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REANALYSIS OF RELATIONSHIPS CONCERNING PACIFIC OYSTER SPATFALL FORECASTING FOR DABOB BAY

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FINAL REPORT

Washington State Department of Fisheries
Service Contract No. 914, Pacific Oyster Set
for the Period January 1, 1978-June 30, 1978

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Submitted July 31, 1978

Robert L Burgner
Director

INTRODUCTION

The purpose of this study was to improve some of the relationships concerning Pacific oyster (*Crassostrea gigas*) spatfall forecasting for Dabob Bay, Washington, that were developed in a previous study (Packer and Mathews 1977). The specific objectives of this study were 1) readjustment of the plankton abundance indices in light of new data concerning vertical migration of oyster larvae, 2) reanalysis of the relationship between larval plankton counts and spatfall intensity, 3) reanalysis of the relationship between larval development and water temperature, and 4) determination of the relationship, if any, between preseason temperatures and the first spawning of oysters. The following discussion covers these points and also gives an evaluation of the 1977 season in relation to the predictive equations

Readjustment of Plankton Count Data

The readjustment of the larval count data with respect to the vertical migration patterns of the larvae did not increase the correlation coefficients of the spatfall forecasting predictive relationships developed in the previous study (Ibid.). The investigation of the vertical migration patterns of the larvae conducted during the 1977 spawning season showed a substantial difference in the percentage of the larval mass being sampled with the multiple depth running sampler (Westley 1954) at different times of the day. To correct for this sampling bias, the data points entered into the model of the predictive relationships were restricted to only those samples collected between 8:00 a.m. and 10:00 a.m. This morning period was chosen because most of the samples from past years were taken during this time. This selective procedure was to refine the data and remove variance due to time of day differences in vertical distribution of the larvae. Unfortunately, this refinement did not reduce the variability between sampling days, in fact the correlation coefficients with the data so refined suggest that morning samples are more variable than late morning and afternoon samples with respect to the other predictive independent variables of the multiple regression predictive relationships.

The vertical migration studies were conducted on three different days during the 1977 season. On each day several series of plankton samples at least seven depths through the water column were taken at various selected times of day. The selected times of day were chosen to determine the vertical migration pattern through a complete diel (24-hour) period. Each of the three days sampled was timed to coincide with a particular stage of larval development. Straight-hinge larvae were sampled on the first day, umbo larvae on the second, and setting-size larvae on the third. The seven depths used for the plankton samples for each time of day sampled were 0.3, 0.9, 1.5, 3.0, 4.6, 6.1, and 7.6 meters. The water for each sample was drawn at depth through a hose and strained with a 35-μ mesh net. The suction was created with a 12-volt impeller pump. The sample counts were adjusted to reflect the portion of the water column they estimated because spacing between the samples was not equal. The adjusted counts were computed by multiplying the distance from the midpoints between samples times the actual plankton count. For instance, the 0.9-m sample count was multiplied by 0.6 m because the midpoint depths between the adjacent samples were 0.6 m and 1.2 m, and the difference equals 0.6 m. The first three samples (i.e., 0.3, 0.9, and 1.5 m) coincide with the intake depths of the multiple depth running sampler. Figure 1 shows a diagram of the running sampler. The sum of all seven adjusted counts and the percentage of this sum from the three samples were computed. The percentage of the first three samples was taken as the percentage of the larval mass that would have been sampled with the running sampler at that particular time of day. The results of these computations are shown in Figs. 2, 3, and 4. A more extensive report on this study will be published at a later date.

A distinct downward migration of the larvae after direct sunlight begins to penetrate the water surface is readily evident from the data. This photonegative response is rapid and appears to be variable between larval stages. The percentages of larvae in the first three samples for the series of samples taken immediately after sunrise were 52% straight-hinge, 3% umbo, and 25% setting size on the three days sampled. These percentages were the lowest recorded for each of the three days. Thus it seems that the very early and later stages of larvae migrate vertically to a lesser degree than the midstages. The depth of the downward migration is restricted to the depth of the thermocline as no larvae were found below the warm water layer. The samples were all taken on clear, sunny days, with a minimum amount of wind, because an inference of a correlation between high plankton counts and cloudy days was determined in the previous study (Packer and Mathews 1977). It is assumed that variability in response to light intensity differences was avoided by sampling only on clear days. More sampling will be necessary to determine the differences between clear and cloudy days.

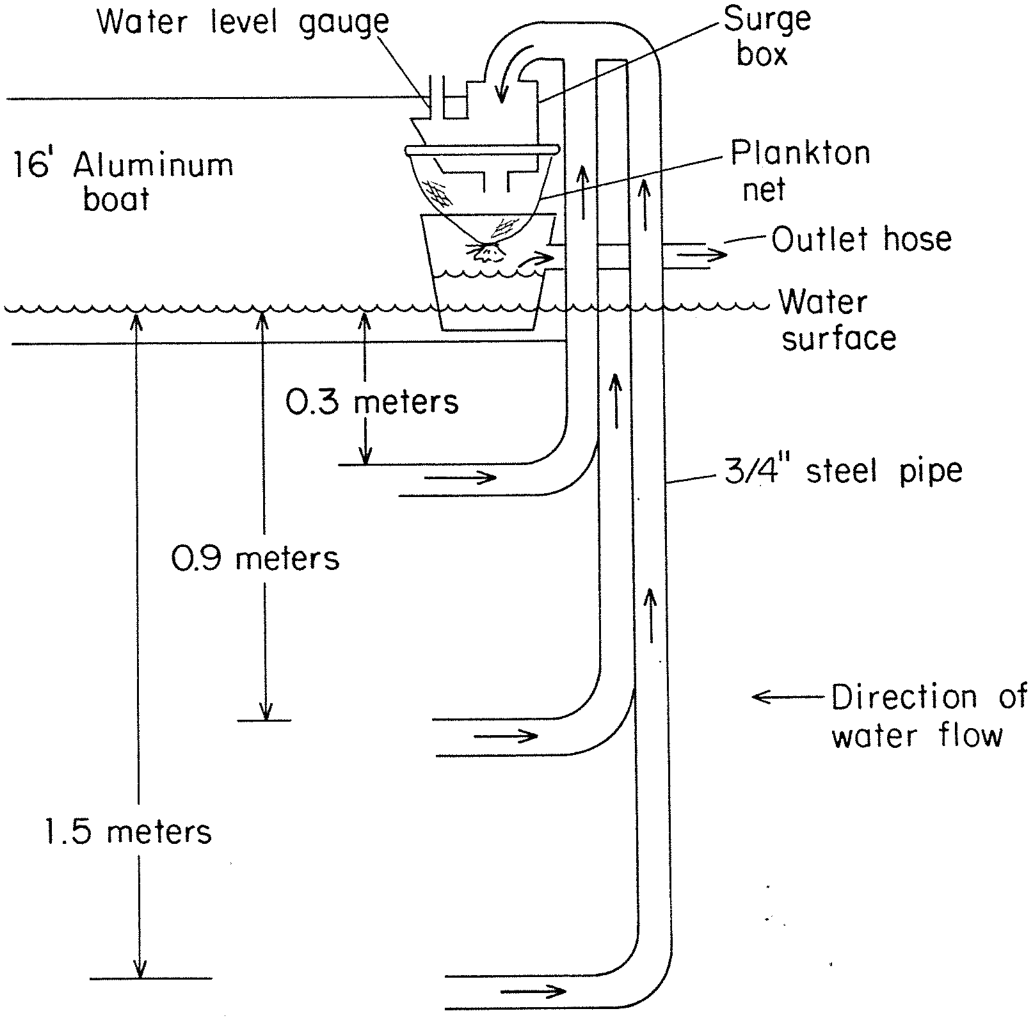

Figure 1. Diagram of multiple depth running sampler (Westley, 1954) shown mounted on the stern of the boat

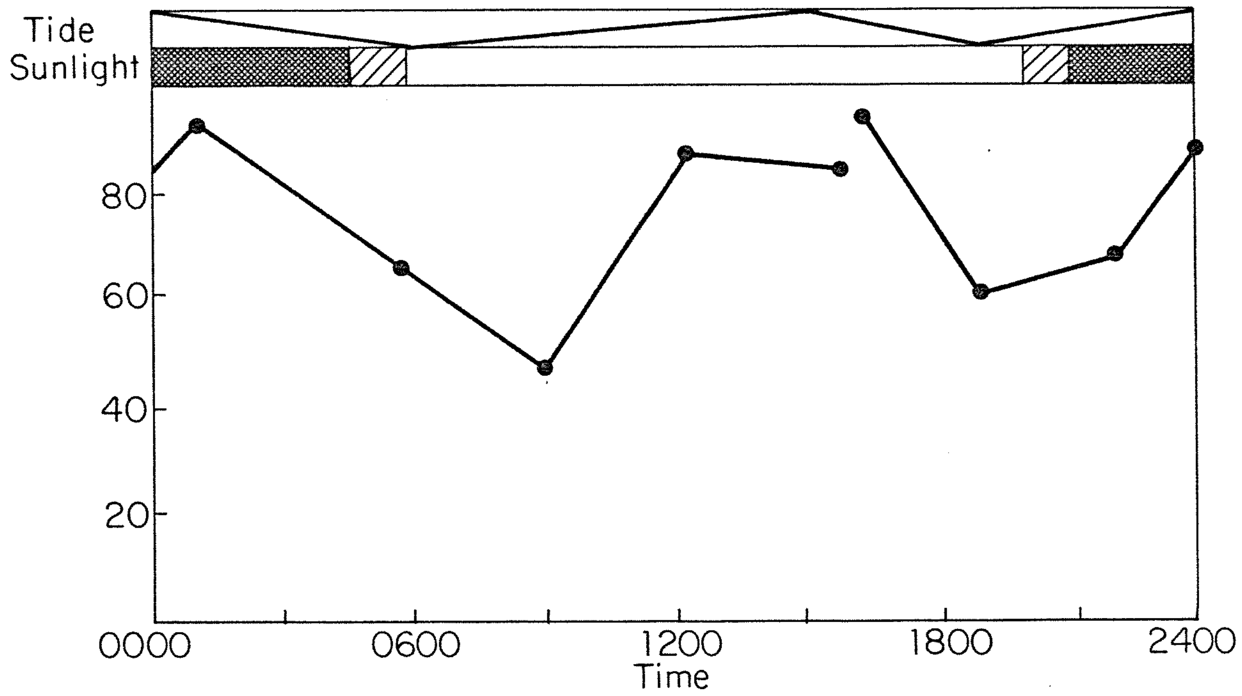

Figure 2. Straight hinge stage, July 26, 27, 1977.

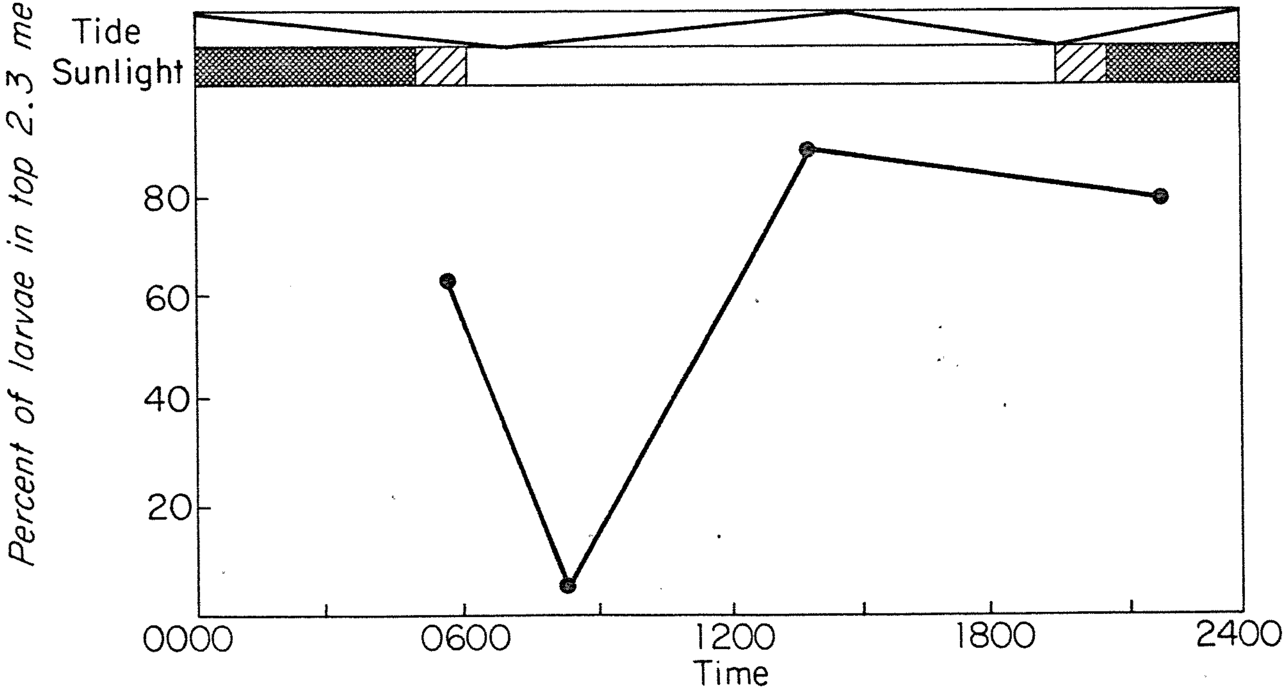

Figure 3. Early umbo stage, August 9, 1977

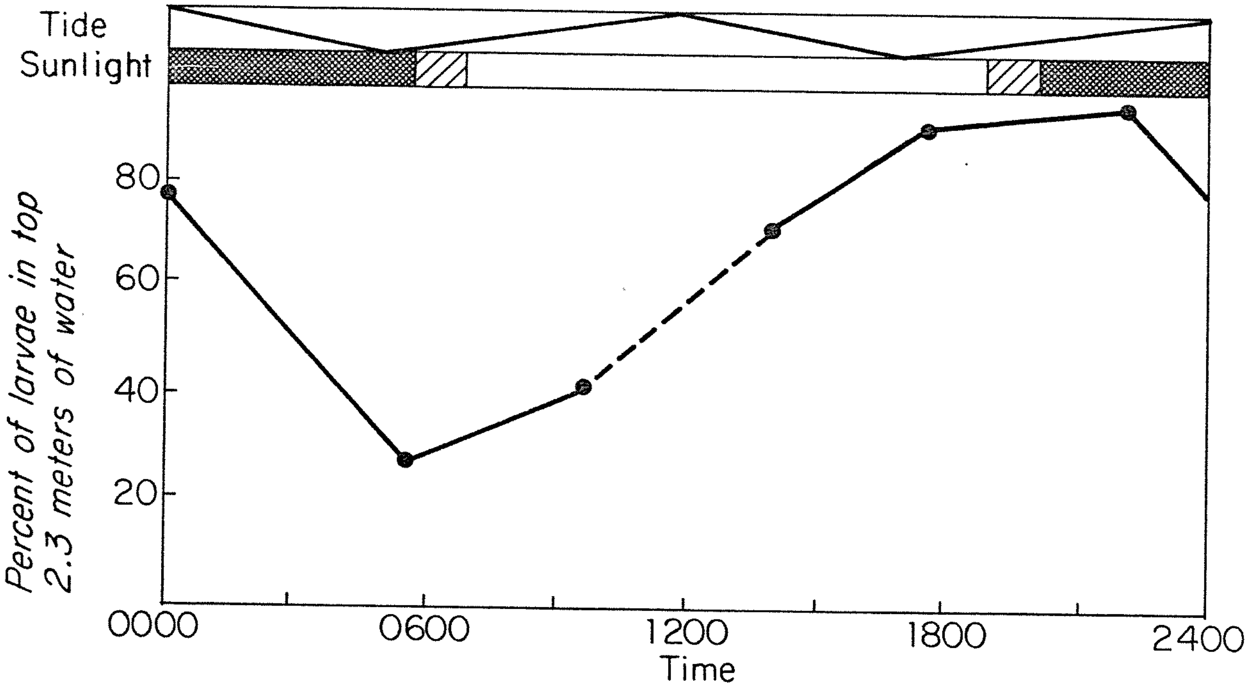

Figure 4. Setting size stage, August 22,23,1977

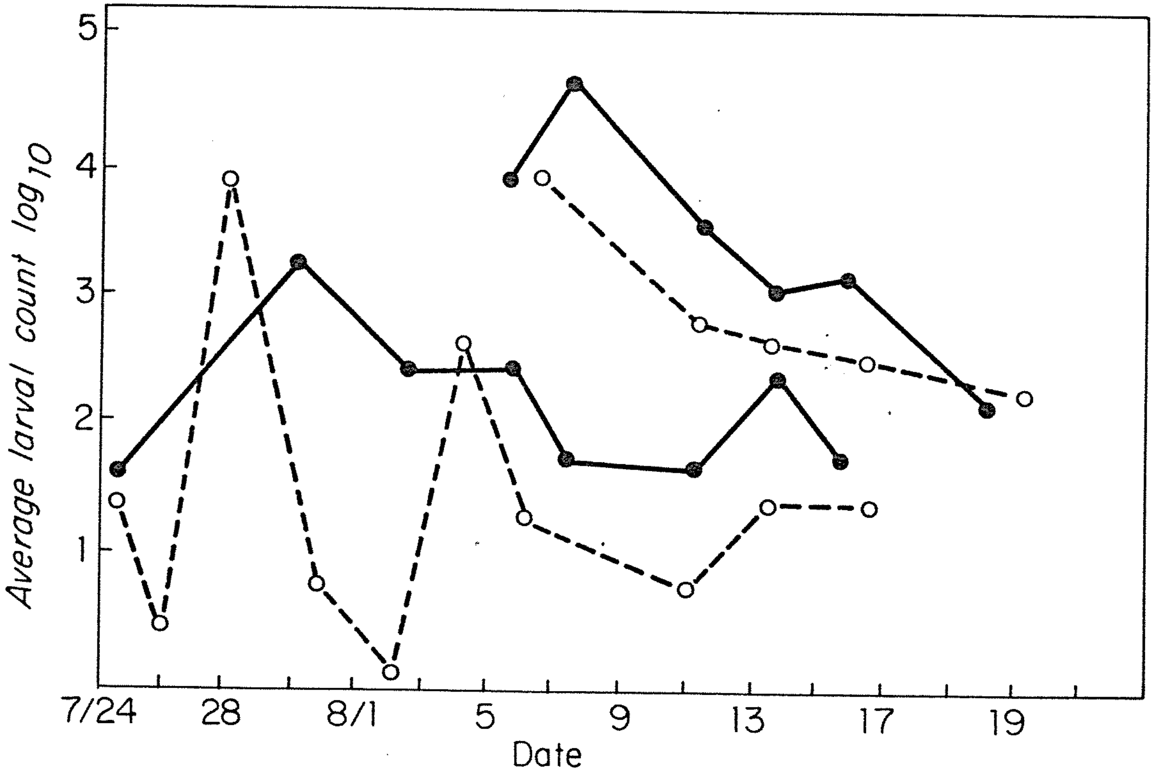

Figure 5. Comparision of morning and evening plankton samples from Dabob Bay, Summer 1977.

An upward migration occurs in the late morning or afternoon, but at a slower rate than the downward migration. The percentages of larvae in the first three samples then remains high through the late afternoon and evening, although there are up and down fluctuations which have some periodicity with tidal stage. It appears that samples taken at low tide have lower percentages in the top layer than samples at high tide.

Short plankton runs with the multiple depth running sampler were taken along with the vertical samples during the second and third days sampled. The resulting counts correlated well with the counts from the first three samples for that particular time of day. Since the first three samples coincide with the intake depths of the running sampler and their average counts correlate with the density of larvae estimated by the running sampler, the variability of running sampler counts can be directly related to the percentage of the larval mass being sampled at that particular time of day.

Vertical migration of the larvae is dependent on many factors which include light intensity determined by time of day and amount of cloud cover, stage of development, depth of the thermocline and possibly halocline, and tidal stage. The responses to these factors are so varied and so little understood that it is not possible to determine what percentage of larvae were being sampled on any particular day from the available data of past years. The reason that the readjustment of the count data was not useful for predictive purposes was probably due to the variability of response in vertical migration to the above factors. During the early morning, the changes in vertical position are more rapid and variable compared to other times of the day, whether the changes are upward or downward. Because of this it is better to include data points at all times of day in estimating average larval densities. Such averages would be most applicable to the regression equations.

Table 1 shows the results of readjusting the count data for reestimating larval densities by the procedure of selecting only those samples taken between 8 a.m. and 10 a.m. Table 2 shows the results of adding 1977 data to the previously computed regression equations. Since both spawnings in 1977 were before August 7, only the early predictive relationships were changed. The changes caused by adding the 1977 data were small. Table 2 also shows the results of an exponential transformation on the surface temperature variable. This transformation was tried because the very high temperatures of the 1977 season did not produce an extremely high spatfall as would be expected with a linear relationship between temperature and spatfall. This transformation did not produce any usable predictive relationships.

Spatfall Intensity and Larval Numbers

The spatfall intensity statistic is determined by limited shell counts from selected stations and is the dependent variable for the predictive equations. This statistic is assumed to be measured with no variance for the regression equations and computed confidence intervals of the previous study (Ibid.). This mathematical assumption is not very realistic considering all the variables inherent to the process of larval settlement. Larval densities, water current patterns, shell size and cleanliness, length of soak time, rate of fouling, and amount of light are factors which can influence spatfall intensity at any particular station. A more extensive shell sampling program was established during the 1977 season, particularly

Table 1. Reestimating average larval densities using early morning samples in a multiple regression model.

0-4 days early Variable	F	MR	0-4 days late Variable	F	MR
LCNT	141.6	0.769	LCNT	132.7*	0.871
Temp	10.2	0.811	Temp	6.2*	0.889
Cloud	6.1	0.820	Tide	6.6*	0.906
Btg	4.5	0.828	Cloud	4.1	0.915
Tide	0.3	0.829	-		
4-8 days early Variable	F	MR	4-8 days late Variable	F	MR
Temp	131.7	0.820	LCNT	136.2*	0.879
LCNT	12.2	0.852	Tide	6.7*	0.899
Cloud	15.7	0.884	Cloud	1.7	0.902
Btg	4.3	0.892	Temp	1.0	0.905
Tide	3.1	0.897	-		
8-12 days early Variable	F	MR	8-12 days late Variable	F	MR
Temp	95.1	0.750	Btg	108.0	0.857
Cloud	4.4	0.766	LCNT	19.7	0.908
Tide	1.7	0.772	Cloud	22.5	0.944
LCNT	0.4	0.774	Tide	18.2	0.963
Btg	0.2	0.775	Temp	0.8	0.964
12-16 days Variable	F	MR	16-20 days Variable	F	MR
Btg	116.8*	0.778	Btg	70.7	0.747
Temp	6.4*	0.798	LCNT	3.2	0.763
Cloud	4.3	0.810	Tide	0.3	0.765
LCNT	0.4	0.811	Cloud	0.1	0.766
Tide	0.2	0.812	Temp	0.1	0.766

F - F statistic to enter variable in a stepwise regression.
MR - Multiple "R".
* - Significant reduction in residual variance at the probability level of 5 percent or less.
LCNT - Natural log of the larval count.
Btg - Bathythermograph statistic

Table 2. Addition of 1977 data to previously computed predictive equations and an exponential transformation of the surface temperature variable (LTMP) with the predictive equations.

0-4 early Variable	F	MR	0-4 early with LTMP Variable	F	MR
LCNT	158.4*	0.764	LTMP	65.1*	0.610
Temp	41.0*	0.824	LCNT	13.3*	0.688
Cloud	13.1*	0.838	Btg	18.1*	0.721
Btg	4.5	0.841	Cloud	8.1*	0.730
Tide	1.2	0.842	Time	7.8*	0.740
Time	0.8	0.844	Tide	0.7	0.742

4-8 early Variable	F	MR	4-8 early with LTMP Variable	F	MR
Temp	193.3*	0.763	LTMP	84.9*	0.615
LCNT	23.7*	0.801	Time	15.1*	0.663
Time	8.3*	0.814	Btg	30.2*	0.735
Tide	6.8*	0.824	Cloud	9.7*	0.756
Cloud	2.1	0.827	LCNT	12.1*	0.779
Btg	1.6	0.829	Tide	2.3	0.783

8-12 early Variable	F	MR	8-12 early with LTMP Variable	F	MR
Temp	213.4*	0.808	LTMP	63.5*	0.600
LCNT	14.9*	0.833	Btg	21.0*	0.679
Cloud	3.1	0.838	LCNT	7.9*	0.705
Time	2.6	0.842	Cloud	8.2*	0.729
Btg	0.6	0.843	Tide	1.8	0.734
Tide	0.1	0.844	Time	1.4	0.738

Table 2. Addition of 1977 data to previously computed predictive equations and an exponential transformation of the surface temperature variable (LTMP) with the predictive equations - Continued.

12-16 days Variable	F	MR	12-16 days with LTMP Variable	F	MR
Temp	357.3*	0.840	Btg	155.8*	0.715
Time	9.6*	0.850	Cloud	18.8*	0.753
LCNT	1.8	0.853	LTMP	9.2*	0.769
Tide	0.3	0.853	Tide	0.4	0.770
Cloud	0.1	0.853	Time	0.1	0.770
Btg	0.0	0.853	LCNT	0.1	0.770

16-20 days Variable	F	MR	16-20 days with LTMP Variable	F	MR
Temp	141.0*	0.757	LTMP	115.1*	0.723
LCNT	12.7*	0.787	Btg	37.7*	0.806
Btg	4.9	0.798	LCNT	18.5*	0.838
Tide	2.6	0.804	Cloud	1.0	0.840
Time	0.0	0.804	Tide	0.7	0.841
Cloud	0.0	0.804	Time	0.1	0.842

F - F statistic to enter variable in a stepwise regression.

MR - Multiple "R".

* - Significant reduction in residual variance at the probability level of 5 percent or less.

LCNT - Natural log of the larval count.

Btg - Bathythermograph statistic.

to study the variability of larval settlement among stations along Dabob Bay. Four new sampling stations were established and the number of samples at existing stations was increased. This increased sampling has improved the understanding of the relationship between setting-size larval plankton counts, and spatfall intensity.

The new sampling stations used in 1977 were 1) Bt 1 - 50 m west of the south end of Longspit, 2) Bt 3 - 35 m west of the boat hull directly opposite Lindsay Beach, 3) CP - Camp Parsons boat dock, and 4) ZP - U.S. Navy float at Zelatched Point. These new stations were sampled once each week. Sampling at the old stations of Broadspit, Point Whitney, and Figure Four (Quilcene Bay) was intensified from once a week to twice a week. Ten uniformly-sized, flat, clean shells were counted for each sample following the procedure of past years.

A comparison was made between the advanced umbo/setting-size larval plankton counts and shell counts. The plankton sample transect nearest the shell station was used for the comparisons (with the date of the plankton sample being the same as the first day of soak time for the shell string). The Bt 1-2 plankton sample transect was compared with the Broadspit and Bt 1 shell counts, Bt 2-3 transect with Bt 3 shell counts, Bt 3-4 transect with Point Whitney shell counts, and Bt Quil transect with Figure Four shell counts. A map of these transects and shell stations is shown in Fig. 6. Both morning and evening plankton samples were compared to the shell counts. The data are shown in Table 3.

It is evident from the data that a linear relationship between evening plankton count densities and spatfall intensity exists. A regression was computed for the data from Table 3 using the evening counts and is shown in

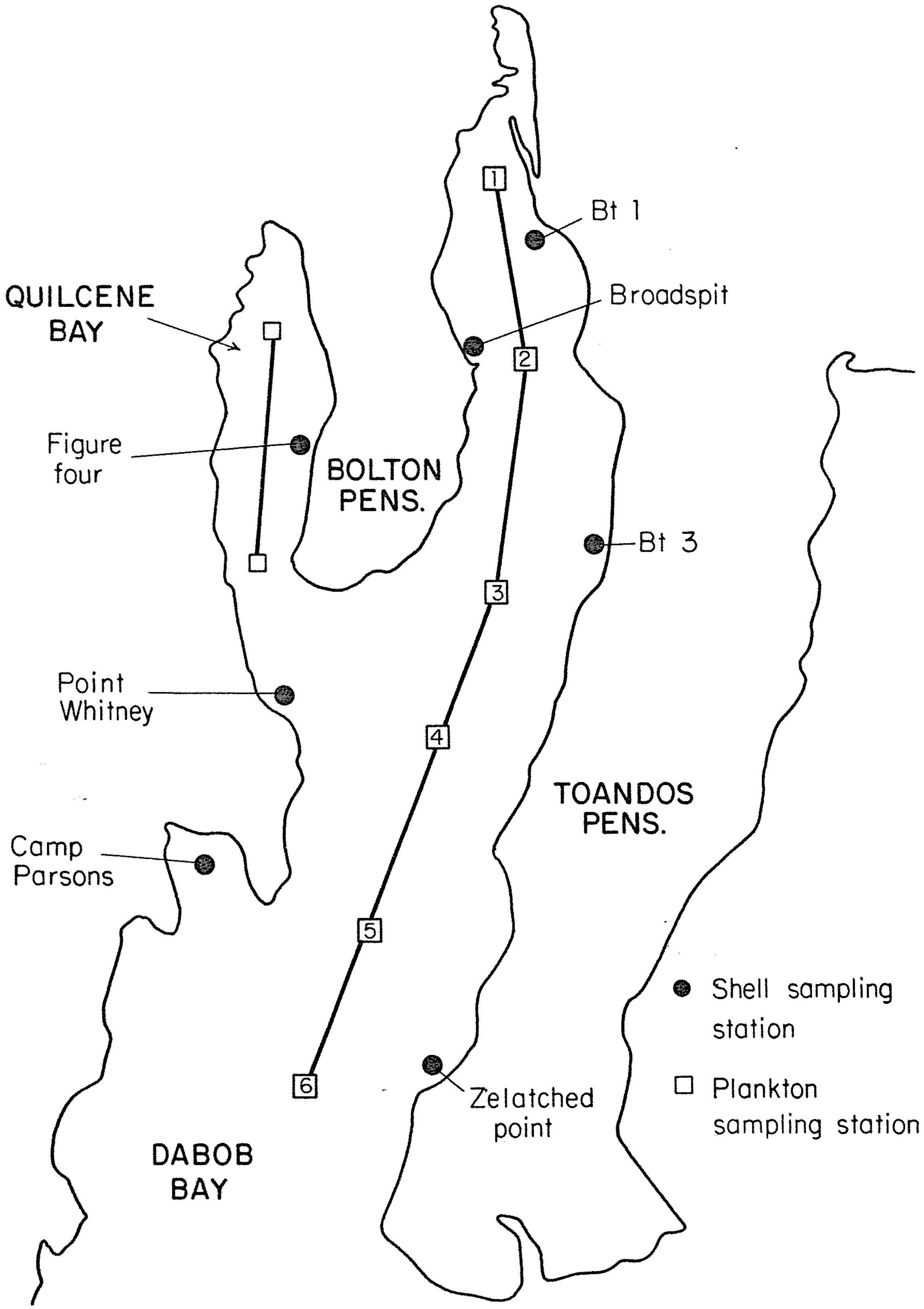

Figure 6. Shell sampling stations and plankton sample transects used by the WDF in Dabob and Quilcene Bays.

Table 3. Shell counts and associated plankton sample counts at various stations along Dabob and Quilcene Bays, August 13 to September 6, 1977.

Shell counts		Plankton counts		Shell counts	Plankton counts	
Broadspit	Bt 1	Morning	Evening	Figure Four	Morning	Evening
1)	15	5	5	19	55	26
7)		65	5	93	1063	-
1135)	1985	387	1487	4739	2484	1975
582)		500	357	365	540	-
551	460	65				
22		6				

Shell counts	Plankton counts		Shell counts	Plankton counts	
Bt 3	Morning	Evening	Point Whitney	Morning	Evening
36	16	36	1		-
3037	351	2135	23	16	85
50	221	137	1933	351	2135
			381	221	137
			54	4	-

Note: Shell counts are in numbers of spat per shell . Plankton sample counts are in numbers of larvae per 20 gallons.

Fig. 7. The very high shell count from Figure Four (4,739 spat per shell) was not included in the regression because later seasonal shell counts indicated that this particular spatfall estimate was too high. Water current patterns due to the proximity of the Quilcene River may have caused this overestimate. With the exception of this data point (circled in Fig. 7), the relationship seems very good with a correlation coefficient of 0.95. More data will be needed to substantiate the relationship, but it could become very useful for spatfall predictions using evening counts. The morning sample counts were so variable that a clear relationship was not evident.

The Broadspit and Bt 1 shell stations are on opposite shorelines at the north end of Dabob Bay (*see* Fig. 6). The purpose of choosing these sites so relatively close together was to determine the variability between sampling stations for a particular portion of the bay. The variability of the Broadspit station is important because the counts are used as the dependent variable in the regression equations and the majority of the commercial cultch is in the nearby vicinity. The spatfall counts from these two stations were highly correlated with one another but varied considerably from counts at other stations along the bay. This result indicates that local conditions such as the water currents do not bias the shell counts at the north end of the bay and that larval plankton densities are somewhat evenly distributed. If the plankton densities were extremely patchy, then a low correlation between the two shell site counts would have been indicated.

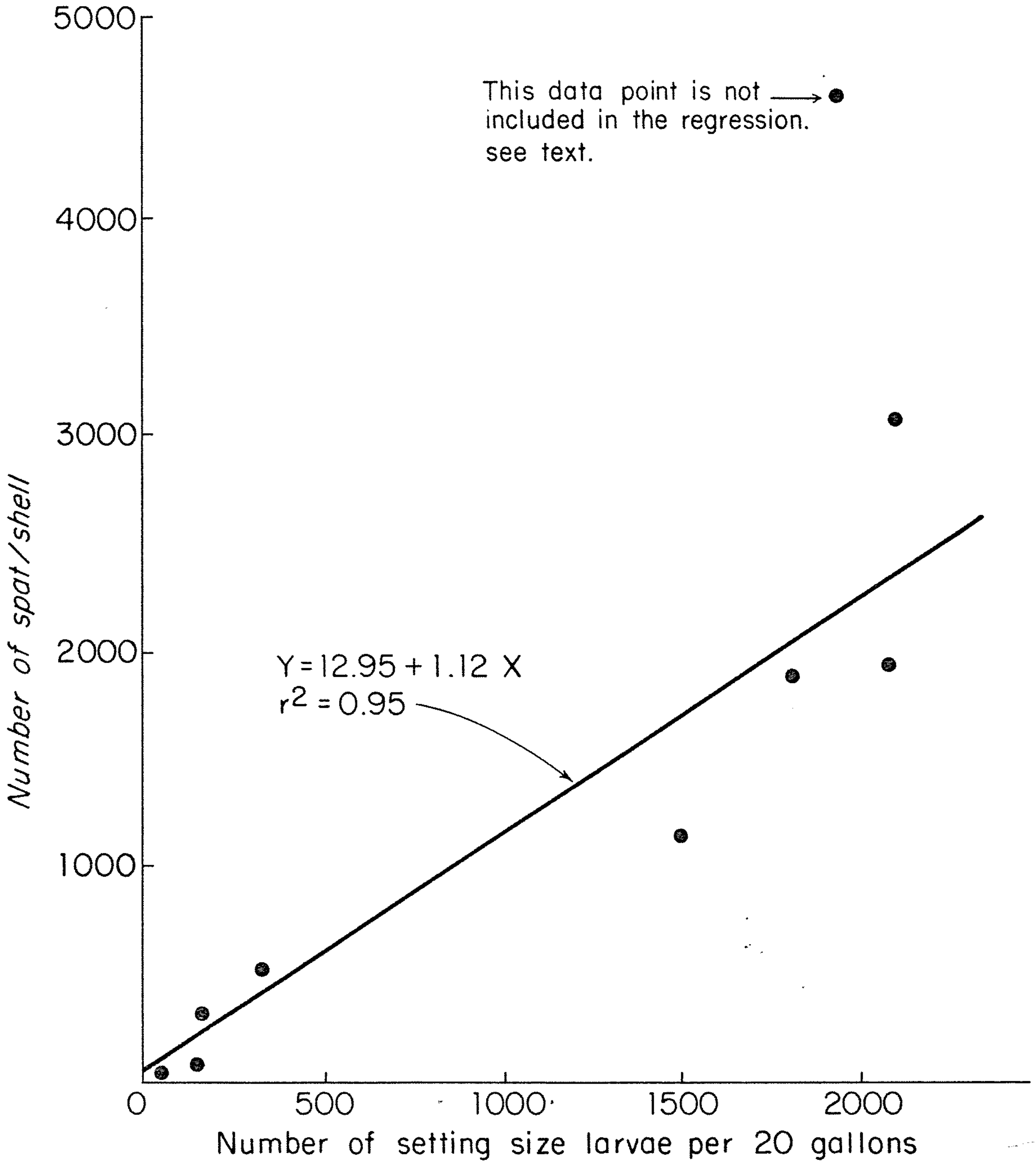

Figure 7. Comparison of spatfall and plankton counts at various stations along Dabob and Quilcene Bays, Summer 1977.

Larval Development and Temperature

The length of time for larval development is dependent on the water temperature during the development period. An attempt to determine the relationship between temperature and number of days for development was made in the previous study (Ibid.), but the computed regression did not accurately reflect the length of time needed for development. The regression attempted to relate the number of days between the first appearance of straight-hinge larvae and the onset of significant larval settlement, to the average daily surface temperature. Determining when the straight-hinge larvae first appeared was the biggest problem with developing this relationship. Trocophore larvae develop the straight-hinge shell approximately two days after spawning has occurred. If plankton samples were not taken by the third day following spawning, the length of time for development would be underestimated. If a plankton sample happened to have been taken on a sunny day, the counts could be low relative to the strength of the actual spawning, and the following sample which had high counts would be taken on the day the straight-hinge larvae appeared. This would again cause the development time to be underestimated. The reason that low straight-hinge counts (i.e., less than 15 larvae) were not taken on the day that they appeared was that it would not be possible to separate these low counts from the low counts of minor spawnings. During the spawning season frequent minor spawnings occur which are not of commercial importance. To compensate for the underestimates of the development time, the day of spawning was estimated by determining when the surface temperatures reached 20°C prior to the appearance of the straight-hinge larvae. Observations of past years indicate that oysters in Dabob Bay do not spawn until the surface temperatures are at least 20°C (Lindsay et al. 1958). Using the day of spawning instead of the day that the straight-hinge larvae first appeared added 2 to 6 days to the development times. The resulting relationship is shown in Fig. 8.

The relationship appears to be nonlinear with the number of days for development increasing more rapidly for average temperatures below 19°C. For the years when the average temperatures fell below 17°C, no spatfall was observed, so the data points of this relationship reflect only successful spawnings. The number of days for development ranged between 19 and 26, or approximately three weeks. The spawnings which had higher temperatures and shorter development times tended to be much more successful.

Preseason Spawning Predictions

No definite relationship between preseason environmental conditions and first spawning of oysters in Dabob Bay was evident from the data available. Daily air temperatures from the Quilcene salmon hatchery and weekly or biweekly water temperatures from the U.S. Navy operations since 1970 were available as data for preseason conditions. This data is fairly limited in describing the preseason conditions because the relationship between air temperatures and water temperatures is not well understood. Oyster spawning is a water temperature dependent phenomena and prediction of spawning time must be based on the timing of warm weather which produces a 20°C stratified warm water layer. Predicting warm weather a few days in advance is not an easy task. Such predictions over many weeks or months is most likely impossible. It must also be considered that the time of the first major successful spawning from 1966 to 1977 varied only within a one-month period, from the first week of July to the first week of August.

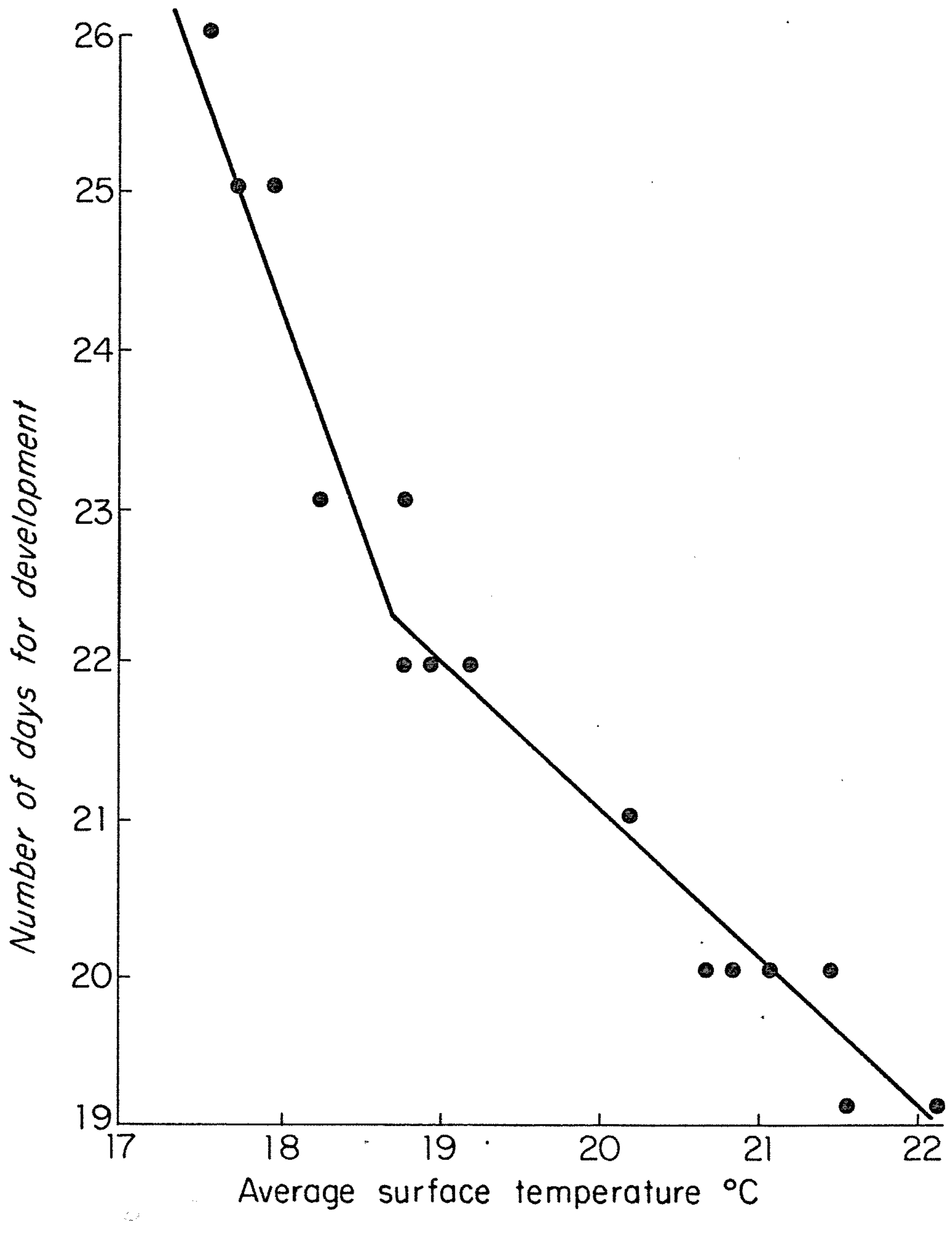

Figure 8. Relationship between length of time for larval development and average daily surface temperature at sampling time, 1966-1977.

This is a very short time period to predict within, even with a few weeks advance notice. A better way to approach this problem might be to determine when the oysters are able to spawn by looking at the ripeness of the gonads in known spawning beds. This would require much more data and the benefits would seem to be somewhat questionable. The major benefit of a preseason spawning prediction would be to commercial cultching operators who might not expect an early spawning. It would seem to be a good practice for oyster companies to be ready to place their cultch in the water by the first week of July, and then wait until the conditions were favorable.

Evaluation of Prediction Model for the 1977 Season

The data from the regular morning plankton samples of the 1977 season were entered into the model developed in the previous study (Packer and Mathews 1977). The resulting estimates of average spatfall intensity were between 110 and 335 for the first spawning and 73 to 2,892 for the second spawning. The actual spatfall counts from the Broadspit station were 1,142 for the first spawning and 1,185 for the second. The 80% confidence intervals generally included the actual spatfall counts; however, the confidence intervals tended to be wide, particularly for high estimates. The model seemed to function well as a predictive indicator of spatfall; however, since sampling time was split among morning, evening, and vertical sampling, the number of data points entered into the model was less than for other years. Fewer data points and the high variability associated with morning samples are the reasons that the spatfall estimates had such a wide range. During the 1977 season the evening plankton counts were considerably higher than the morning counts. Most of the morning samples were taken on clear, sunny days which usually results in depressed counts due to downward migration. For these reasons the spatfall was expected to be much higher, approaching the counts of several thousand spat per shell as in 1967, 1971, and 1974. Since the model had not been tested before and the estimates of spatfall were seemingly low, the spatfall predictions were not included in the WDF Pacific Oyster Bulletin forecasts. The primary function of spatfall forecasting is to determine whether or not an adequate commercial spatfall of at least 10 spat per shell on floating cultch will occur. The conditions were so favorable during the 1977 season that a commercial spatfall was almost assured, barring an unexpected change in the weather. In the future the spatfall estimates will be included in the WDF forecasts, but caution must be taken in interpreting the results due to the decreased morning sampling. Table 4 shows the spatfall estimates and confidence intervals and Fig. 5 shows a comparison of morning and evening samples from the 1977 season.

Table 4. Spatfall intensity estimates for the 1977 season.

First spawning (spatfall = 1142 spat/shell) Broadspit			Second spawning (spatfall = 1185 spat/shell) Broadspit		
Regression time period	$\hat{y}$ (spat/shell)	0.8 C.I. (spat/shell)	Regression time period	$\hat{y}$ (spat/shell)	0.8 C.I. (spat/shell)
0-4 days	335	45 - 2475	0-4 days	73	7 - 727
4-8 days	244	44 - 1804	4-8 days	1158	157 - 8556
8-12 days	110	21 - 1096	8-12 days	1393	188 - 10286
12-16 days	205	-	12-16 days	2892	-
16-20 days	1	-	16-20 days	24	-

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