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 (xxxxPxxxxxxx) 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 ~~xx~~ at the edges ~~than~~ as in the center of the cultch.

2. The ~~catch~~ 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 ~~collection~~ 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 ~~type~~ 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 "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:

YEAR	OYSTER BAY		MUD BAY		NORTH BAY	
	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, ~~XXXXXX~~ 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.

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 ~~catch~~ cultch. This may come about in two ways: either the bryozoa set first and oyster spat have not been observed to set ~~in~~ 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.