FILE REPORT - PINK SHRIMP FECUNDITY STUDIES 12/11/91

by Robert W. Hannah

INTRODUCTION

Maintaining an adequate level of parent stock to ensure future recruitment is, perhaps, the primary goal of fishery management. Ultimately, this endeavor is actually aimed at maintaining the reproductive output of the stock, more appropriately expressed in terms of the production of viable eggs or larvae. To accomplish this goal, managers need to know not only how fishing influences the adult spawning stock, but also about effects on sex composition of the population, age-specific average fecundity, and egg size or larval condition. In the case of pink shrimp (*Pandalus jordani*), we have crude estimates of the spawning stock. We also have sex composition estimates that are accurate enough to show that these protandric hermaphrodites are very effective at altering the age of sex change, subsequently acheiving a roughly balanced sex composition in most years (Charnov et al 1976, Hannah and Jones 1991). This capacity is very impressive, considering that the stock experiences heavy, size-selective fishing pressure. Unfortunately, much less is known about how various levels of spawning stock translate into actual total reproductive output for pink shrimp.

Some work was done in the early years of the fishery to characterize the basic fecundity of pink shrimp. Dahlstrom (1970) presents data from 1964 on the length-fecundity relationship for pink shrimp from northern California, and also asserts that their is no relationship between egg size and carapace length for pink shrimp. A limited amount of data on the length-fecundity relationship is also available from Oregon waters (ODFW unpublished data). While this early data seems to be of high quality, it suffers from several shortcomings when applied to the present day shrimp population. First, overall sample sizes were fairly small, the largest single sample being from only 62 shrimp, with other samples being much smaller. Second, the early samples were almost exclusively age 2 and older shrimp, while the modern day spawning population is composed of a large percentage of age one females. A third problem is that age-specific mean lengths are quite variable and have increased since the early years of the fishery (Hannah and Jones 1991), raising two important questions. First, what effect have changes in growth had on the length-fecundity relationship? Also, when growth is highly variable, how useful is an "average" age-specific fecundity in estimating reproductive output of the stock?

To fully describe the factors effecting variability in the reproductive output of pink shrimp will probably take a long time and require analysis of samples from a wide variety of locations and years. To begin chipping away at this task, in 1989 we began collecting and analyzing samples of egg-bearing pink shrimp as opportunity allowed. This report summarizes progress to date in our ongoing study of the fecundity of pink shrimp.

METHODS

Shrimp for analysis were obtained at sea during "ride-along" trips with commercial shrimpers in 1989 and 1990. Samples of approximately 5 kg were taken directly from the hopper, as soon as the codend was emptied, to minimize any possibility of egg loss. Egg-bearing shrimp from the sample were individually measured (mm carapace length), labeled, and preserved until a set number of shrimp from each 0.5 mm length interval was reached. In 1989, the first five shrimp from each interval were taken. In 1990 we preserved the first ten shrimp from each interval to increase total sample size. At sea, shrimp were preserved in 70% ethanol. After returning from sea the shrimp were fixed for 24 h in 10% formalin and then returned to 70% ethanol for storage. To process each sample all shrimp eggs were first removed from the abdomen and then counted under a dissecting scope or illuminated magnifying lens.

To assess the influence of egg location on egg size we measured the length and width of 10 eggs from the anterior, mid and posterior sections of the abdomen for three shrimp ranging in size from 18.7 to 22.7 mm carapace length. We used a two factor ANOVA to compare egg length and width from the three regions for the three shrimp. To assess the relationship between carapace length and egg size we measured egg length and width for 20 randomly selected eggs from 20 shrimp of various sizes and combined these measurements with those from the previous three shrimp. The scattergrams of egg size versus carapace length were then inspected for evidence of a relationship, and tested for a significant slope using standard linear regression.

A stepwise process was used to assess the relationship between carapace length and fecundity in this study. First, all available length-fecundity samples, including previous collections, were analyzed graphically to determine the approximate form of the underlying relationship and to determine whether any transformation of the data was needed to stabilize the variance. Next the length-fecundity relationship was fit to each sample using standard linear regression techniques and the 95% confidence intervals for the slopes were compared. Geometric mean regression was also used to estimate the slope of the length-fecundity relationship for each sample. Geometric mean regression is probably the most appropriate method to estimate the functional regression of fecundity on carapace length. Standard linear regression can lead to incorrect conclusions when comparing slopes based on different ranges in the independent variable (Ricker 1975), as is the case in this study. The results of these two analyses were then compared. Finally, analysis of covariance, employing standard regression techniques, was used to test for differences in average fecundity at length, assuming a common slope for the length-fecundity relation. This analysis is only useful however, if the comparisons of slopes using standard and geometric mean regression techniques both suggest no significant differences between samples. Analysis of covariance provides a mean and 95% confidence interval for shrimp fecundity after adjusting all samples to a common average carapace length. This

author knows of no approach which allows for using geometric mean regression methods in conducting an analysis of covariance.

RESULTS

Samples of 115 and 101 gravid female pink shrimp were analyzed from collections made in October 1989 and 1990, respectively. These shrimp originated from Pacific States Marine Fisheries Commission (PSMFC) statistical area 84 (Figure 1), and spanned carapace length ranges of 17.0 to 23.5 and 20.5 to 26.0 mm, respectively. The lack of shrimp below 20.5 mm carapace length in the 1990 samples reflects the failure of the 1989 year class (year of larval release, unless noted). Three other samples are also included in some of the following analyses, for comparative purposes. The earliest sample consists of 35 shrimp collected in November, 1964, and was previously described by Dahlstrom (1970). These shrimp were taken from PSMFC statistical area 92. Another sample consisted of 10 shrimp collected from area 86 in March, just before larval release. The final sample of 62 shrimp was collected using pots in November, 1967, from area 82. These three samples, along with fecundity data for the more southern California populations of pink shrimp, have been analyzed previously by Robinson (1971, ODFW draft).

The results of the analysis of variance comparing egg size and egg location (Table 1) suggest that although there are large differences in egg size between individual shrimp ($p<0.0001$), there is no significant difference in egg width based upon location on the abdomen ($p>0.1221$). The highly significant differences between individual shrimp may be due to variability in the concentration of the initial preservative, which was not stringently controlled, or may be due to natural variation. Additional measurements on fresh specimens are needed to evaluate this hypothesis. There does seem to be a statistically significant difference in egg length ($p<0.0168$), with eggs carried near the front of the abdomen being slightly shorter (Table 1). As a result, for further analysis of the influence of carapace length on egg size in pink shrimp, egg width will be used as the measurement of egg size.

The relationship between carapace length and egg width (Figure 2) shows wide variation in egg size for a given carapace length and no positive relationship between carapace length and egg size. This scattergram actually has a marginally significant ($p<0.04$) negative slope. Since this is a marginal finding, without a simple biological explanation, it will be considered spurious until further confirming measurements can be taken on fresh, rather than preserved, shrimp.

Scattergrams of carapace length versus fecundity for all five samples (Figures 3, 4 and 5) show very little evidence of upward curvature or increasing variance. This suggests that a simple linear relationship between carapace length and fecundity fits these data, rather than the traditional power curve that is used for most fish species. The slope for each of these length-fecundity scattergrams, estimated using both standard and geometric mean regression techniques, is shown

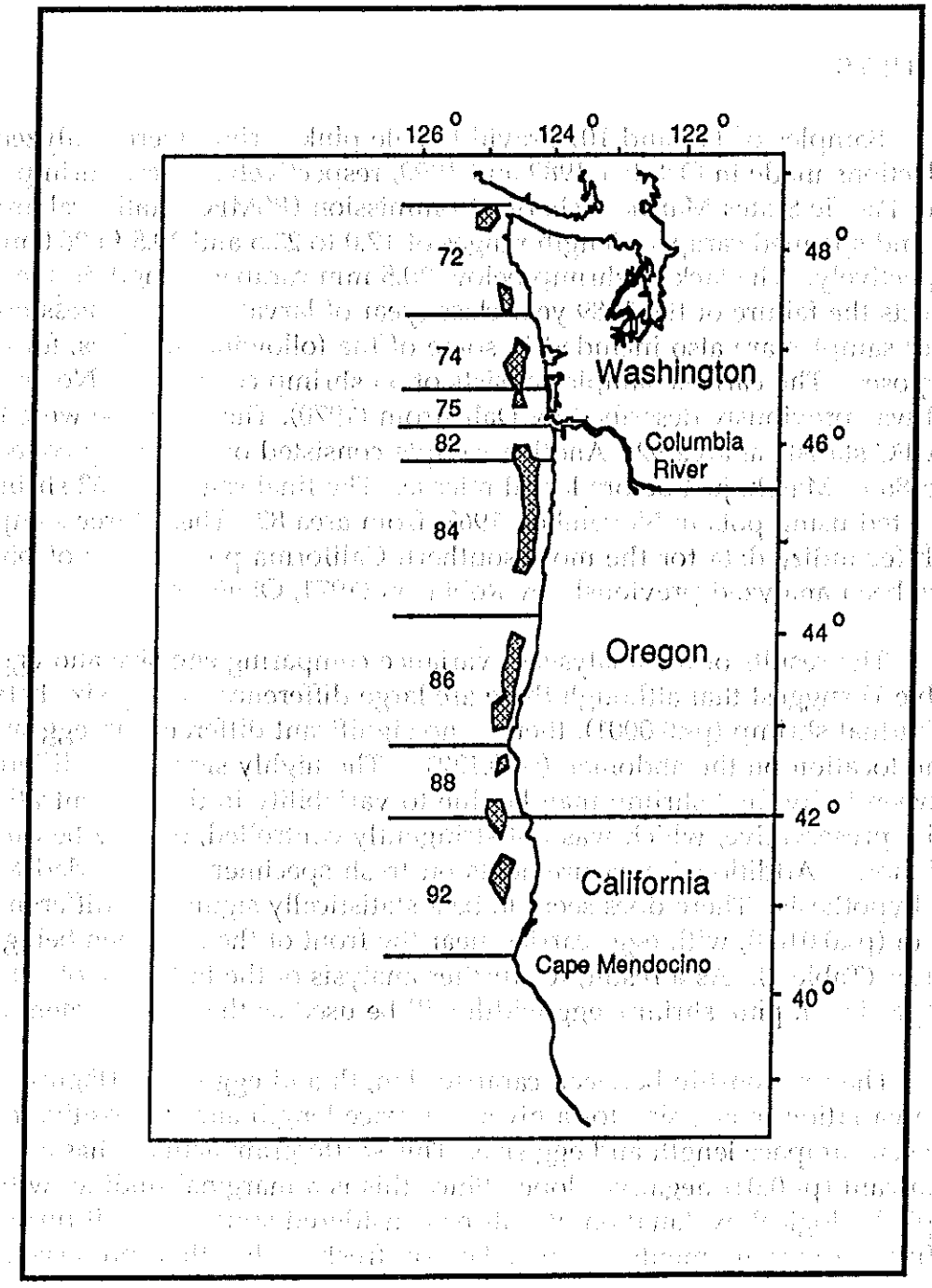


Figure 1. Location of commercial concentrations of pink shrimp *Pandalus jordani* along the U.S. Pacific coast (shaded areas) and PSMFC statistical areas 72-92.

Table 1. Results of analysis of variance for egg length and width versus location on the abdomen for three pink shrimp.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F	p>F
Dependent Variable - Egg Width					
Location	2	0.007	0.004	2.159	0.1221
Individual Shrimp	2	0.278	0.139	85.253	0.0001
Interaction	4	0.011	0.003	1.72	0.1535
Error	81	0.132	0.002		
Dependent Variable - Egg Length					
Location	2	0.028	0.014	4.298	0.0168
Individual Shrimp	2	0.473	0.237	73.691	0.0001
Interaction	4	0.004	0.001	0.339	0.851
Error	81	0.259	0.003		

Means Table - Egg Length			
Shrimp Number	1	2	3
Egg Location on Abdomen			
Front	0.985	0.792	0.912
Mid	0.995	0.837	0.96
Back	1.010	0.840	0.958

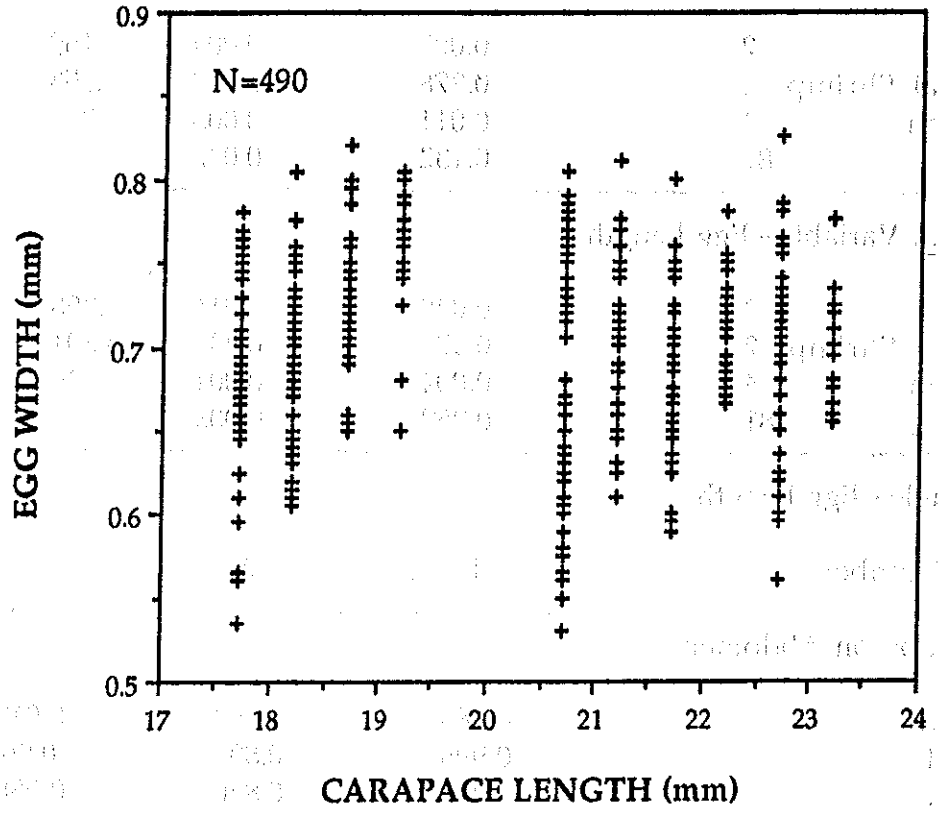


Figure 2. Egg width versus carapace length for pink shrimp collected in 1989.

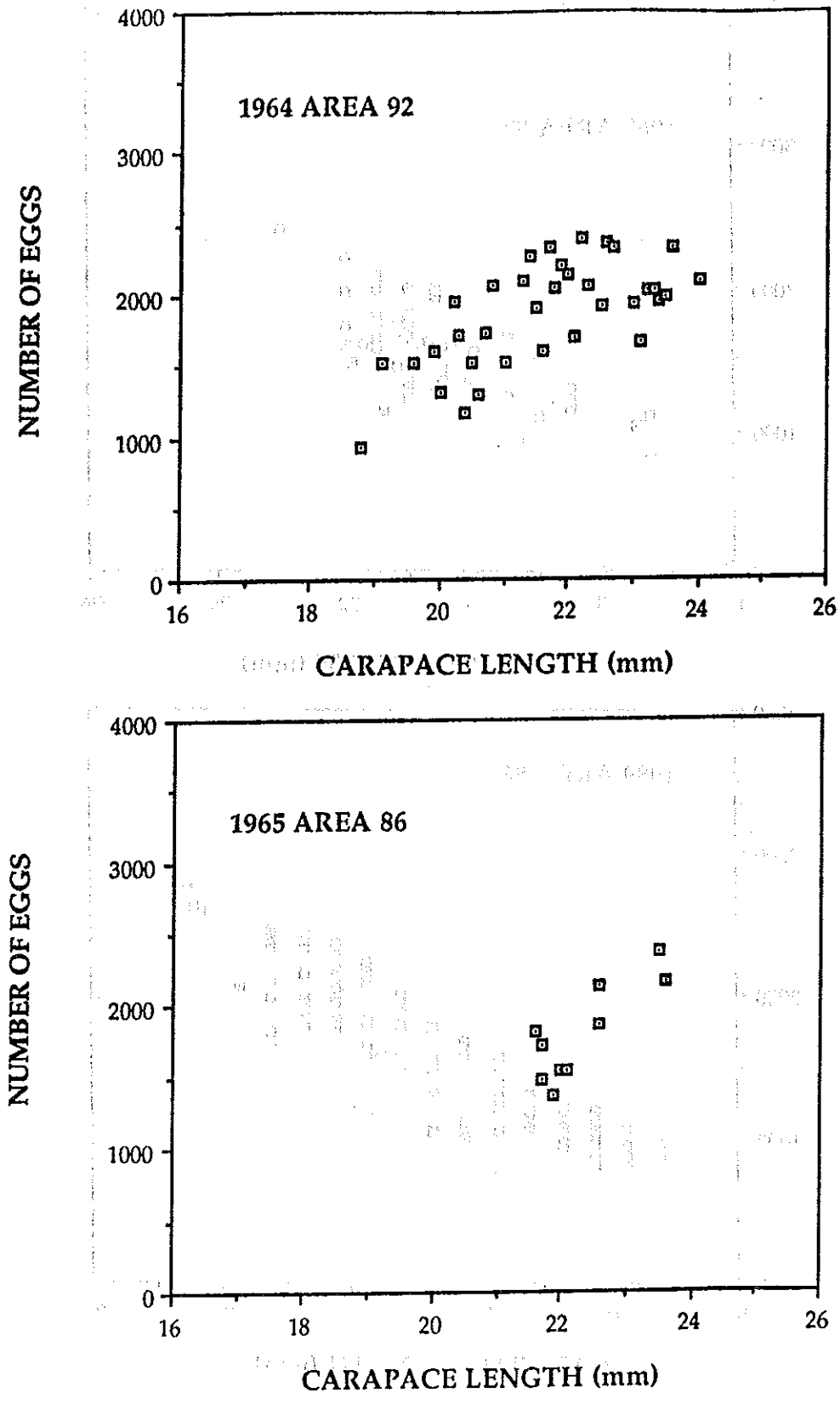


Figure 3. Fecundity versus carapace length for pink shrimp from 1964 (Dahlstrom 1970) and 1965 (Robinson 1971, ODFW draft).

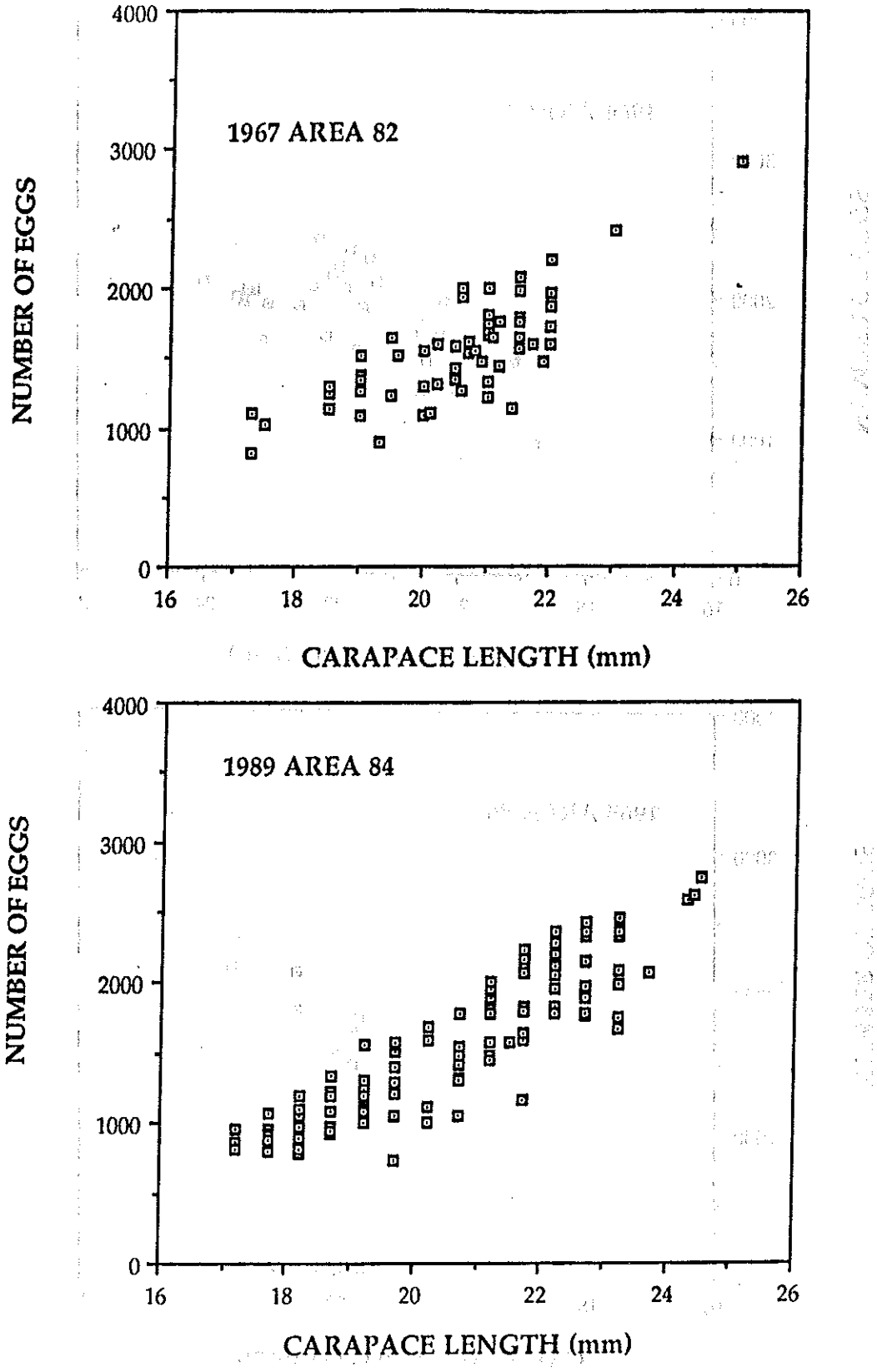


Figure 4. Fecundity versus carapace length for pink shrimp collected in 1965 (Robinson 1971, ODFW draft) and 1989.

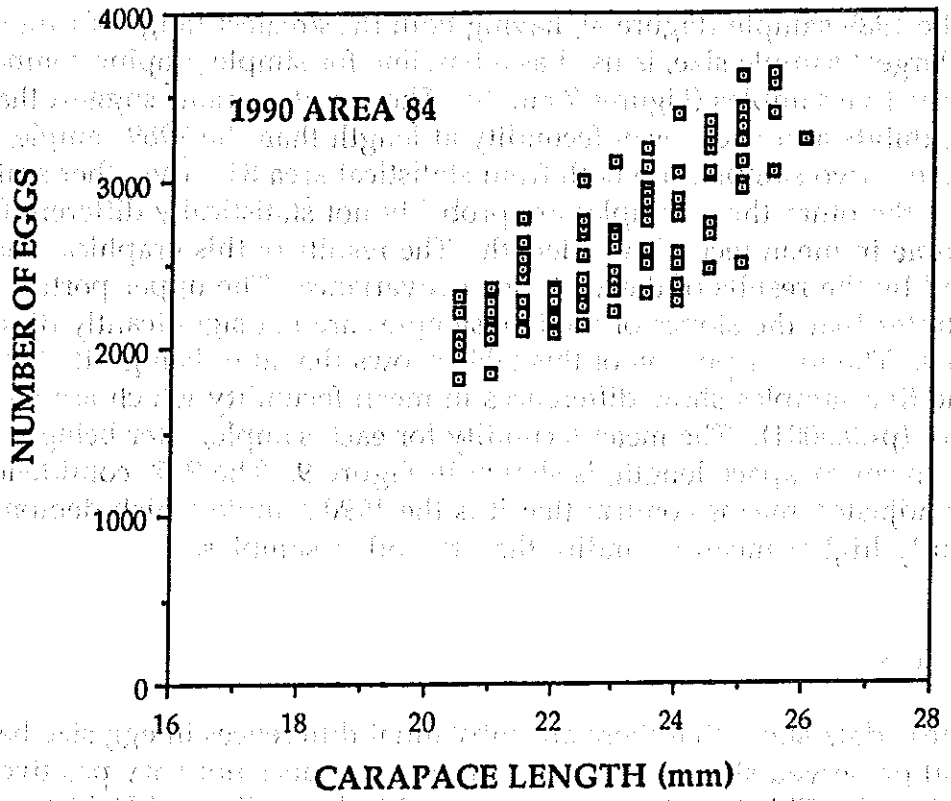


Figure 5. Fecundity versus carapace length for pink shrimp collected in 1990.

in Figure 6. The overlap of the 95% confidence intervals argues that the samples do not have significantly different slopes. The slopes estimated using geometric mean regression techniques are all higher than those estimated with standard techniques, with the smaller samples showing a greater shift in estimated slope between the two methods. Despite the differences in estimated slopes, both approaches yield a similar conclusion about the heterogeneity of slopes from the five samples.

The 1989 sample (Figure 3), having both the greatest range of carapace lengths and the largest sample size, is used as a baseline for simple graphic comparisons of pairs of the five samples (Figures 7 and 8). These scattergrams suggest that the 1990 sample exhibits a greater mean fecundity at length than the 1989 sample, even though these two samples are both from statistical area 84. The other scattergrams show that the other three samples are probably not statistically different from the 1990 sample in mean fecundity at length. The results of this graphical analysis are confirmed by the results of the analysis of covariance. The upper portion of Table 2 demonstrates that the slopes of the five samples are not significantly different ($p>0.1365$). The lower portion of this table shows that after being fitted to a common slope, the five samples show differences in mean fecundity which are highly significant ($p<0.0001$). The mean fecundity for each sample, after being adjusted to a common mean carapace length, is shown in Figure 9. The 95% confidence intervals for these adjusted means confirm that it is the 1990 sample which demonstrates a significantly higher mean fecundity than the other samples.

DISCUSSION

These data show that there are substantial differences in egg size between individual preserved shrimp, but also that egg size does not vary positively with carapace length. This is in basic agreement with the findings of Dahlstrom (1970). Although there was a marginally significant negative slope to the relationship between carapace length and egg width, the slope of this relationship was very nearly zero (Figure 2). It seems safe to assume, therefore, that mean egg size does not vary in a systematic way with age structure of the shrimp population. If we assume that systematic, qualitative differences between the larvae of individual shrimp do not develop between fall spawning and larval release, then total egg production should be a good measure of reproductive output for pink shrimp.

The length-fecundity relationship for pink shrimp seems to be best described by a simple straight line. This is in agreement with the approach used by Robinson (1971, ODFW draft) for pink shrimp, and by Apollonio et al. (1986) for *Pandalus borealis*. Other researchers have used the power curve approach for *P. borealis*, citing an a priori belief that the underlying relationship was probably curvilinear (Parsons and Tucker 1985, Teigsmark 1983). Given the variability in fecundity at a given length, even within one sample, and the short range of carapace lengths in these short-lived animals, it isn't possible to choose between these two approaches on strictly empirical grounds. This is unfortunate, since analysis of covariance on

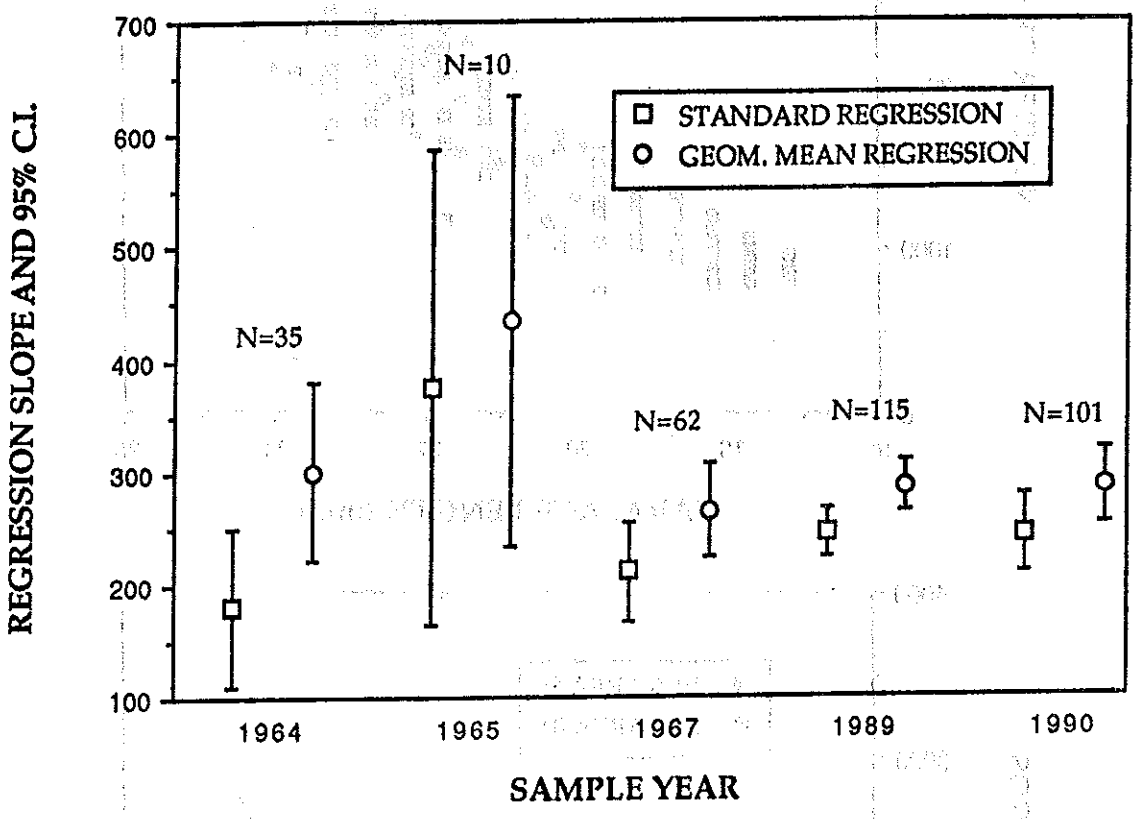


Figure 6. Comparison of regression slopes from five pink shrimp fecundity samples. Square is slope coefficient computed by standard linear regression. Open circle is slope coefficient from geometric mean regression methods.

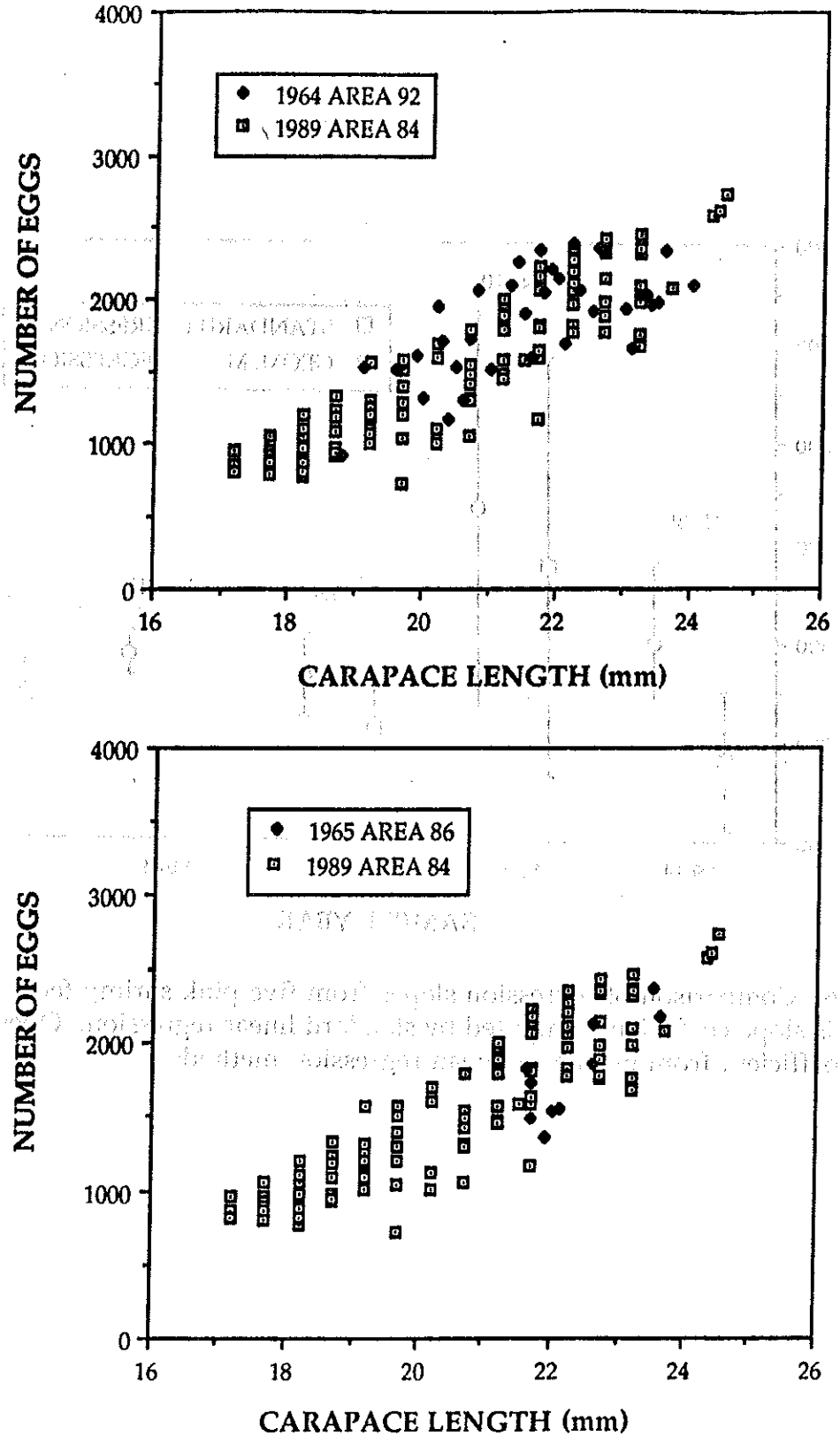
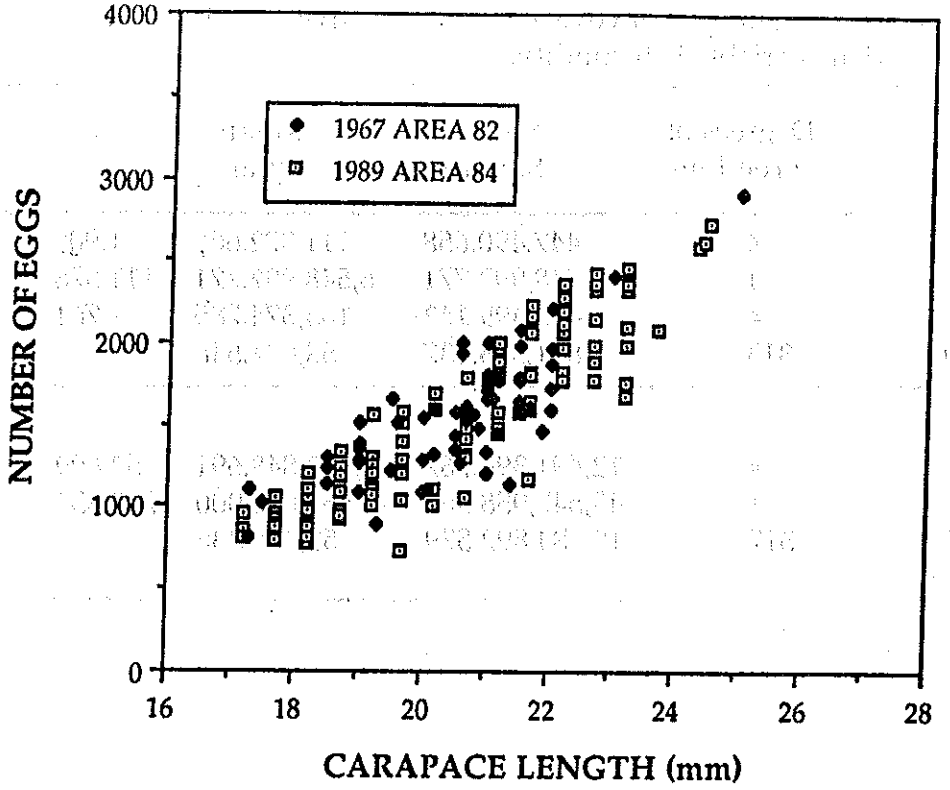


Figure 7. Comparison of length-fecundity plots for the 1964 (Dahlstrom 1970), 1965 (Robinson 1971, ODFW draft) and 1989 samples of pink shrimp.



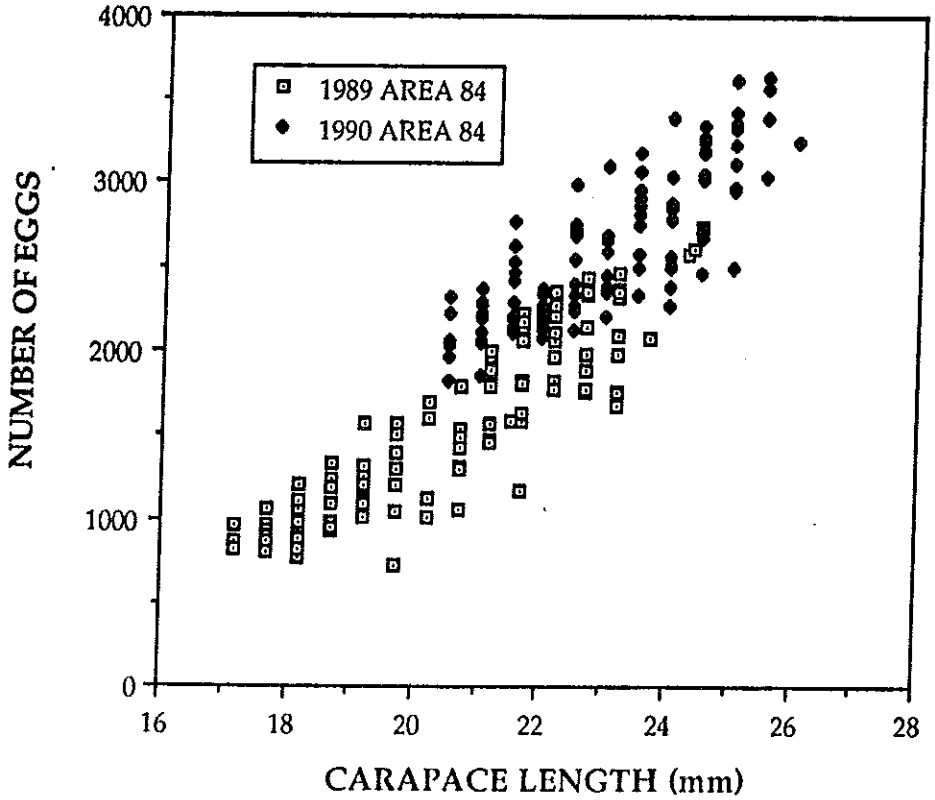


Figure 8. Comparison of length-fecundity plots for the 1967 (Robinson 1971, ODFW draft), 1989 and 1990 samples of pink shrimp.

Table 2. Results of analysis of covariance for the five length-fecundity samples, 1964-1990. Dependent variable is fecundity.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F	p>F
Sample	4	447,490.658	111,872.665	1.906	0.1092
Length	1	6,548,992.771	6,548,992.771	111.578	0.0001
Slopes	4	413,499.142	103,374.785	1.761	0.1365
Residual	313	1,871,393.437	58,694.548		
Sample	4	12,491,394.762	3,122,848.691	52.699	0.0001
Length	1	45,547,958.964	45,550,000.000	768.634	0.0001
Residual	317	18,784,892.579	59,258.336		

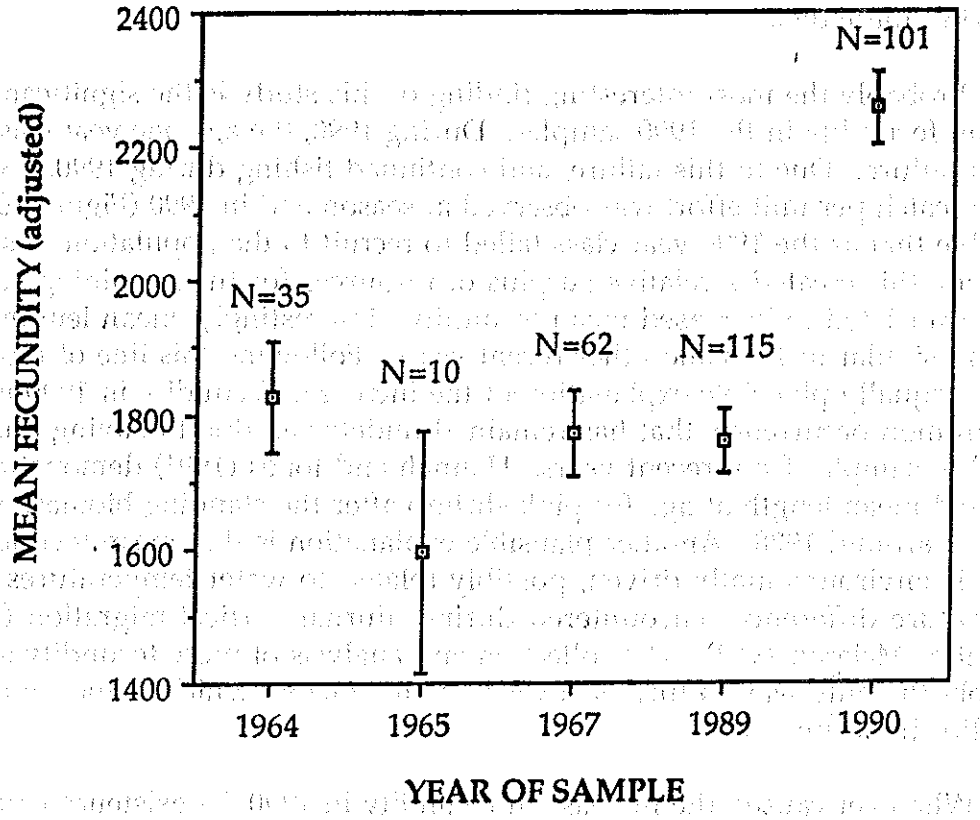


Figure 9. Mean fecundity and 95% confidence interval for five samples of pink shrimp. Sample mean fecundities are adjusted to a common mean length.

two sets of fecundity data can lead to very different conclusions, depending on whether the linear, or power curve, approach is applied. As an example, in this analysis, if the power curve approach is applied, the 1989 and 1990 data sets demonstrate significantly different slopes, while using the linear approach they do not. The interpretation of this apparent significant difference in slopes, would be that these two scatters of points demonstrate significantly different degrees of curvature. Since neither sample demonstrates detectable curvature in a simple graphic analysis, it is difficult to see how using a power curve approach can assist in analyzing these data.

Probably the most interesting finding of this study is the significant increase in mean fecundity in the 1990 samples. During 1990, the age one year class was a dismal failure. Due to this failure, and continued fishing during 1990, a very low level of catch per unit effort was observed at season end in 1990 (Figure 10). It is plausible that as the 1990 year class failed to recruit to the population in significant numbers, this created a relative surplus of resources for the remaining shrimp, which translated to increased mean fecundity. Interestingly, mean lengths at age for 1990 are similar to 1988 and other recent years. Following this line of thought, another equally plausible explanation of the increased fecundity in 1990 is that this is a common occurrence, that has remained undetected due to having only two fecundity samples from recent years. Hannah and Jones (1991) demonstrated increased mean length at age for pink shrimp after the standing biomass was reduced, around 1978. Another plausible explanation is that mean fecundity at length is environmentally driven, possibly related to water temperatures or temperature differences encountered during diurnal vertical migration (Appollonio et al. 1986, Mclaren 1963). The collection and analysis of more fecundity samples is probably the only way to further investigate the factors which influence mean fecundity in shrimp.

Whatever caused the increase in fecundity in 1990, its existence creates a slightly different view of pink shrimp population dynamics. To date, a stock-recruitment relationship has not been demonstrated for pink shrimp. It may be that systematic fluctuations in fecundity at a given length are causing the classic measures of parent stock abundance, such as spawner biomass, to be poor inicators of reproductive output. Fluctuations in reproductive output could be partially responsible for the wide fluctuations in recruitment seen in this stock.

RECOMMENDATIONS

1. If more precise information is needed on the relationship between egg location on the abdomen and egg size, or on the relationship between carapace length and egg size, this data should be collected from fresh, not preserved, shrimp.

2. Mean fecundity at length for pink shrimp can exhibit significant variations between years, suggesting that we should collect more samples to study the

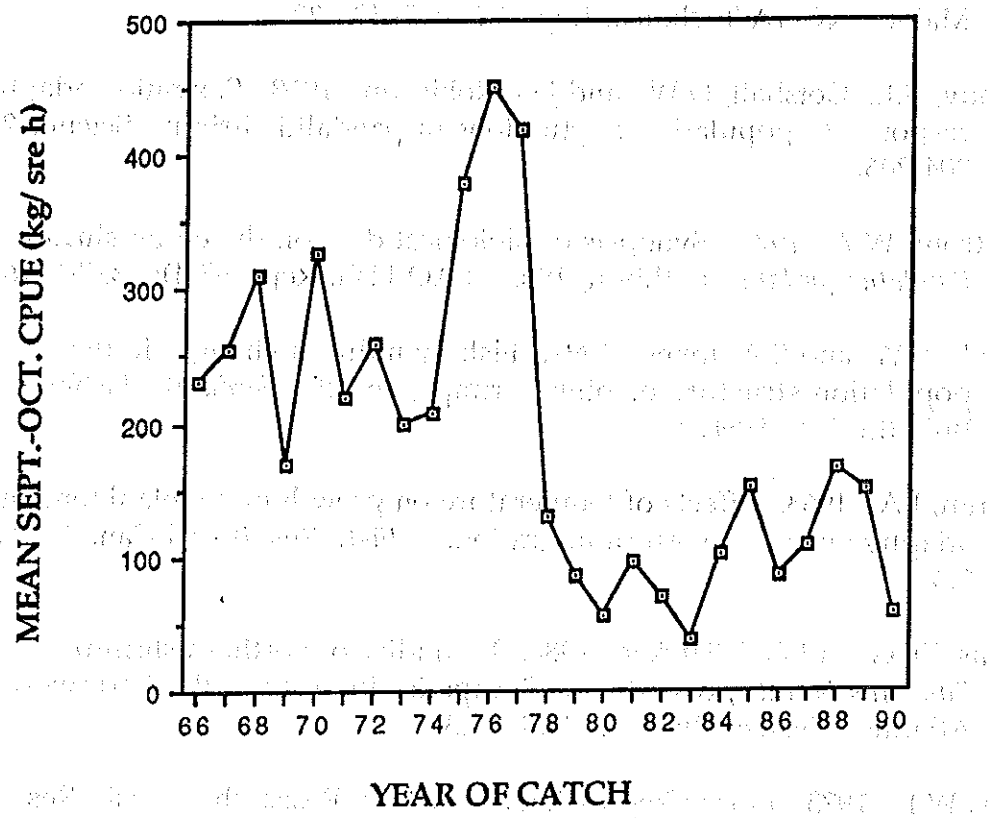


Figure 10. Mean Sept.-Oct. catch per unit effort (kg/single-rig-equivalent hour) for the Oregon pink shrimp fishery, 1966-90.

frequency and potential causes for this variation, and its impact on stock dynamics.

LITERATURE CITED

Apollonio, S., D.K. Stevenson, and E.E. Dunton. 1986. Effects of temperature on the biology of the northern shrimp *Pandalus borealis*, in the Gulf of Maine. NOAA Technical Report NMFS 42. 22 p.

Charnov, E.L., Gotshall, D.W., and J.G. Robinson. 1978. Sex ratio: adaptive response to population fluctuations in pandalid shrimp. Science 200: 204-206.

Dahlstrom, W.A. 1970. Synopsis of biological data on the ocean shrimp *Pandalus jordani*, Rathbun, 1902. FAO Fish. Rept. 57(4): 1377-1416.

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

McLaren, I.A. 1963. Effects of temperature on growth of zooplankton, and the adaptive value of vertical migration. J. Fish. Res. Board Can. 20: 685-727.

Parsons, D. G. and G.E. Tucker. 1986. Fecundity of northern shrimp, *Pandalus borealis*, (Crustacea, Decapoda) in areas of the northwest Atlantic. Fishery Bulletin. U.S. 84(3):549-558.

Ricker, W.E. 1973. Linear Regressions in Fishery Research. J. Fish. Res. Board Can. 30: 409-434.

Teigsmark, G. 1983. Populations of the deep-sea shrimp (*Pandalus borealis* Krøyer) in the Barents sea. Fiskeridir. Skr. Serv. Havunders. 17: 377-430.