HARVEST OF OVIGEROUS PINK SHRIMP IN THE OREGON AND CALIFORNIA TRAWL FISHERIES

By

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INTRODUCTION

Recently, ODFW research efforts on pink shrimp have focused on identifying environmental and parent-stock effects on recruitment. These efforts have demonstrated a strong influence of ocean environmental factors on recruitment, but failed to show a dependence of recruitment on parent stock (Hannah 1991a ODFW, draft). In evaluating the influence of parent stock, we have utilized September-October mean catch-per-unit-effort (CPUE) as an index of spawning stock biomass, which is assumed to measure reproductive output. The absence of parent -stock effects on recruitment is not surprising; documented stock-recruitment relationships are rare for shrimp. However, the pink shrimp fishery provides a long data series, with large fluctuations in parent stock, precisely the conditions required to detect a stock-recruitment relationship.

Recent data (Hannah 1991b ODFW, draft) suggest that age-specific, and length-specific average fecundity in pink shrimp may show considerable interannual fluctuations. This finding is based upon very limited sampling, and needs further study to define the magnitude and frequency of variations in fecundity. However, the finding is significant, in that it may partly explain the lack of success to date in defining a stock-recruitment function for pink shrimp. Simply put, if length-specific fecundity is quite variable, then the standard measures of parent stock; numbers of parents, parent biomass, and estimates of larval release based on static average fecundity values, may be poor measures of shrimp reproductive output. To further investigate the influence that fishing exerts on recruitment, we need to focus on improving how we measure reproductive output.

Another potential source of error in using spawning stock biomass to index reproductive output is the harvest of egg-bearing females. The fishery catches egg-bearing shrimp near the end of the season in October, and also the following April, sometimes in large numbers. This catch, especially in the spring just prior to larval release, may be depressing the reproductive output of the stock below the levels implied by CPUE at the end of the previous season. The purpose of this study is to analyze the sample data from the trawl fishery to determine the potential impact of catching egg-bearing shrimp. A secondary objective is to determine how a change in the fishing season for shrimp might reduce this impact.

METHODS

I analyzed shrimp sample data collected from the Oregon and California trawl fisheries for the months of April and October, from 1961-1990. The study area encompassed Pacific States Marine Fisheries Commission (PSMFC) statistical areas 72-92 (Figure 1). Most of the sample data for area 92 was provided by the California Department of Fish and Game. For a detailed description of standard sample analysis and summarization see Hannah and Jones (1991).

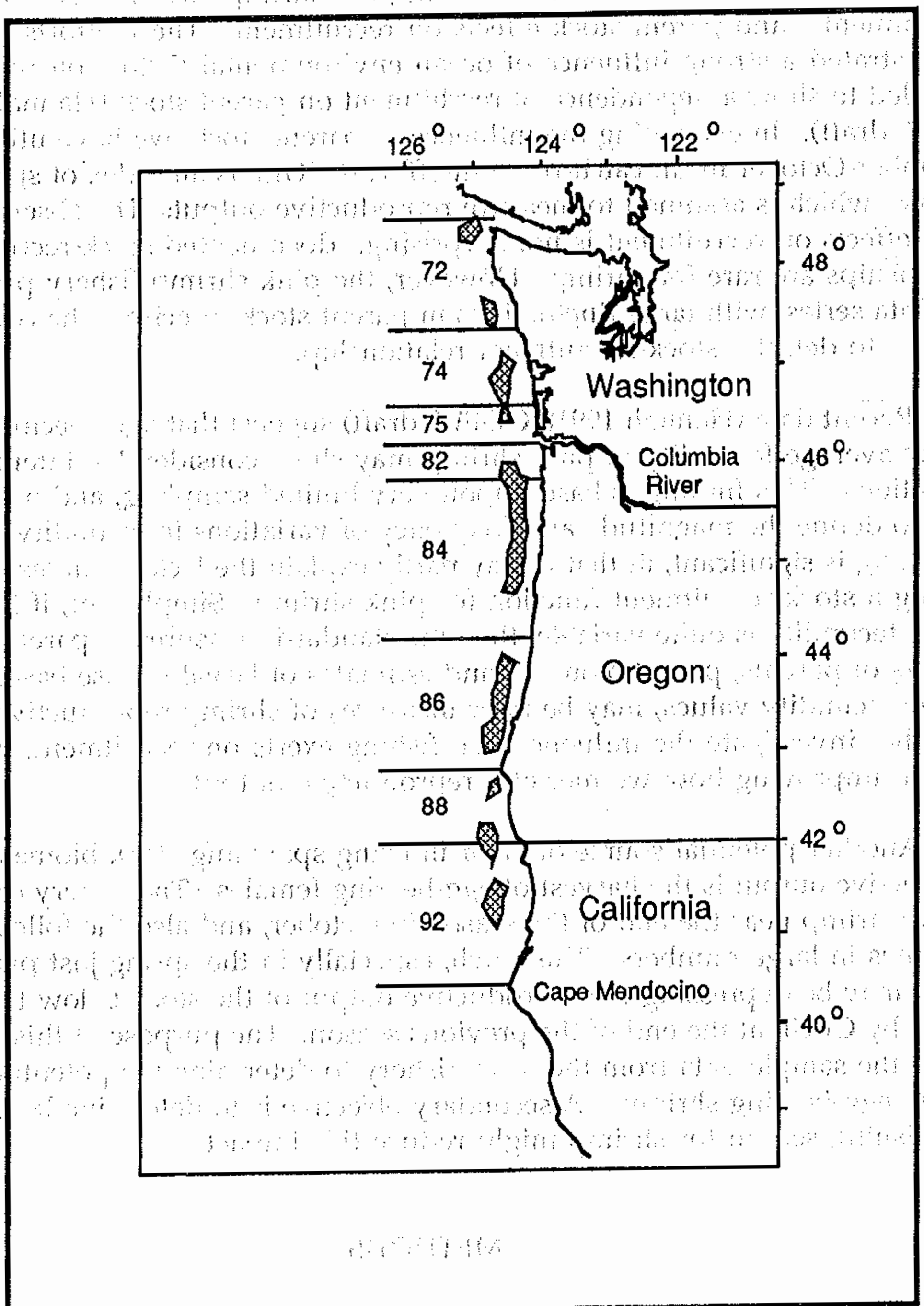


Figure 1. Location of commercial concentrations of pink shrimp Pandalus jordani along the U.S. Pacific coast (shaded areas) and PSMFC statistical areas 72-92.

The primary statistic utilized was simply the percentage of egg-bearing shrimp in the sample. A graphical analysis was used to identify which areas consistently showed levels of egg-bearing shrimp above zero, in either April or October. For this analysis all samples were used. Graphs were also used to examine the percentage of ovigerous shrimp by date, to see how much of a change in the season might be needed.

Catching egg-bearing shrimp in October represents a fundamentally different impact on the population than the same catch made the following April. This is because natural mortality rates for shrimp are quite high. Using the average monthly natural mortality rate of 0.096 reported by Gotshall (1972), to discount the October population, suggests that it will be reduced by nearly 40% over the five months that follow. An egg-bearing shrimp saved from harvest in April has a much greater chance of surviving to release larvae, than a similar shrimp spared in October. Accordingly, our impact assessment focused more on harvest of egg -bearing shrimp in April than in October.

The first step in assessing the impact of catching ovigerous shrimp in April was to estimate the total catch of these shrimp for a series of years. I focused on the years after 1978, since the fishery was still in a developmental stage prior to this. The graphical analysis suggested that it would be most productive to focus on statistical areas 86-92, since these areas showed consistently higher levels of egg-bearing shrimp in April.

Since the percentage of egg-bearing shrimp is generally declining throughout April, a time-stratified estimate was needed for each area. The graphical analysis suggested that the number of samples taken each year, and the distribution of these samples across the month, varied considerably from year to year, and area to area. For example, some years which had excellent sample coverage in the first two weeks of April had no samples at all for the second half of the month. To make maximum use of the data available estimates of the percentage of egg-bearing shrimp from individual samples were averaged for the first and second halves of the month, respectively. These semi-monthly figures were then averaged and multiplied by the catch of shrimp, in numbers, for the month and area. The resulting number is a crude, time-stratified estimate of the total catch of egg-bearing shrimp for the month and area. While it would have been more accurate to use shorter time periods for averaging, this would have resulted in more years being excluded from the analysis due to uneven sample coverage.

This approach still resulted in some years with estimates of egg-bearing shrimp for only one half of the month, in some areas. Since the percentage of egg-bearing shrimp is declining throughout April, some conservative assumptions still allowed the use of these data. When samples were missing from the latter half of the month, a zero level of ovigerous shrimp was assumed. When samples were missing for the first half of the month, the level of ovigerous shrimp for the second half was applied to the first half. Accordingly, the estimates presented are minimum estimates of the catch of egg-bearing shrimp.

To put the catches of egg-bearing shrimp into perspective, estimates of the total number of female spawners in the area, at the time, are needed. Clearly, the harvest of a million egg-bearing shrimp from an area has a very different significance when the total female population is two million than when it's a billion. To obtain population estimates I first estimated q, the catchability coefficient, for areas 86-92, using the method of Paloheimo (1961) as described in Ricker (1975). Briefly, this method constructs a linear relationship between fishing effort and the change in CPUE between two time periods. The slope and intercept of the line are the catchability coefficient and natural mortality coefficients, respectively. I used the time periods of April-June and July- September, from each year to construct the CPUE ratios. Since age one shrimp are incompletely recruited to shrimp trawl gear, CPUE data for age two shrimp were used. The data series for this procedure ran from 1966-89.

The simplest form of Baranov's catch equation (Ricker 1975) was then used to calculate an estimate of the total female shrimp population in areas 86-92, combined, from April CPUE and our estimate of q. The equation is:

$C/f = q N$ where,

C = the April catch of female shrimp, in numbers and,
f = fishing effort (SRE hours)in April and,
q = the catchability coefficient and,
N = the estimated population.

In April, all female shrimp are age two or older. Consequently the catchability coefficient derived from age two shrimp should be applicable for estimating the April female population. The total catch of egg-bearing shrimp was then divided by the population estimates to calculate the percentage of the female population which was harvested before completing larval release.

The accuracy of the population estimates depends on an accurate estimate of q. As a test of the catchability coefficient used, age two population estimates were also calculated from shrimp CPUE in April. These estimates were compared to virtual population estimates, made by simply summing the catch of the age two cohort from April through the end of the following year. Since shrimp are known to experience fairly high rates of natural mortality, the virtual population estimates should be lower than the age two population estimates based on CPUE. If the virtual population estimates routinely exceed the CPUE-derived ones, then our estimate of q is probably too high. This comparison is far from a complete validation of the accuracy of the population estimates developed here. However, it should limit the chances of grossly under-estimating the female population, and consequently limit the chances of over-estimating the fishery impact.

RESULTS AND DISCUSSION

In all, 1200 and 704 samples from the April and October catch, respectively, were analyzed. The samples covered statistical areas 72-92 (Figure 1) and spanned the years of 1960-1991. The range of percentages of egg-bearing shrimp in these samples, is shown in Figures 2-9. The incidence of elevated levels of egg-bearing shrimp in the April catch (Figures 2-5) is low north of area 84, and is only consistently higher than 5% in areas 86-92. From a coastwide perspective, April 1989 stands out, showing elevated levels of ovigerous shrimp in most areas, even the northern ones. Higher maximum levels of ovigerous shrimp are also evident in 1989 in areas 86-92. However, time-stratified average values for April (Figure 10) show that the average levels seen in 1989 in the southern areas are only slightly higher than are routinely observed. These graphs show clearly that, with the exception of 1989, the harvest of egg-bearing shrimp in April is almost exclusively a southcoast problem.

Based on the range of values observed, the incidence of egg-bearing shrimp in the October catch appears to be much more uniform along the coast (Figures 6-9). However, simple average values of the percent ovigerous shrimp (Figures 11-14) show that egg-bearing shrimp in October are much more common in the northern areas. The similar range of values from north to south, in light of the lower average levels in the southern areas, suggests that spawning may be more synchronous, and slightly earlier, in the northern areas. This is also supported by the lack of egg-bearing shrimp in the April catch in the northern areas.

An examination of the percentage of ovigerous shrimp by day of the month for April and October (Figures 15-19) is useful in determining approximately when during the month shrimp harvest is free of egg-bearing individuals. The graphs for April suggest that, for areas 84 and 86, levels of egg-bearing shrimp have generally dropped below 10% by the 15th of the month. In fact, no samples above 10% were observed at all after April 20th. For the extreme southern harvest areas (Figure 16), samples above 10% are still fairly common after the 25th of April. These data suggest that delaying the season opening date to April 15th would substantially reduce the spring harvest of egg-bearing shrimp, but that an opener as late as May 1st would be required to nearly eliminate the impact. A less extreme, and reversed situation seems to exist for the October samples (Figures 17-19). For areas 86-92, levels of ovigerous shrimp above 10% are generally not encountered prior to the 20th of October. For the northern areas, however, a number of samples above 10% are observed between the 10th and 20th of October. Similarly to the month of April, eliminating only the latter half of the month of October would largely, but not completely, eliminate the harvest of ovigerous shrimp.

The results of applying Paloheimo's (1961) method for estimating q to age two CPUE data are shown in Figure 20 and Table 1. The overall regression is significant ($p < 0.05$) and results in an estimated q of 0.00001392. The intercept of this regression, 0.375, is an estimate of the three month natural mortality rate. This

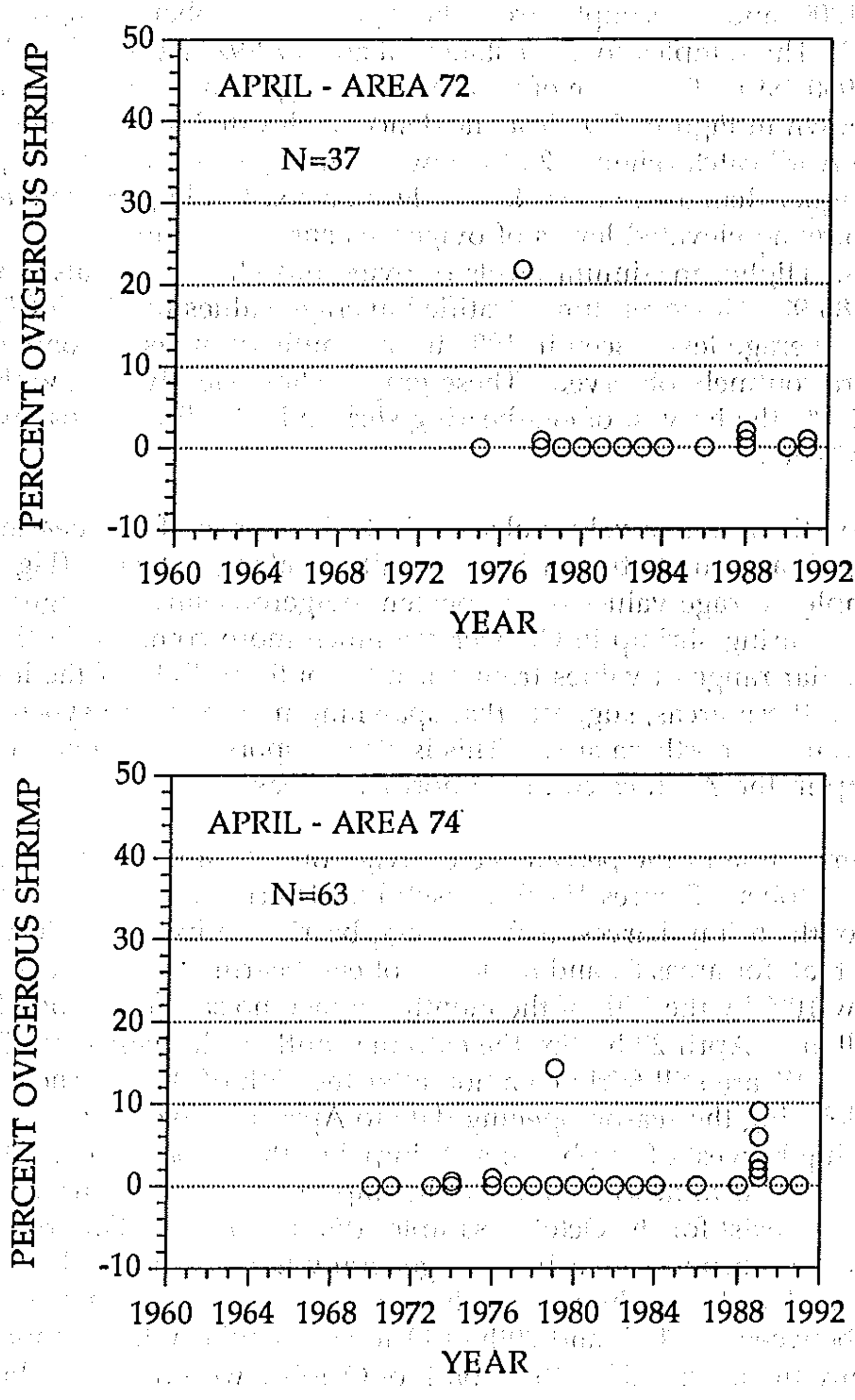


Figure 2. The percentage of egg-bearing shrimp in April samples from statistical areas 72 and 74, for the years 1960-1991 (repeated values, especially zeroes, are superimposed).

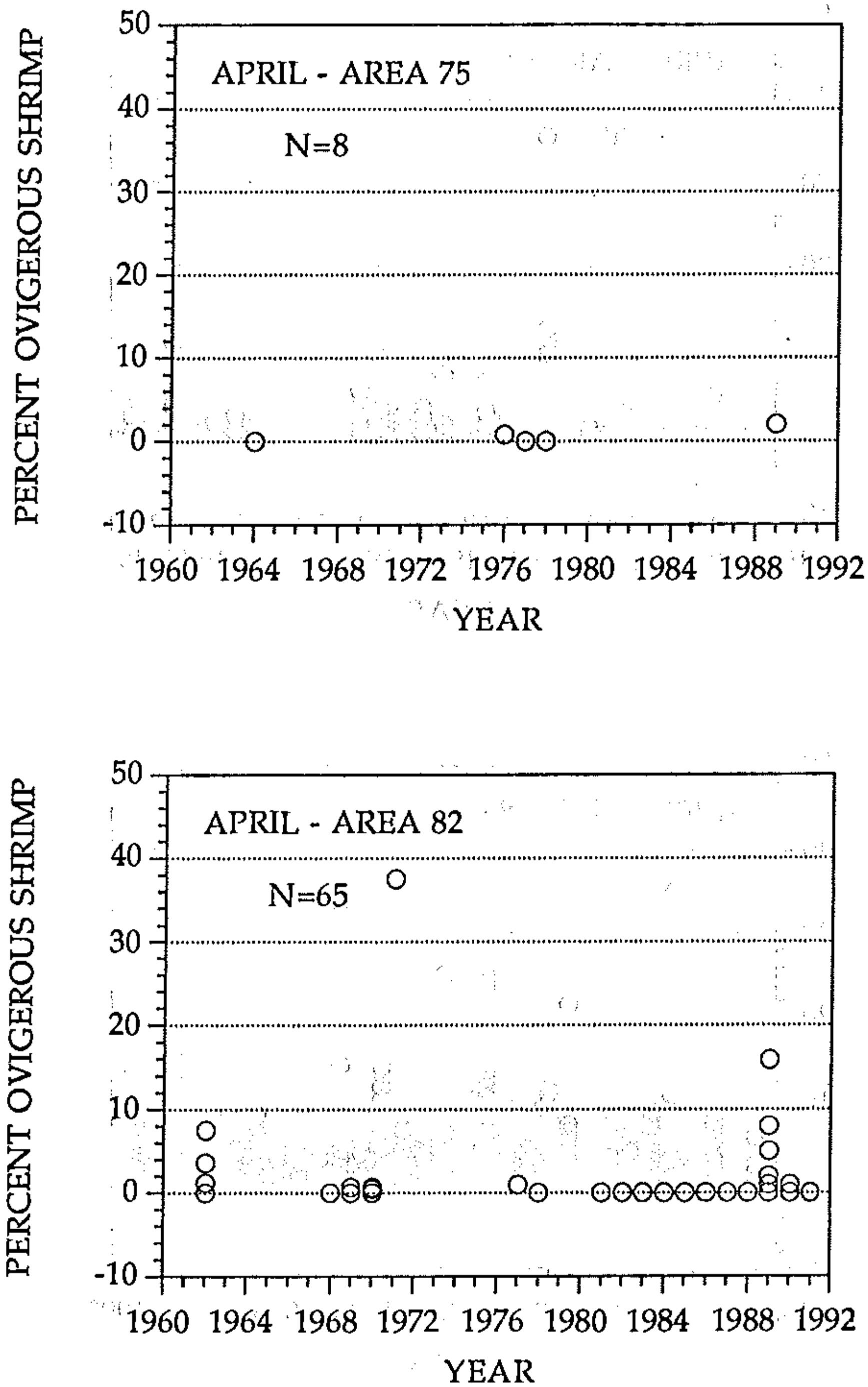


Figure 3. The percentage of egg-bearing shrimp in April samples from statistical areas 75 and 82, for the years 1960-1991 (repeated values, especially zeroes, are superimposed).

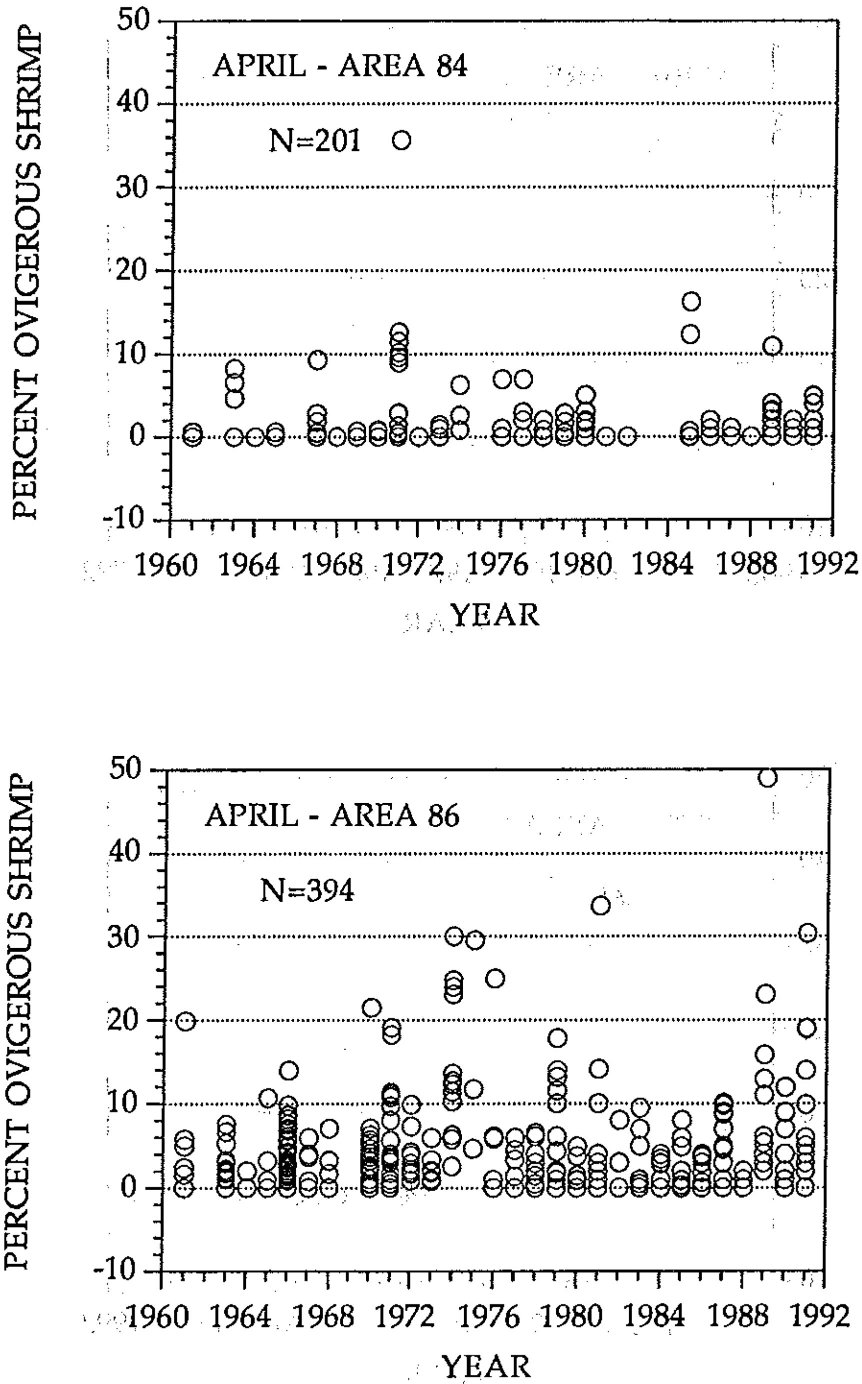
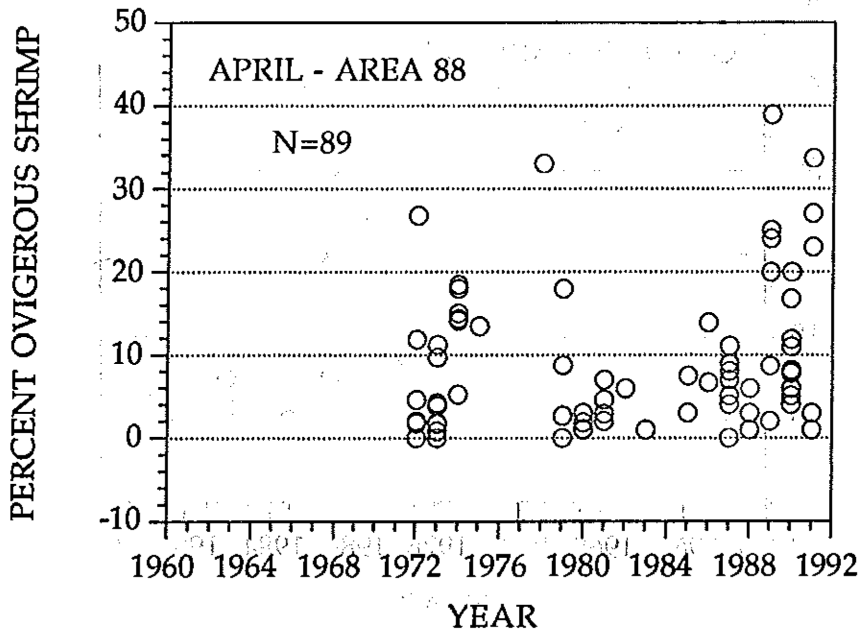


Figure 4. The percentage of egg-bearing shrimp in April samples from statistical areas 84 and 86, for the years 1960-1991 (repeated values, especially zeroes, are superimposed).



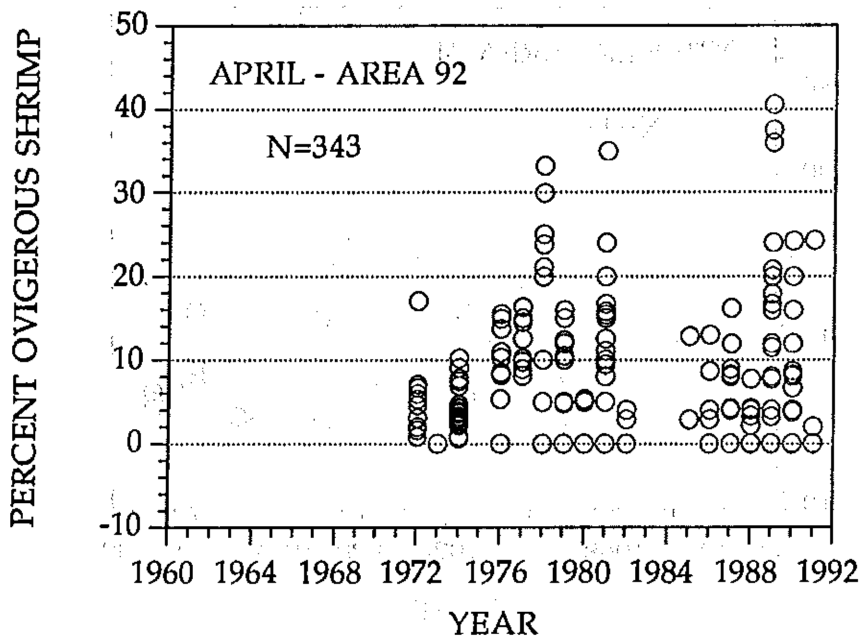
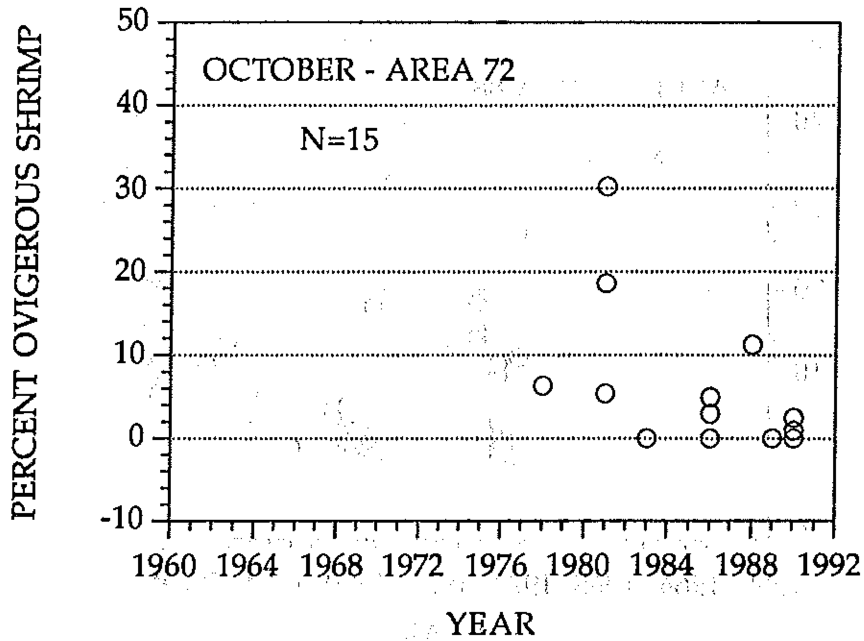


Figure 5. The percentage of egg-bearing shrimp in April samples from statistical areas 88 and 92, for the years 1960-1991 (repeated values, especially zeroes, are superimposed).



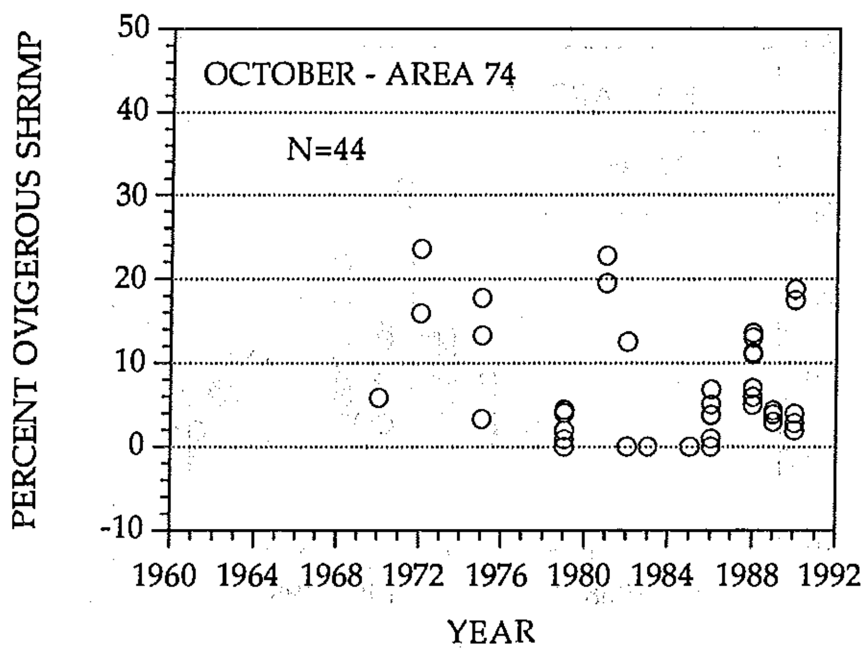
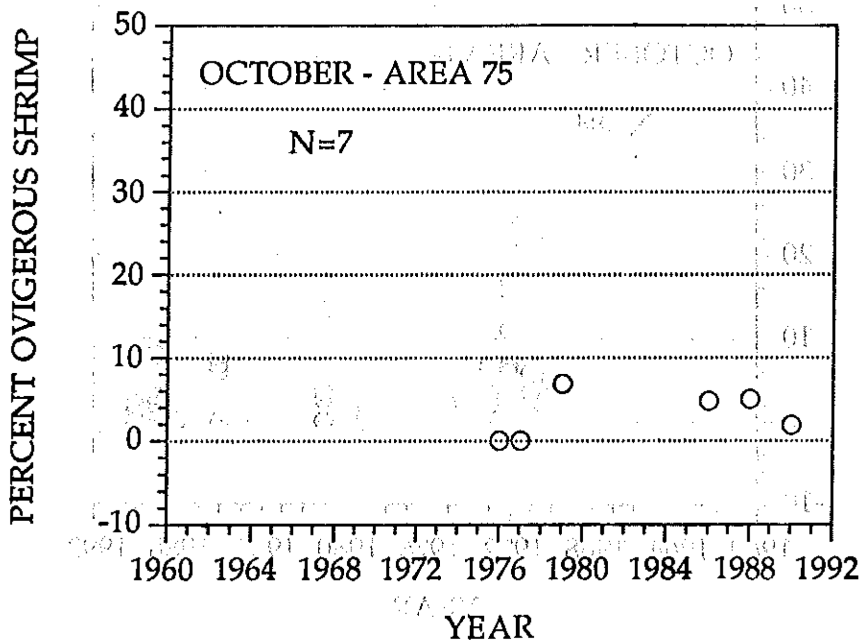


Figure 6. The percentage of egg-bearing shrimp in October samples from statistical areas 72 and 74, for the years 1960-1991 (repeated values, especially zeroes, are superimposed).



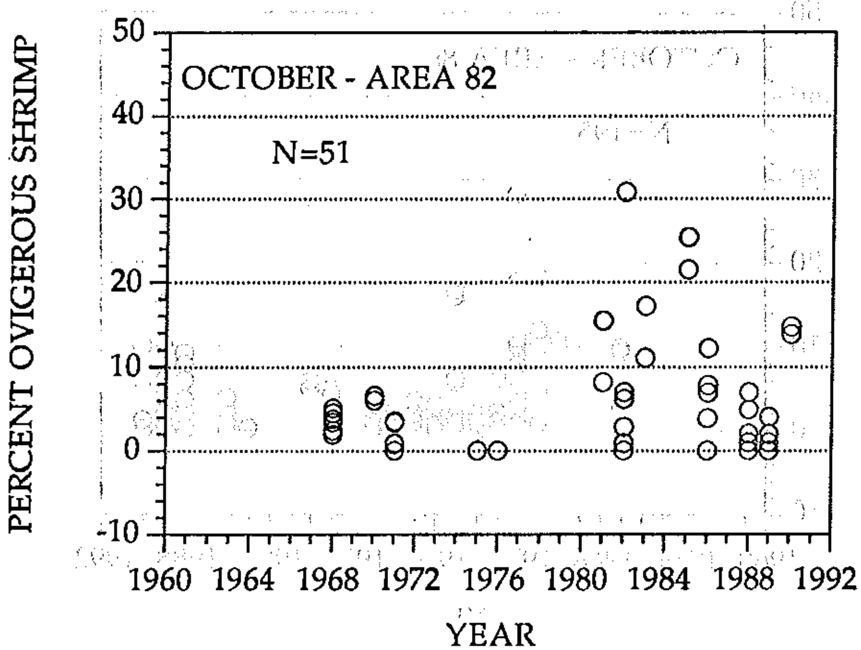
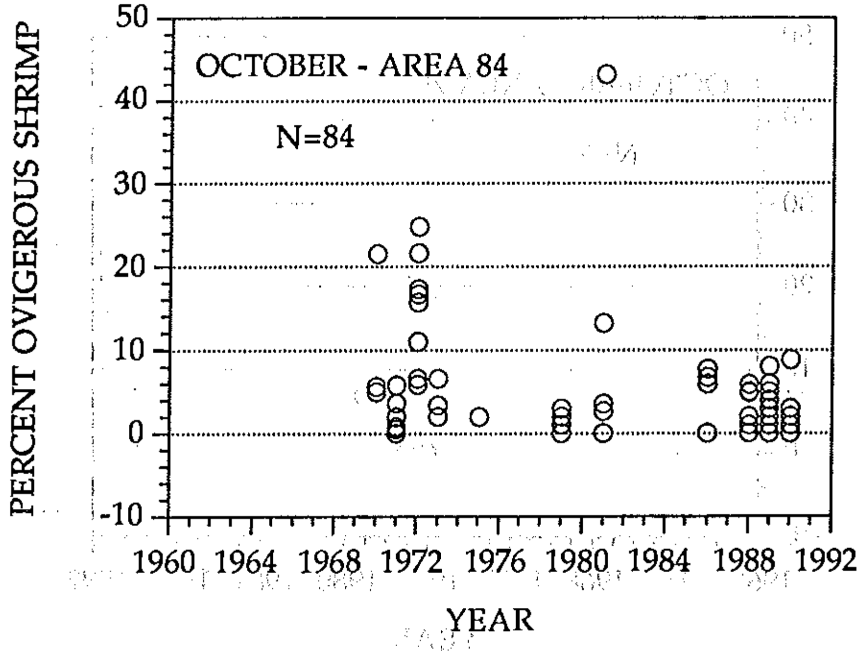


Figure 7. The percentage of egg-bearing shrimp in October samples from statistical areas 75 and 82, for the years 1960-1991 (repeated values, especially zeroes, are superimposed).



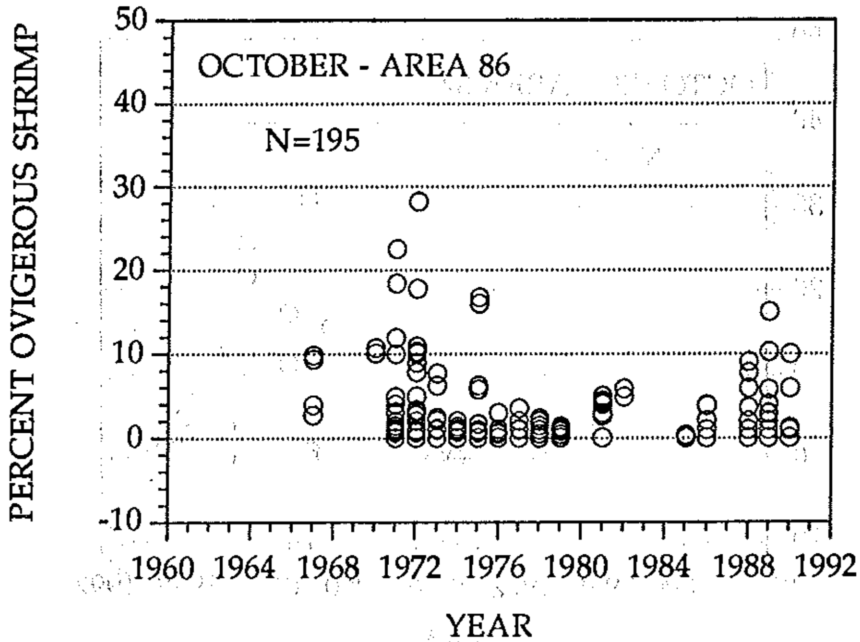


Figure 8. The percentage of egg-bearing shrimp in October samples from statistical areas 84 and 86, for the years 1960-1991 (repeated values, especially zeroes, are superimposed).

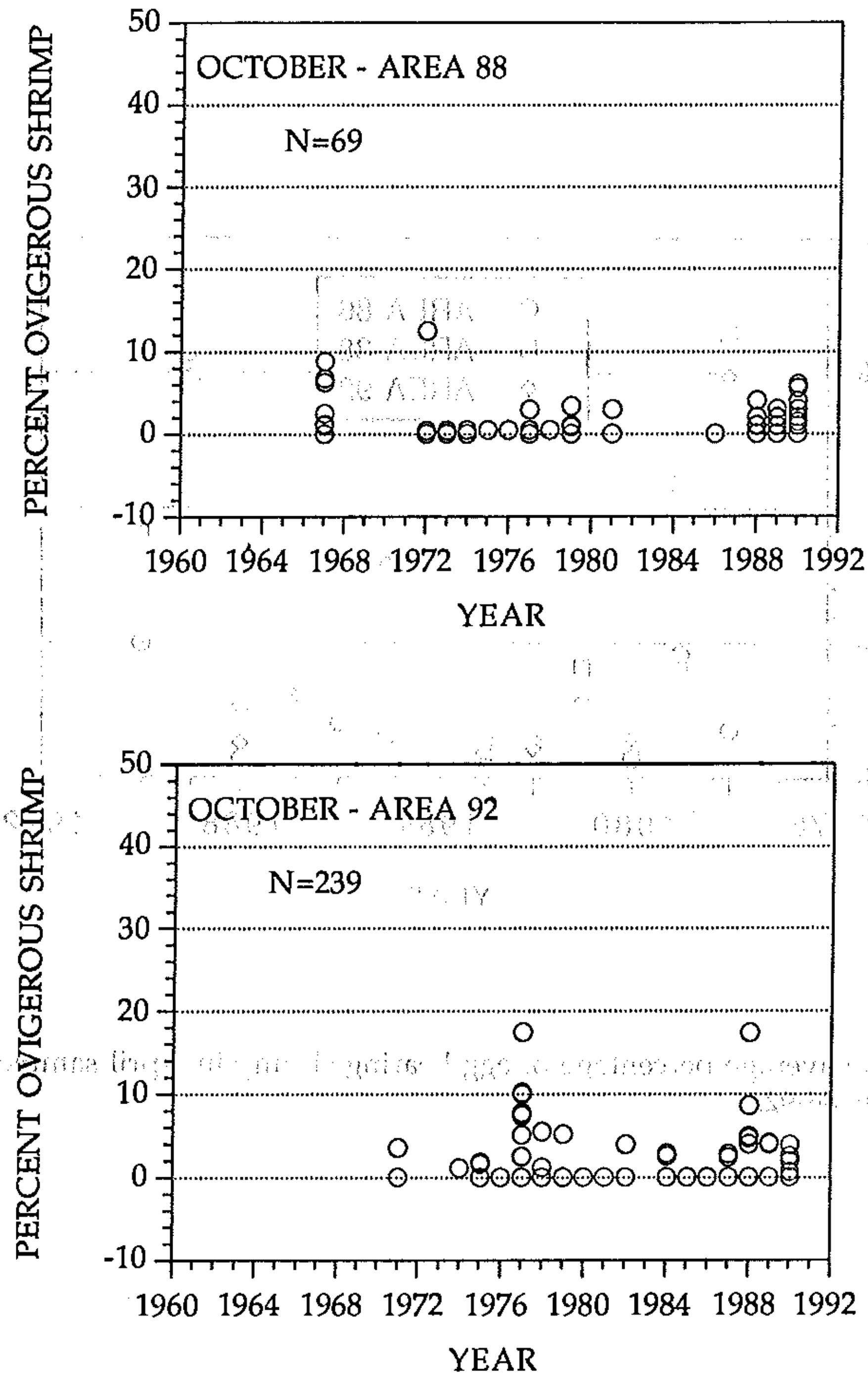


Figure 9. The percentage of egg-bearing shrimp in October samples from statistical areas 88 and 92, for the years 1960-1991 (repeated values, especially zeroes, are superimposed).

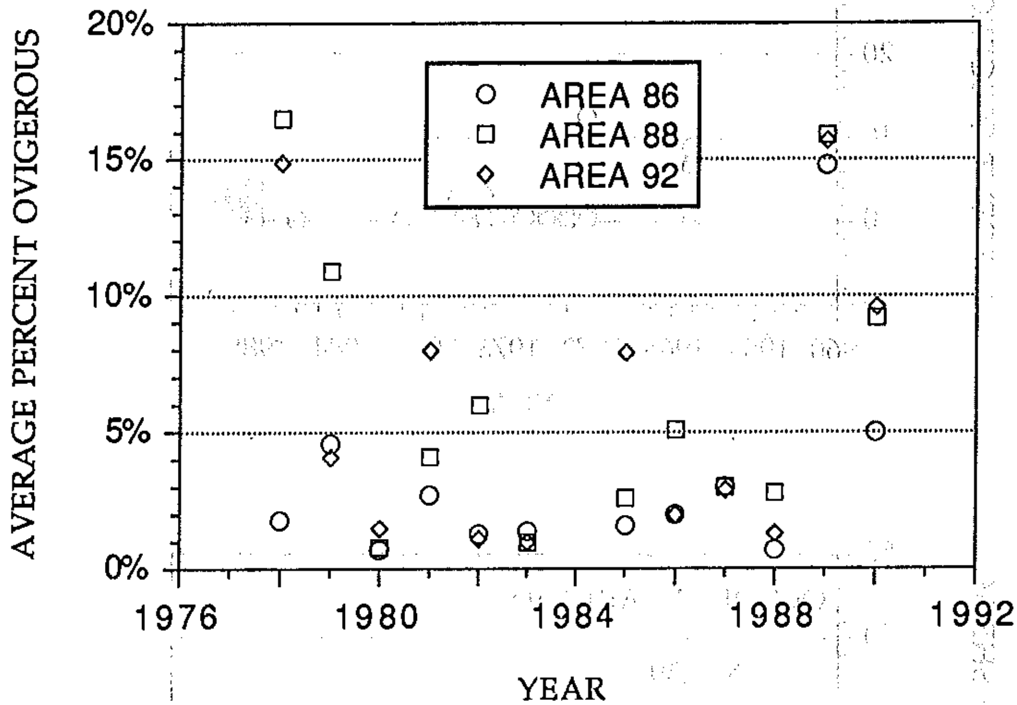
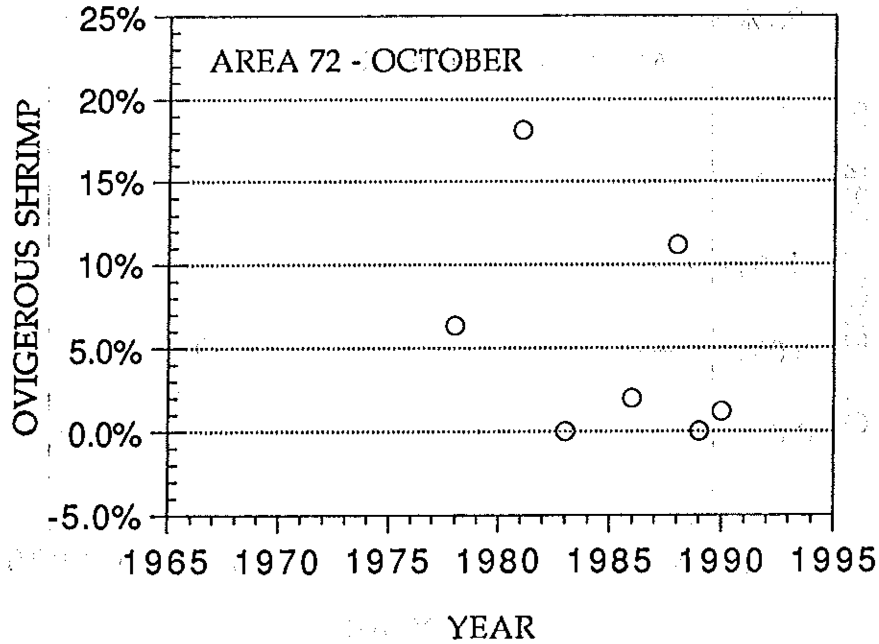


Figure 10. The average percentage of egg-bearing shrimp in April samples from statistical areas 86-92.



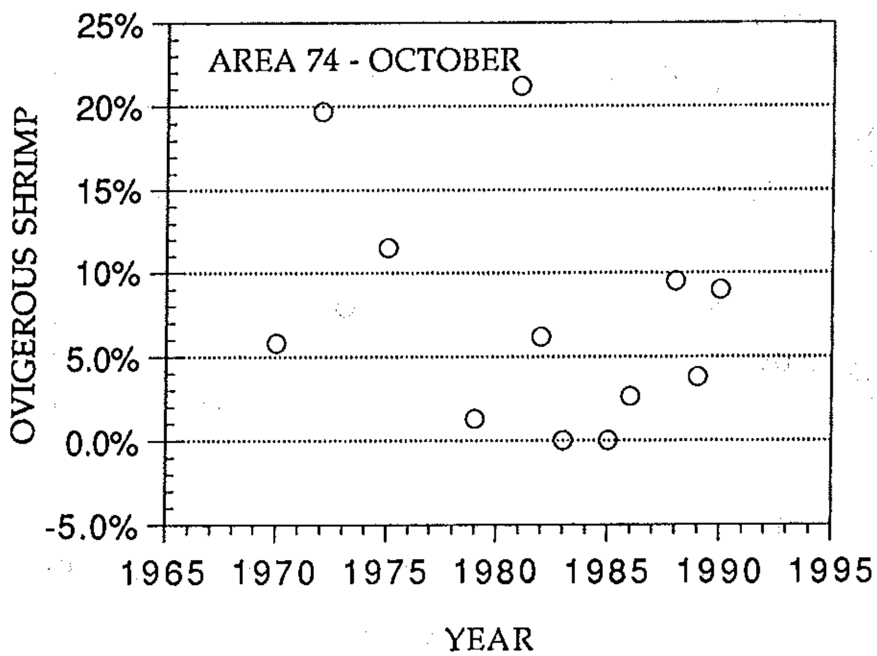


Figure 11. The average percentage of egg-bearing shrimp in October samples from statistical areas 72 and 84.

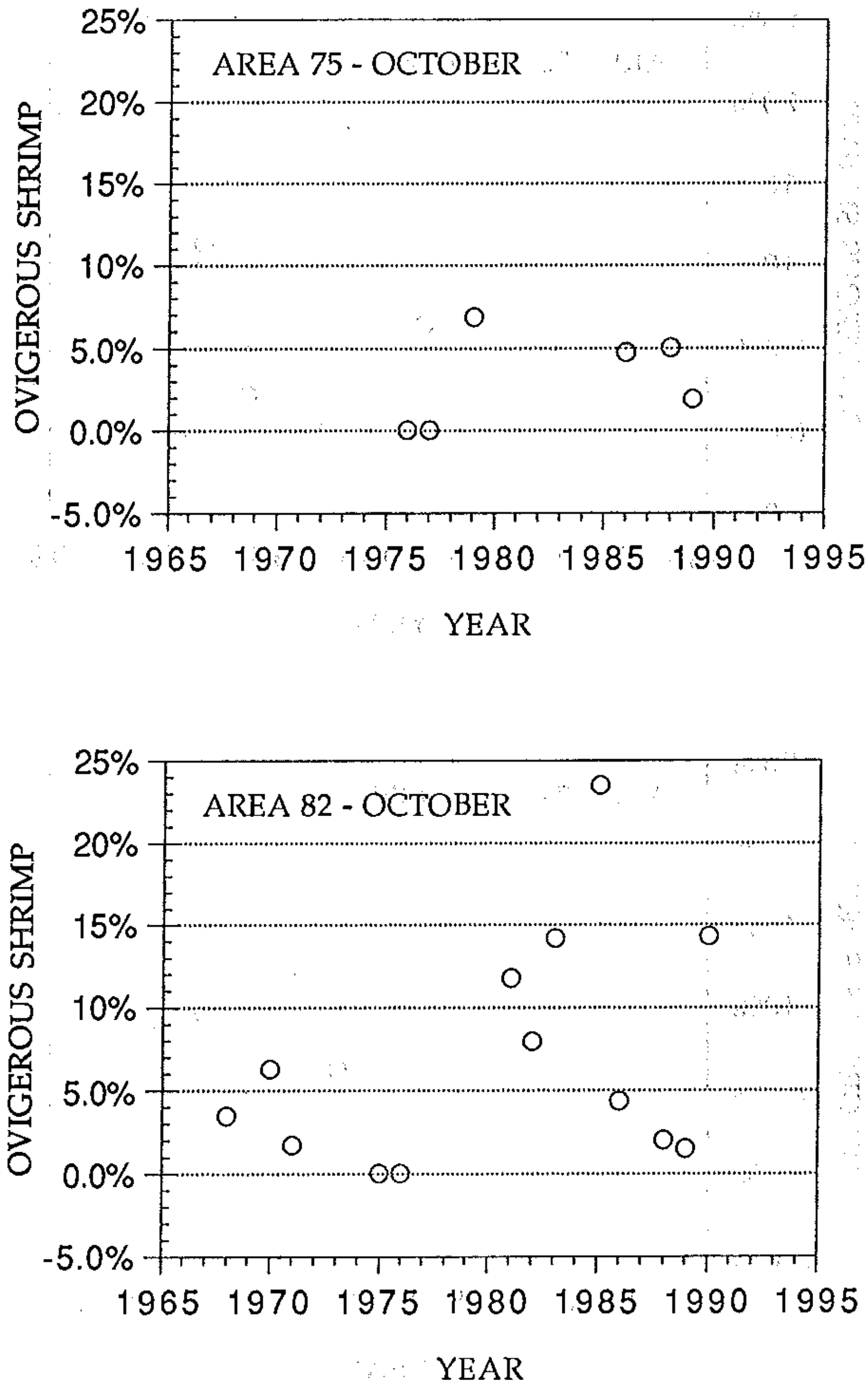
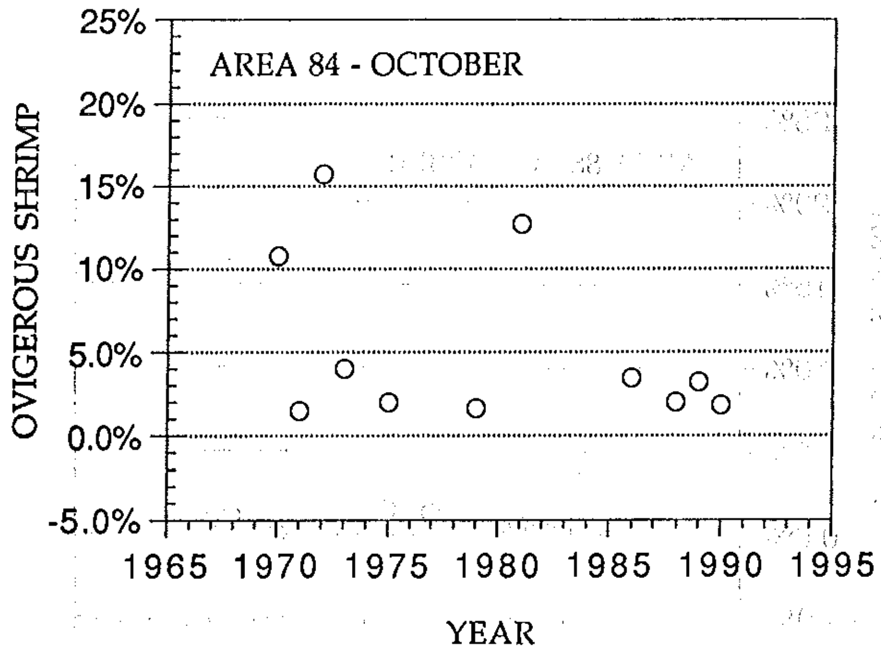


Figure 12. The average percentage of egg-bearing shrimp in October samples from statistical areas 75 and 82.



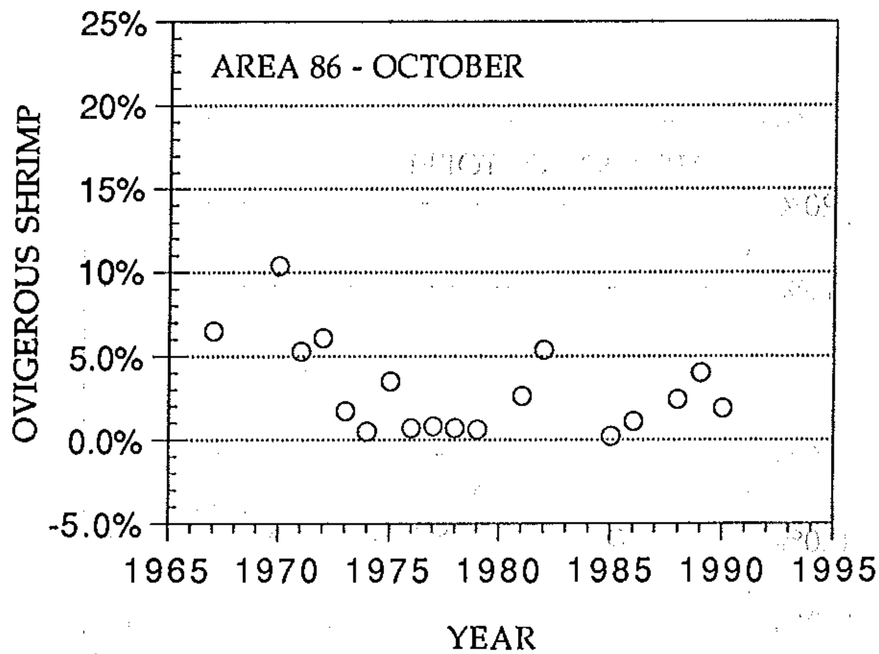
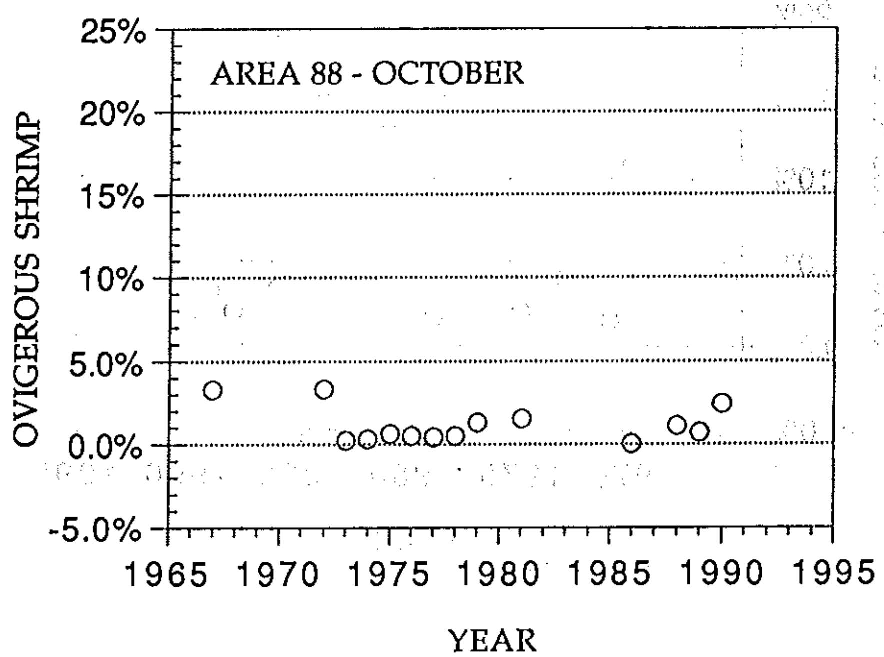


Figure 13. The average percentage of egg-bearing shrimp in October samples from statistical areas 84 and 86.



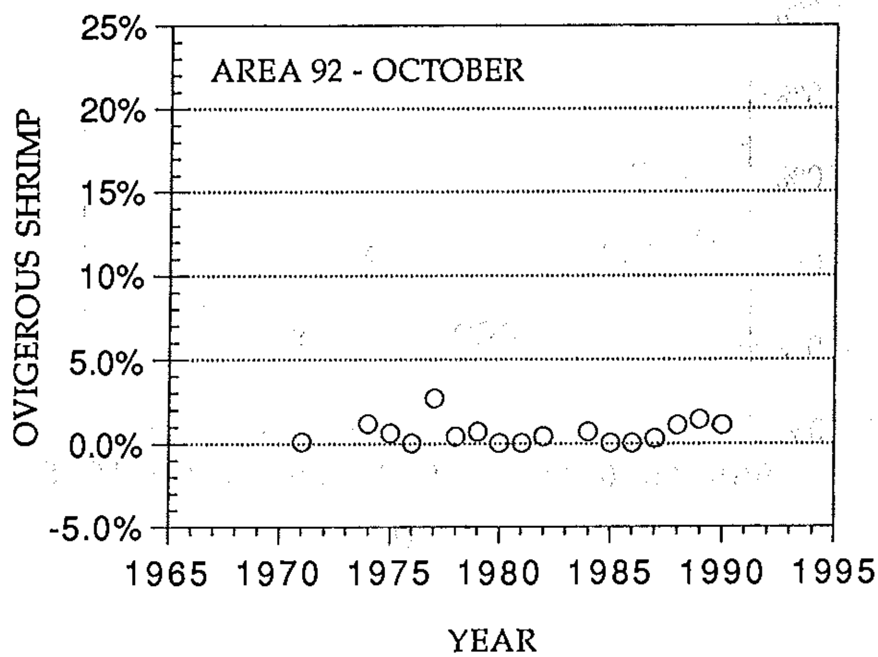
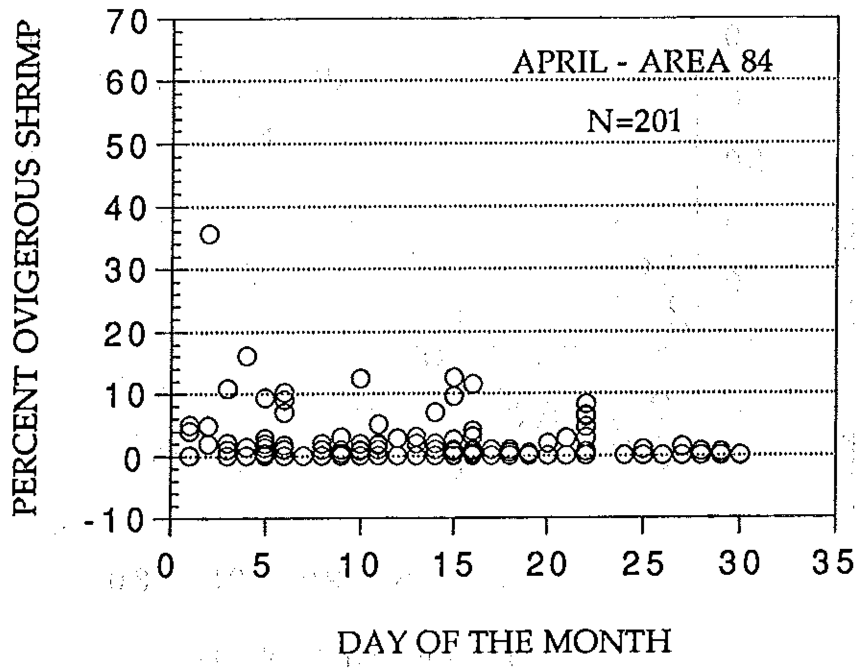


Figure 14. The average percentage of egg-bearing shrimp in October samples from statistical areas 88 and 92.



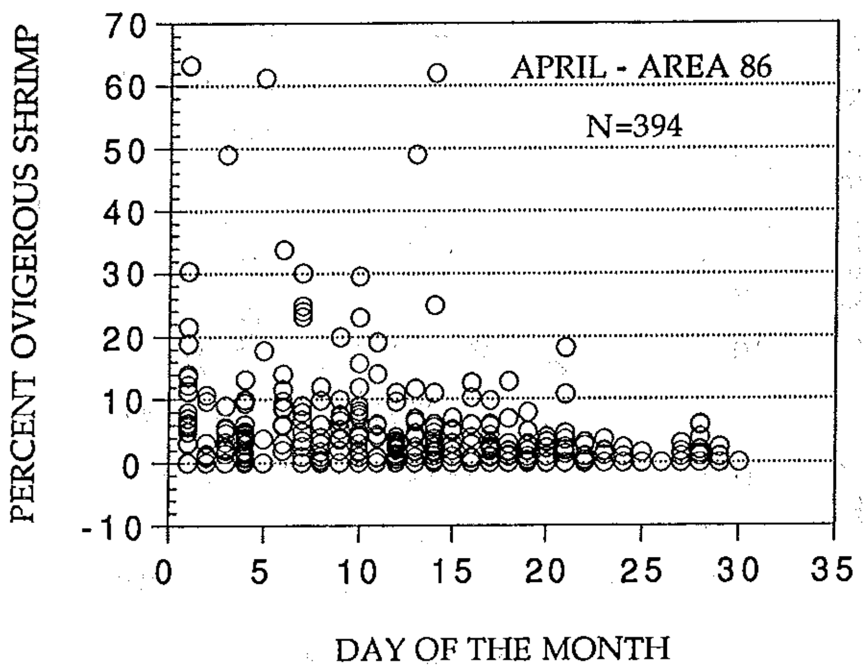
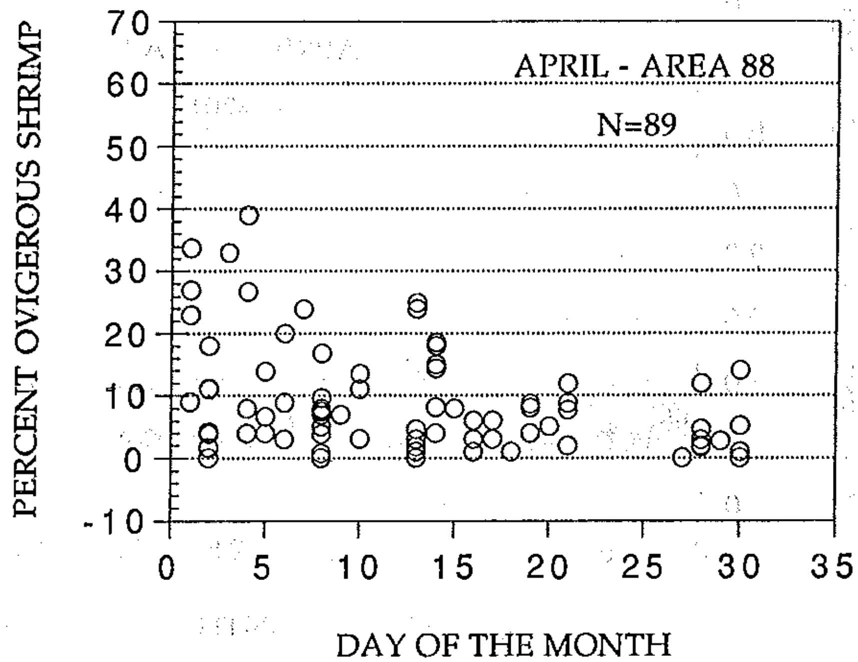


Figure 15. The percentage of egg-bearing shrimp in April samples from statistical areas 84 and 86, by sample date.



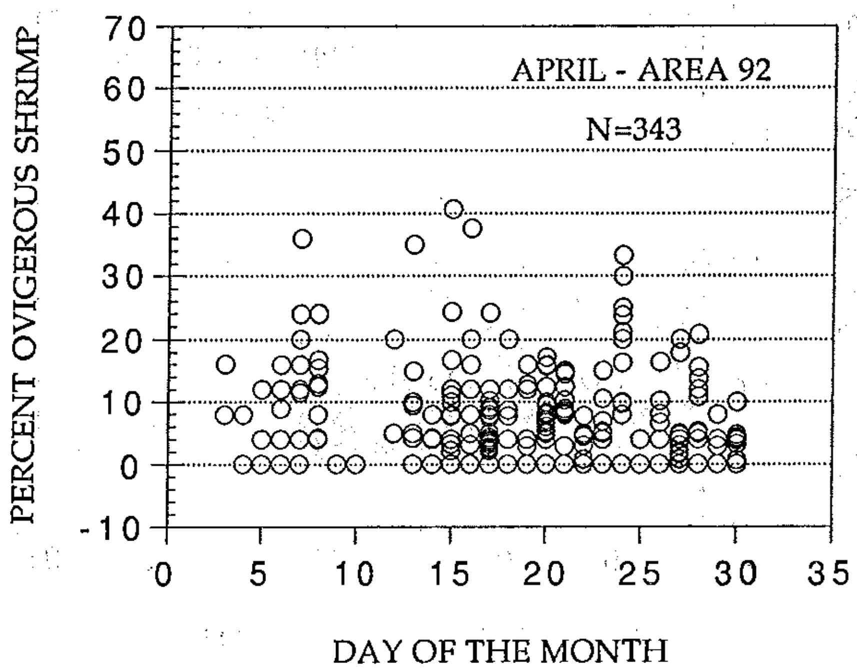
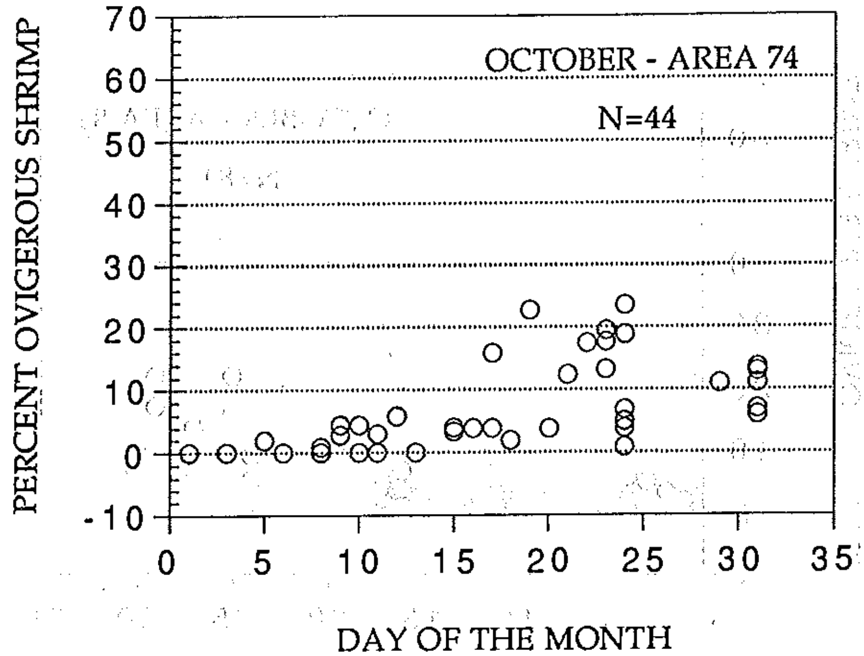


Figure 16. The percentage of egg-bearing shrimp in April samples from statistical areas 88 and 92, by sample date.



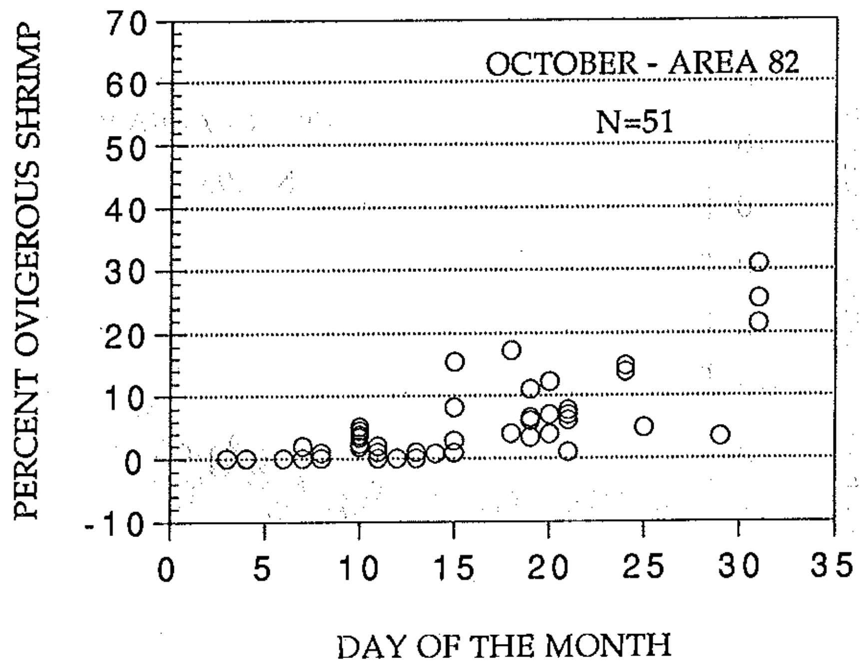
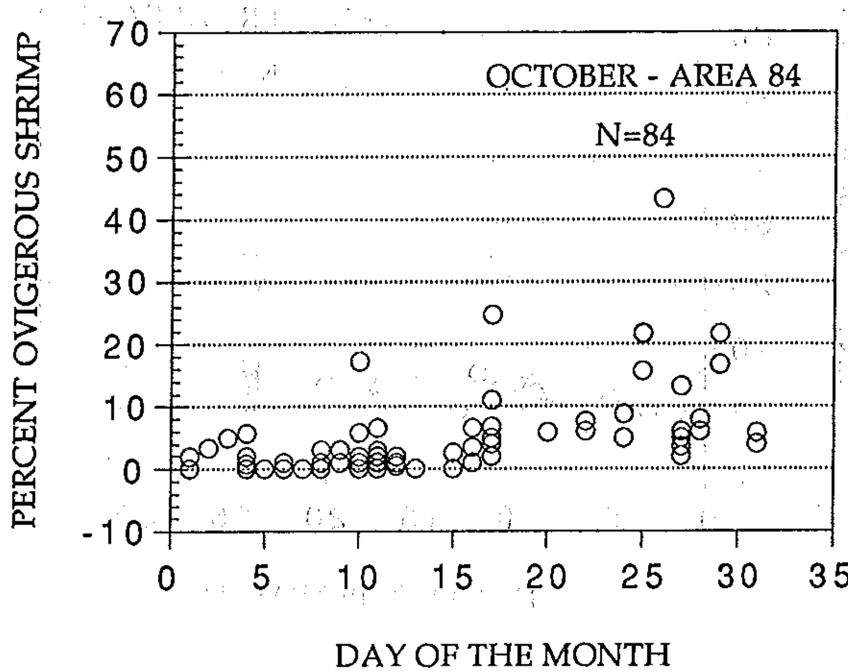


Figure 17. The percentage of egg-bearing shrimp in October samples from statistical areas 74 and 82, by sample date.



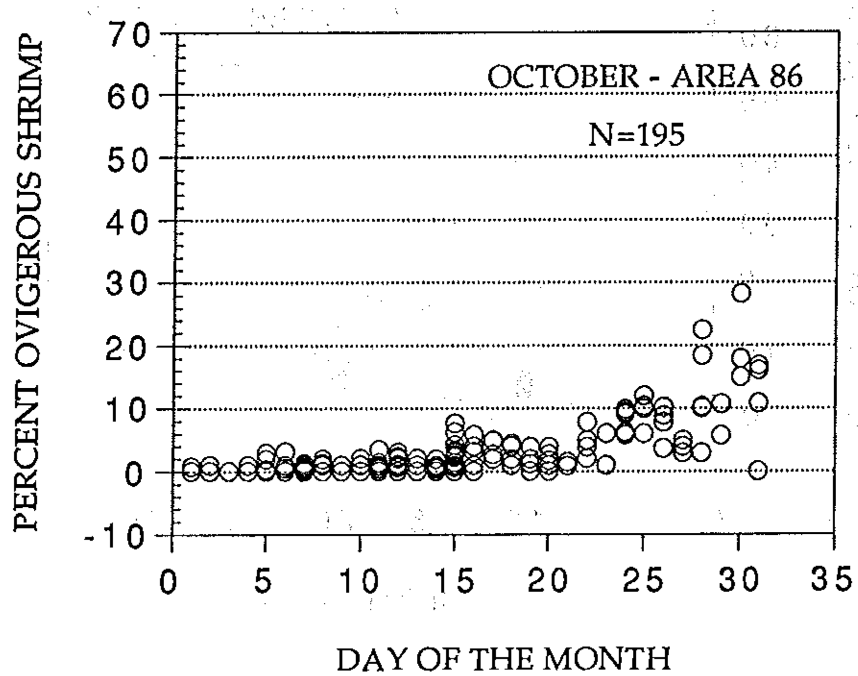
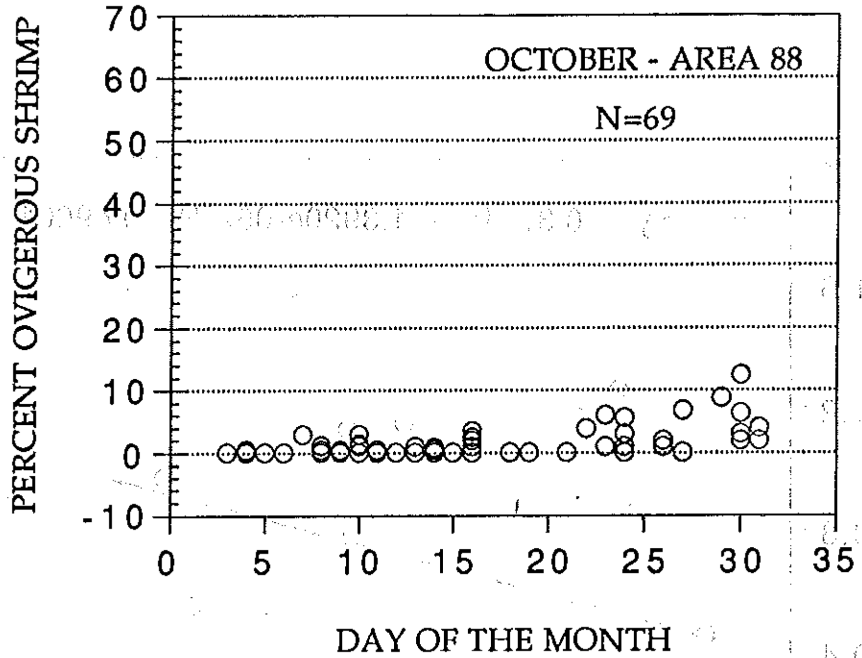


Figure 18. The percentage of egg-bearing shrimp in October samples from statistical areas 84 and 86, by sample date.



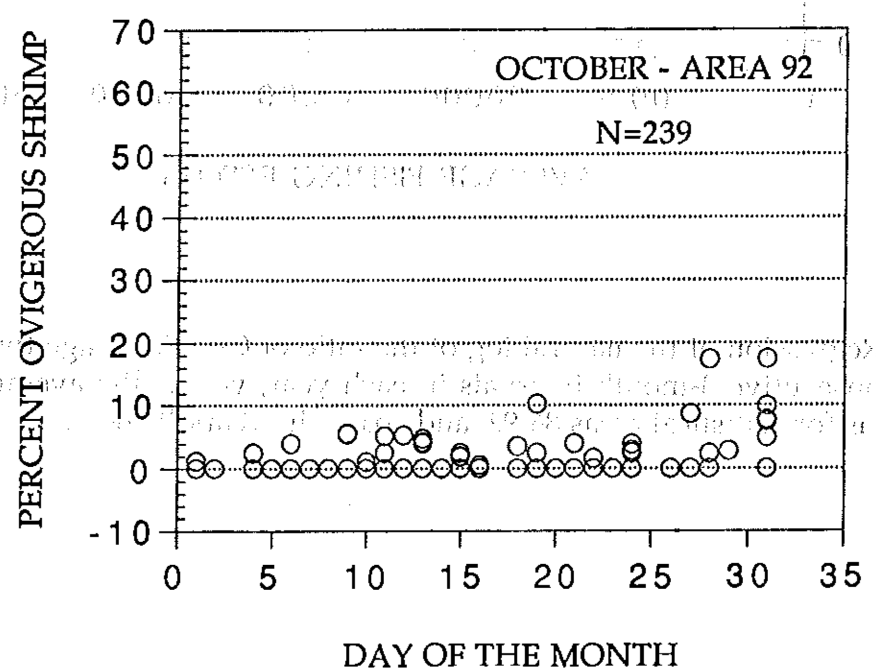


Figure 19. The percentage of egg-bearing shrimp in October samples from statistical areas 88 and 92, by sample date.

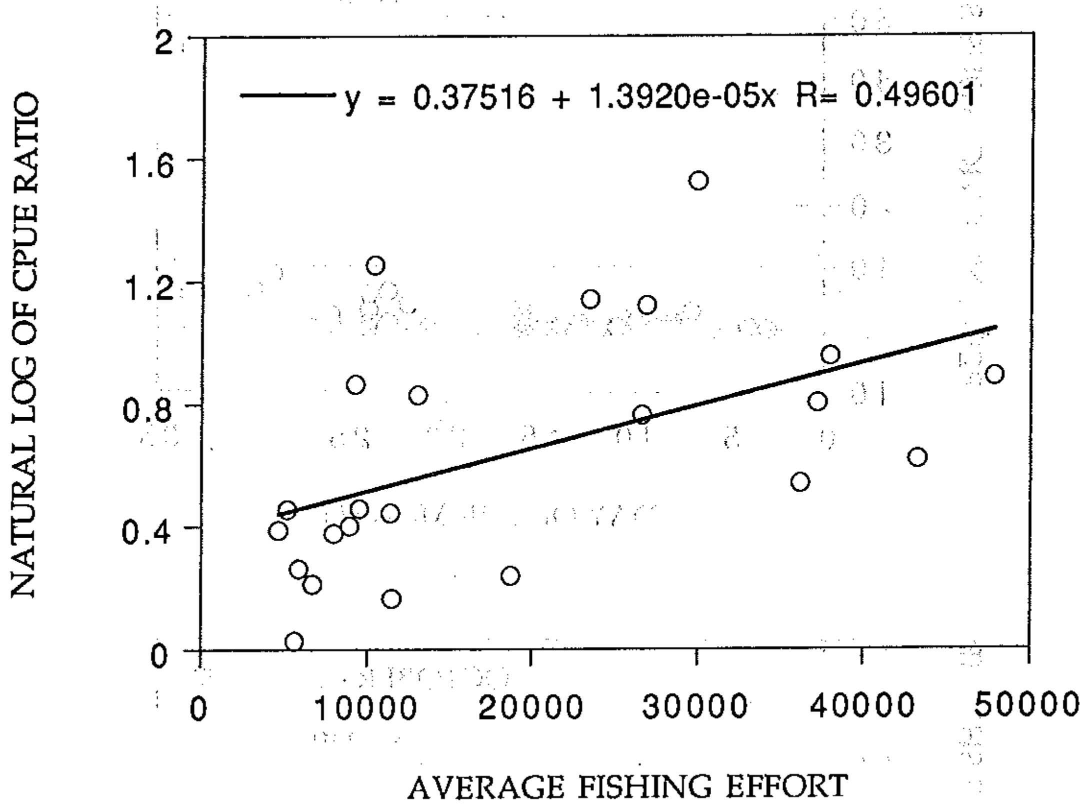


Figure 20. Regression of the natural log of the ratio of CPUE, for age two shrimp, from two consecutive 3-month intervals in each year, versus the average fishing effort. Data is for statistical areas 86-92, and spans the years 1966-89.

Table 1. Results of estimating the catchability coefficient for pink shrimp using linear regression and CPUE and effort data (Figure 20). Dependent variable is the natural log of the ratio of CPUE, for age two shrimp captured in Areas 86-92, from two sequential three month periods, for each of the years 1966-89.

Parameter	Coefficient	Standard Error	F value	p>F	R^2
Intercept	0.375				
q	0.00001392	.00000532			
Full Model			6.854	.0161	0.246

results in an average monthly rate of natural mortality of about 0.125. This is well within the range of estimates reported by Gotshall (1972). The population estimates derived from q and April CPUE for age two shrimp, are shown in Table 2. The CPUE-derived estimates are generally higher than the virtual population estimates for the same cohort, and display a similar pattern (Figure 21). This suggests that the catchability coefficient has not been grossly over-estimated. Accordingly, the female population estimates (Table 2) are probably not far below the true levels. This test however, is not sensitive to modest over-estimation of q, up to about 30%. More severe over-estimation would cause considerable overlap of the CPUE-derived and virtual population estimates, and would signal that q is too high. The female population estimates could, therefore, be under by up to 30%. Conversely, the population estimates may well exceed the true values. If so, then our estimates of the percentage of the female population harvested prior to larval release will be conservative.

The harvest of egg-bearing shrimp in April is shown, as a percentage of the total estimated female population, in Figure 22. Three of the 12 years show greater than 5% of the female population being caught before completing larval release, with two years exceeding 15%. Adjusting these data for over-estimation by up to 30% would not change these results dramatically. Three out of 12 years would still exceed 4%, with 2 years exceeding 11%. These estimates are for areas 86-92 only. In previous work, areas 82-92 have been considered a stock unit. Areas 86-92 produced, on average, 55% of the annual catch for the larger stock unit, over the years 1985-90. Accordingly, the impact estimates could be multiplied by 0.55 to give a rough estimate of the impact on the whole stock unit. This approach assumes, however, that large scale interchange of pelagic larvae occurs between northern and southern fishing areas. The validity of this assumption is unknown. More troubling, is the suggestion in Figure 22 that the impact on the population in southern areas is increasing. Additional years of data are needed to determine whether the high levels in 1987 and 1989 are part of a trend, or simply some odd years. If April fishing effort increases, impact levels above 5% are likely to become more common.

The data suggest that delaying the start of the fishing season by two weeks to a month could increase the average reproductive output of the pink shrimp stock. The Oregon shrimp fishery landed an average of 2.5 million lb of shrimp during the first two weeks of the 1989-91 seasons. This represents roughly 40% of the average landings for the whole month of April, for the same years. Based on a monthly natural mortality rate of .1, roughly 5% of these shrimp would die before the season opened. This figure could be too low, primarily if natural mortality is higher for females immediately following larval release. Assuming this figure is correct, the lost catch would equal about 122,000 lb. At $0.50/lb, the ex-vessel value of this catch is around $60,000. If the season is delayed a full month, the impact on the fishery should be about twice as large. These impact estimates are probably closer to maximum estimates since the foregone catch would be offset considerably by the continued growth of the surviving shrimp.

Table 2. Comparison of shrimp population estimates for Areas [illegible]6-92 combined, 1978-89. Virtual population is the sum of all catches for the cohort at age two and older. Age two population estimate is derived from April CPUE for age two shrimp and catchability coefficient estimate of 0.00001392. Female population estimate is derived from CPUE and estimates of the percentage of female shrimp in April samples.

Year of Catch	Virtual Population Estimate (milions)	Age Two Population Estimate (millions)	Female Population Estimate (millions)
1978	1884.1	4468.8	3452.6
1979	1119.3	1620.2	950.3
1980	536.1	844.4	525.3
1981	503.6	742.6	470.5
1982	1438.2	769.0	195.0
1983	72.3	771.7	269.3
1984	-----	-----	-----
1985	50.3	1022.6	183.5
1986	194.2	1418.4	239.4
1987	384.7	1041.2	162.0
1988	451.8	1061.1	212.9
1989	444.0	2078.7	618.1

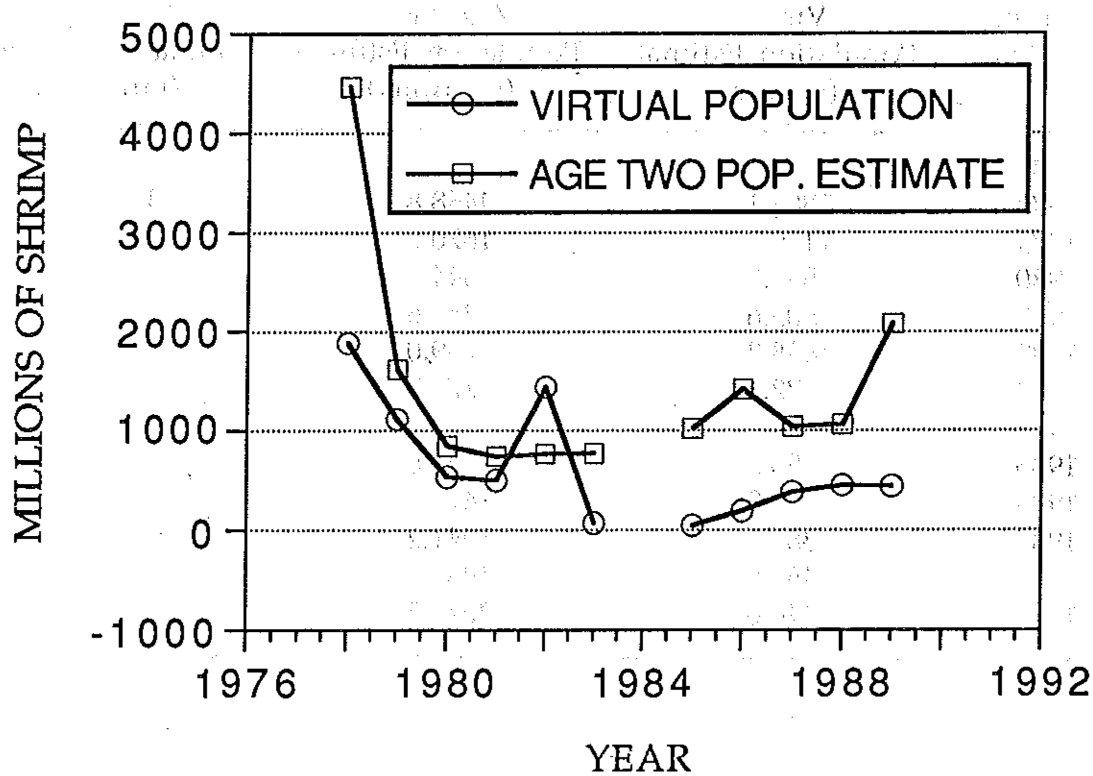


Figure 21. Comparison of shrimp population estimates derived by two different methods. Age two population estimates (circles) are derived from April CPUE data. Virtual population estimates are from summing the catches of age two and three shrimpfrom the same cohort.

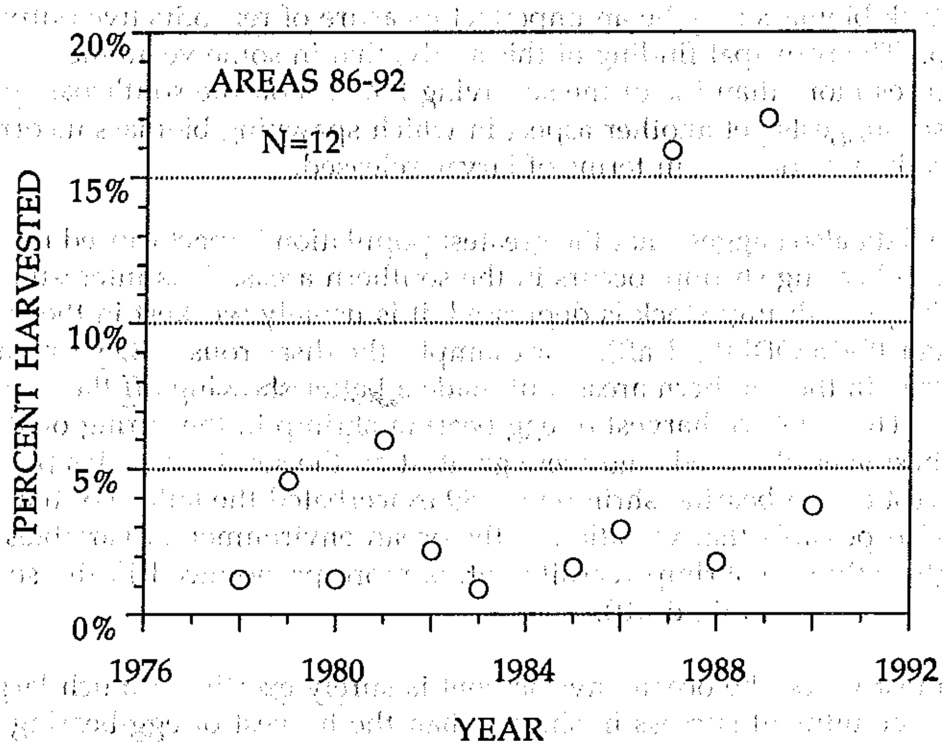


Figure 22. Estimated percentage of female shrimp population captured in April, prior to larval release, 1978-89 (excluding 1984).

After 1978, the pink shrimp fishery was active enough to depress the average shrimp spawning stock biomass to levels roughly 70% below the near-virgin levels that existed previously (Hannah 1991a ODFW, draft). This large reduction in spawning stock has not, as yet, been shown to reduce recruitment. The lack of a proven stock-recruitment relationship for pink shrimp is certainly due to many factors. First, the indices of recruitment and parent stock that have been developed to date are fairly crude. Also, the ocean environment exerts a strong influence on recruitment success (Hannah 1991a ODFW, draft). Evidence for interannual variation in average fecundity at length (Hannah 1991b ODFW, draft) suggests that spawning stock biomass may be an imperfect measure of reproductive output for pink shrimp. The principal finding of this study, that in some years the fishery captures more than 5% of the surviving females on the southcoast prior to larval release, suggests yet another aspect in which spawning biomass incorrectly reflects reproductive output, in terms of larvae released.

These data also suggest that the greatest population impact caused by harvesting egg-bearing shrimp, occurs in the southern areas. It is interesting to note that when the pink shrimp stock is depressed, it is usually weakest in the southern areas (Hannah 1991a ODFW, draft). For example, the disastrous 1989 year class was most depressed in the southern areas, but made a better showing off the coast of Washington. The levels of harvest of egg-bearing shrimp in the spring of 1989 were also the highest ever observed, and were greatest on the southcoast. It's possible that the harvest of egg-bearing shrimp in 1989 exacerbated the failure of that year class. It is also possible that variation in the ocean environmental variables which most strongly influence shrimp recruitment, is more pronounced in the southern areas (Hannah 1991a ODFW, draft).

For most years, the ocean environment is surely exerting a much larger influence on recruitment success in shrimp than the harvest of egg-bearing shrimp. There may be, however, some interaction between harvest of ovigerous shrimp and the effect of the environment. The timing and intensity of the spring transition in coastal currents has been identified as important for recruitment success in pink shrimp (Hannah 1991a ODFW, draft). Specifically, an early and strong transition increases subsequent recruitment. This suggests that larvae which are released early or late may experience different environmental conditions and mortality rates. It is possible that the harvest of egg-bearing shrimp in April, which is often after the spring transition, may be impacting the larvae with the most chance of contributing to recruitment. Conversely, in years with an early spring transition, the larvae which are released early may contribute more heavily to the population, negating any effect from the later harvest of ovigerous females. Extensive larval studies over several years would be required to further investigate this hypothesis.

SUMMARY

1. Due to high natural mortality rates for pink shrimp, the harvest of egg-bearing females in the fall and spring represent fundamentally different impacts on the total reproductive output of the shrimp population. An ovigerous shrimp which escapes harvest in late October is much less likely to survive and release larvae than a similar shrimp which escapes harvest in early April.

2. In October, average levels of egg-bearing shrimp are higher in the northern areas (72-84) than in the south (86-92), although some samples with elevated levels are found in all areas, in many years. In April, egg-bearing females are much more common in areas 86-92. Samples with elevated levels of egg-bearing shrimp are uncommon in the northern areas in April. The data suggest that spawning may be earlier, and more synchronous in the northern areas.

3. In roughly 3 out of twelve years from 1978-89, the shrimp fishery in areas 86-92 harvested more than 5% of the female shrimp population before they completed larval release. In two of the twelve years studied, the impact exceeded 15%. These impact estimates could be high by as much as 30%, but are unlikely to be any more deviant on the high side. The estimates are constructed conservatively, and the actual impact could be higher. Although the effect of this harvest on subsequent recruitment is unknown, it could be confounding attempts to define a stock-recruitment relationship for pink shrimp. There are some indications that, at least in 1989, the catch of egg-bearing shrimp in April could have exacerbated the year class failure which occurred.

4. To eliminate all harvest of egg-bearing shrimp, a May 1 to September 30 shrimp season would be required. Most of the harvest, however, could be eliminated with a season opening on April 15th or 20th and closing on October 15th. Some impact would still occur in the extreme southern harvest areas, in April. If the focus is on eliminating most of the impact on the stock's reproductive output, only changes in the season opening date are required.

LITERATURE CITED

Gotshall, D.W. 1972. Population size, mortality rates, and growth rates of northern California ocean shrimp *Pandalus jordani*, 1965 through 1968. Calif. Dept. Fish and Game, Fish Bull. 155:1-47.

Hannah, R.W. and S.A. Jones. 1991a. Fishery induced changes in the population structure of pink shrimp (*Pandalus jordani*). Fishery Bulletin. U.S. 89:41-51.

Paloheimo, J.E. 1961. Studies on estimation of mortalities. I. Comparison of a method described by Beverton and Holt and a new linear formula. J. Fish.

Res. Board Can. 12: 447-450.

Ricker, W.E. 1975. Computation and interpretationn of biological statistics of fish populations. Fish. Res. Board Can., Bull. No. 191. 382 p.