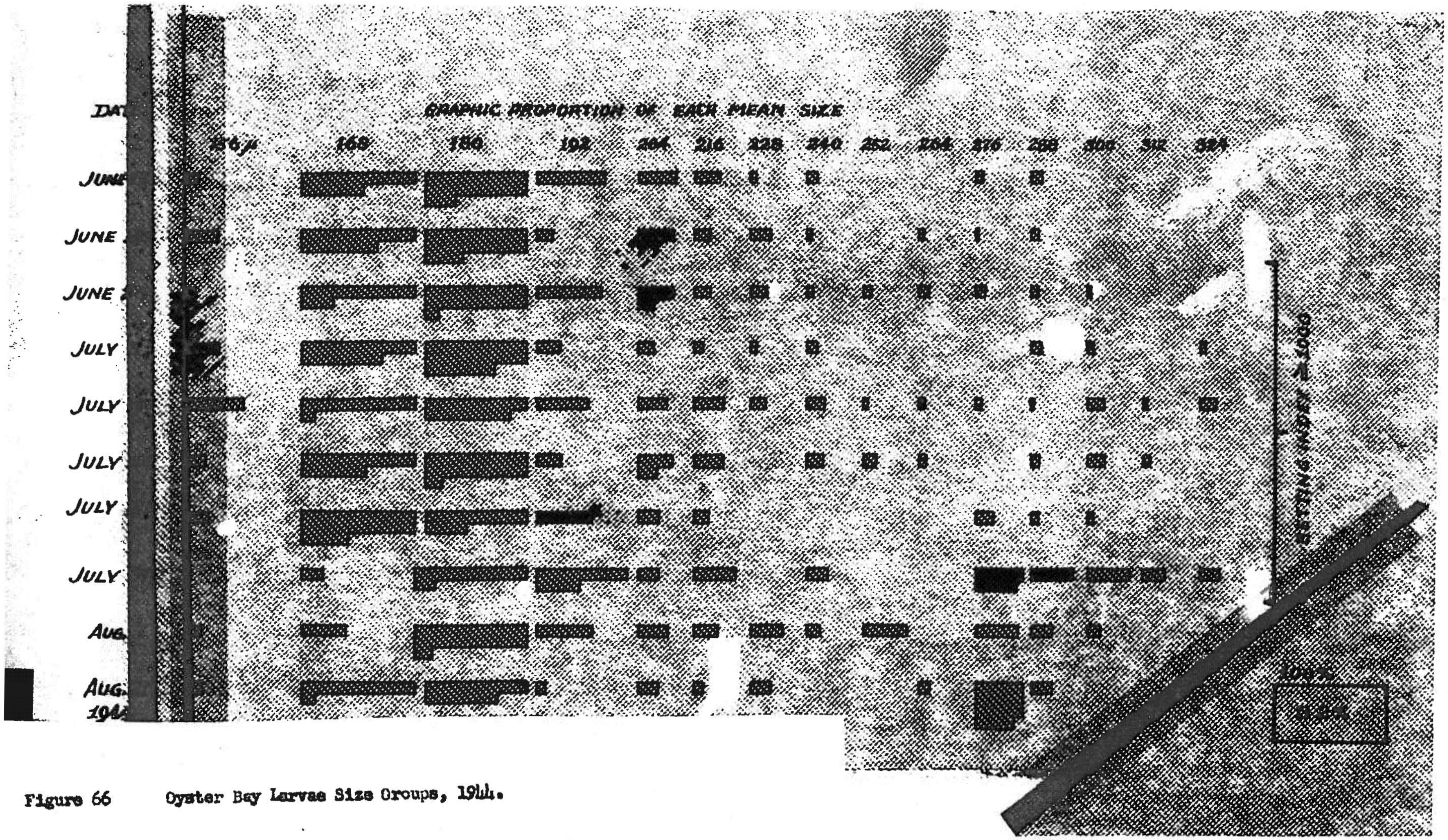


Figure 66 Oyster Bay Larvae Size Groups, 1944.

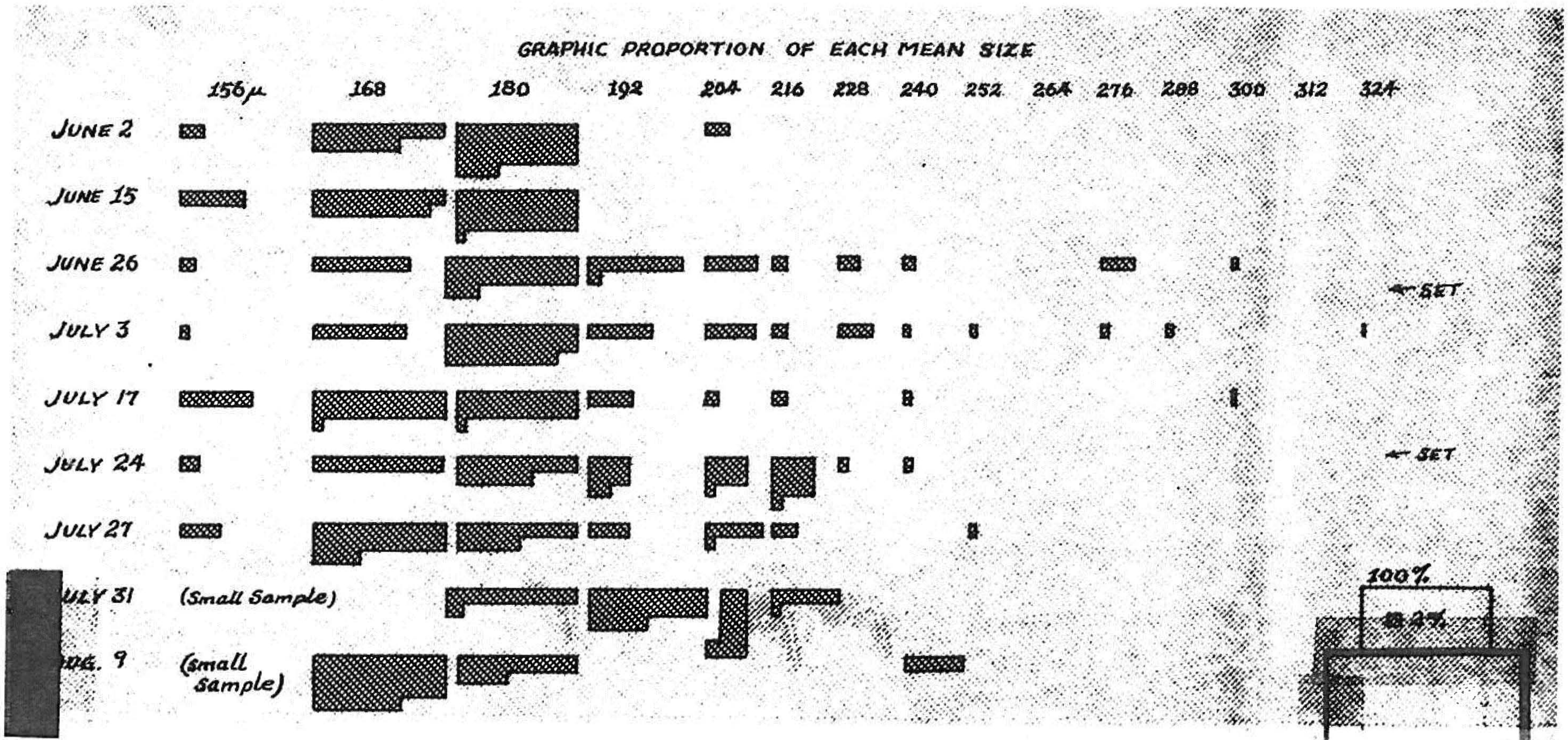


Figure 67 Mud Bay Larvae Size Groups, 1944.

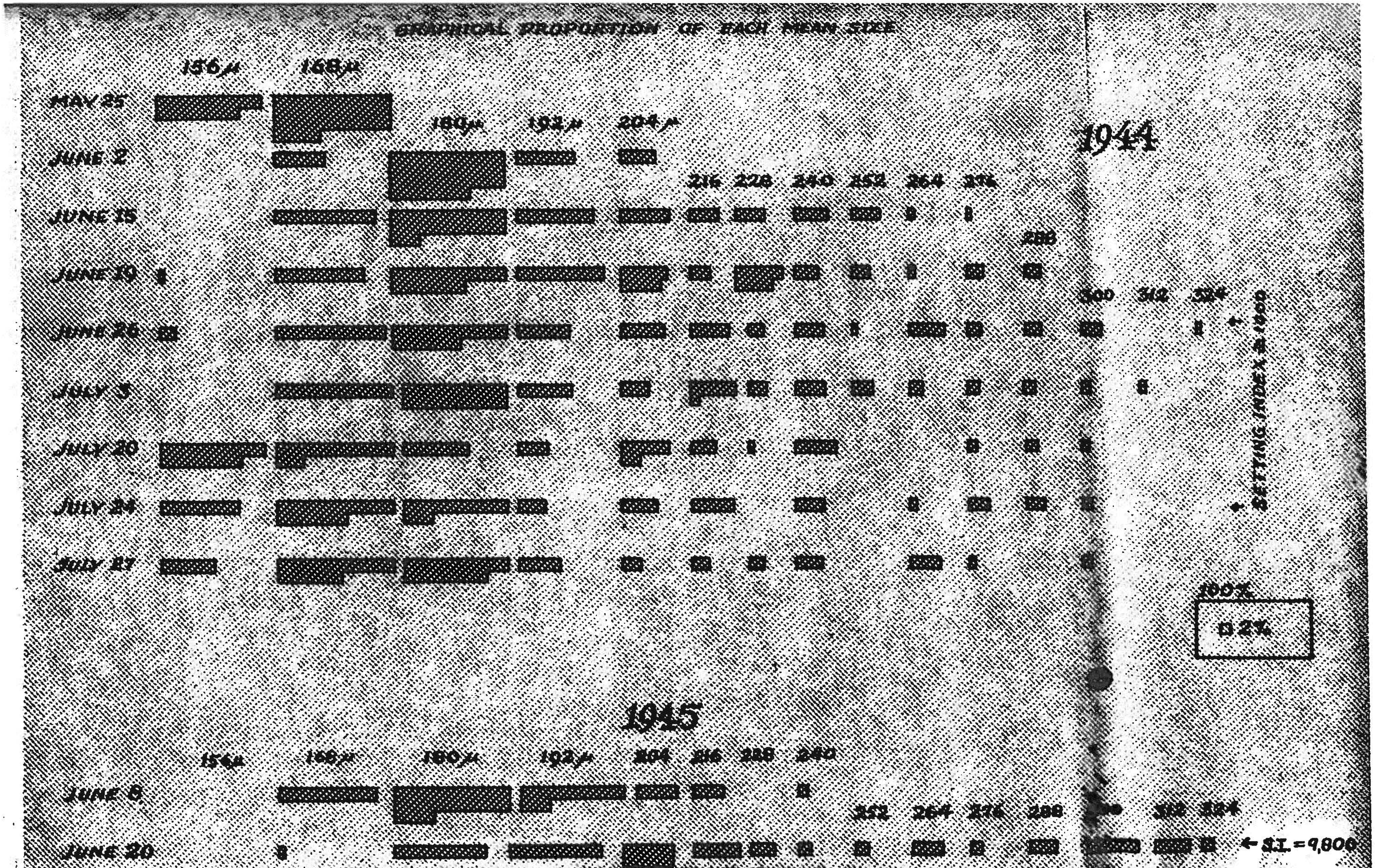


Figure 68 NORTH BAY Distribution of Larvae Size in Dated Plankton Samples during Two Years.

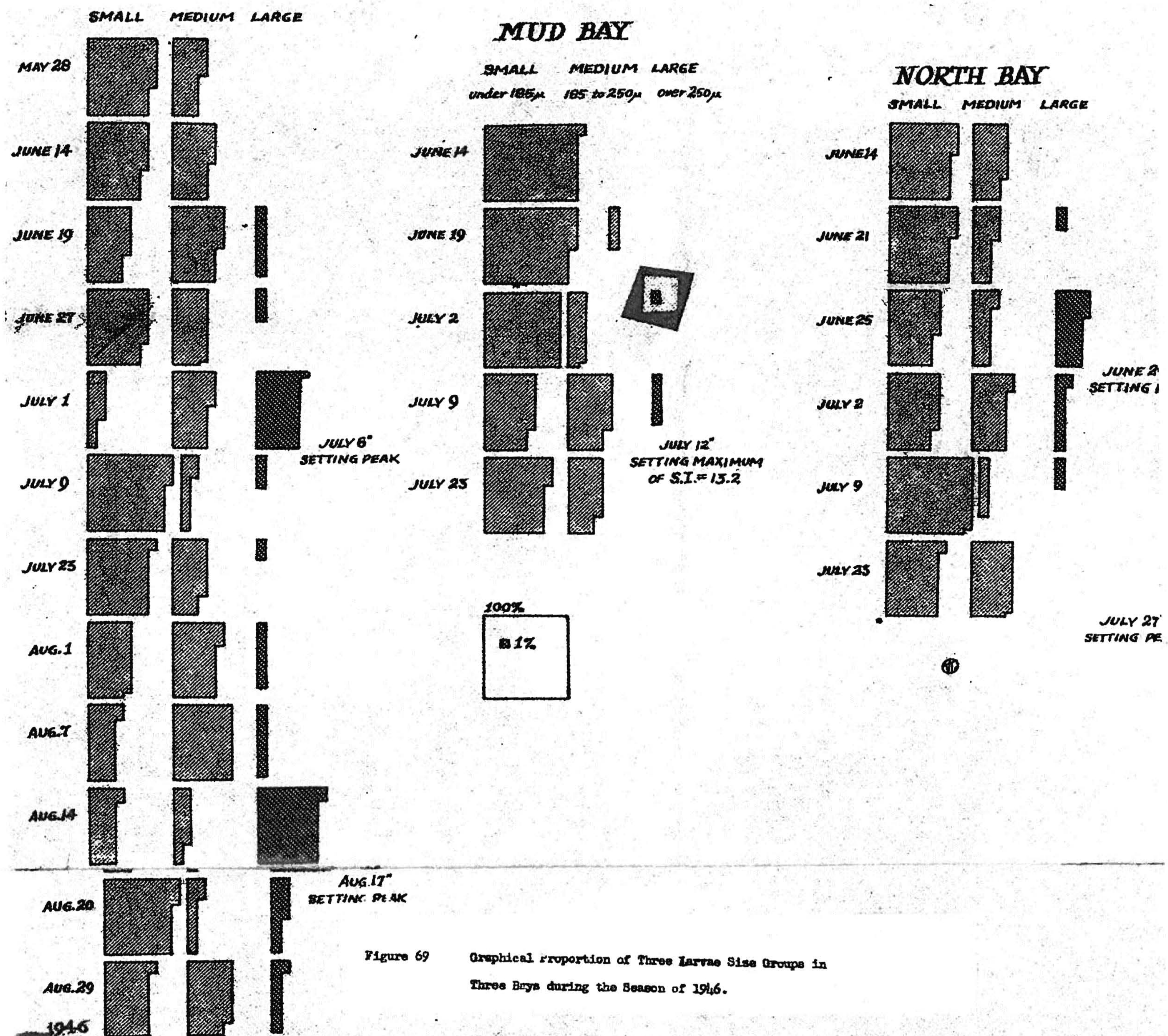


Figure 69 Graphical Proportion of Three Larvae Size Groups in Three Bays during the Season of 1946.

1st sec. Cut down acknowledgements. (Suggest back of paper anyway)

Consider dividing paper into pieces.

Hopkins sec in acknowledgments. rather than separate.

Consider "piling" graphs

check inconsistencies in graphs.

P. 14 — put out at or before the initial spotfall —

Olympia Oyster Publications (from "Practical Biol. of Olympia Oyster in Puget Sound")

p. 29 p. 73--- Distribution of pelagic Olympia oyster Larvae in Puget Sound

1) What we know concerning vertical distr'n of larvae.
- including size distribution,
2) Spatting in relation to depth on floating cultch strings
We do not agree with Hopkins in the matter,
3) Tidal Cycles in Oyster B, Mud B, & North Bay.

4) Concept of the Larvae Mass.

5) Implications:

a) Regarding design of floating catch racks.
How deep?
Main point is that Rig should allow circulation of larvae-bearing water.

b) Each bay is a separate, geographically isolated breeding population because the long inlets retain the spawn.
Openers can identify them races as to bay of origin

c) Best cultching ground is under mid-point of oscillation of the Larvae Mass. (Cf. Hopkins' poor up-bay & down-bay catches

d). Knowledge of the distribution & movement of the larvae is essential to adequate larvae Sampling for (1) prediction of intensity of spatting & (2) understanding an important aspect of the reproductive season.

6) Compare these findings w Korringa in the Oosterschelde, etc.

7) Importance of transport of larvae to the cultch.
Tests on egg-case fillers laid flat, stringled, & stood upright (p. 78)
Refer also to Hopkins' work on angle of cultch & effectiveness of catch.

p. 41..
p. 57.. Effective seasonal catch of Olympia oysters in Puget Sound

1) The question of saturation of cultch. (p. 41)

2) Difference in survival in different years in relation to Setting Index: eg. good survival w low S.I. during 1953

3) Mortality of late-caught spat

a) As shown by regular seasonal strings.

b) As shown by Tollefson's tests.

c) Subsequent tests

d) Description of condition of seasonal shells: a few large, good spat plus multitudes of tiny dead spat.

e) Relative predation of drills on large & small spat.

4) Cf. Hopkins: discovered second wave of spatting & thought they could be catched w profit.

5) Implications:

Best cultching date is at initial spatfall of season.

6) Possible causes of lack of survival of late-caught spat:

a) They cannot survive low fall temperatures?

b) They are more susceptible to predation, smothering & silting?

) p.114 Spatting failures of Olympia oysters in a bay of southern Puget Sound (Mud Bay)

1) The record — an anomaly for the region.
2) Possible explanations:
   a) Abnormal salinity due to rainfall
   b) Tidal heights at time of spatting as affecting transport of larvae to the cultch.
3) Provisional rules for predicting years of spat failure.

) p.43 Pests of Olympia oysters in Puget Sound

1) Japanese oyster drill
2) Eastern oyster drill
3) "Keyhole"-producing worm
4) Black-clawed crabs
5) Crepidula
6) Moon snail & mud shrimps
7) Shell worm
8) Mytilicola
9) Bryozoa
10) Not the stone crabs.

Stages in the reproductive cycle of the Olympia oyster in relation to effective catch of seed oysters.

0) p.52... Methods by which quantitative data were obtained.

1) Records of female-spawning: in a season

a) Show that some oysters must spawn twice, once as males, again as females ___ as described by Coe for the "California oyster".

2) Proportion spawning bears no relation to effective amount of catch. (Cf. Korringa also, in Oosterschelde.) This is expected, since it is the number of larvae produced which counts.

3) Abundance of larvae & of large larvae in relation to height of Setting Index.

4) Rate of spatfall (S.I.) in relation to effective seasonal catch.

5) Reproductive performance of the bays during 10 yrs. is shown in quantitative terms: proportion spawning, larvae abundance from year to year, Setting Index, seasonal catch.

p.105... Empirical rules for predicting time of spawning of Olympia oysters in Puget Sound

2) Description of the formulae

1) Graphs date of beginning spawning in relation to early spring air temperatures.

3) Explain that the empiricism will be removed when, by laboratory experiments, the relation of gonadal ripening to water temperature is defined. The implications of the rules for the physiological response are noted, e.g. as long as water temps. is cold enough to inhibit ripening, any further drops in temperature does not completely "count".

Discuss Davis' studies on O. lurida