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 large 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 ~~withxxx~~ 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-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 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 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. ~~XXXXX XXX Oyster Bay and Mud Bay we have added the~~

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

For <u>South 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 ~~of the time~~ years 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 <u>Oyster Bay</u>: Dsp = -3.4 (x - 4.8) gives the date of beginning significant spawning to plus or minus 7 days.

For <u>Mud Bay</u>: Dsp = -2.63 (x -5.8) gives the time to plus or minus 7 days.

For <u>North Bay</u>: Dsp = -2.63 (x - 7.0) gives the date to plus or minus 4 days, and

For <u>South Bay</u>: 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 <u>will already have commenced</u> 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 after 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 <u>time</u> 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 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, without 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]~~