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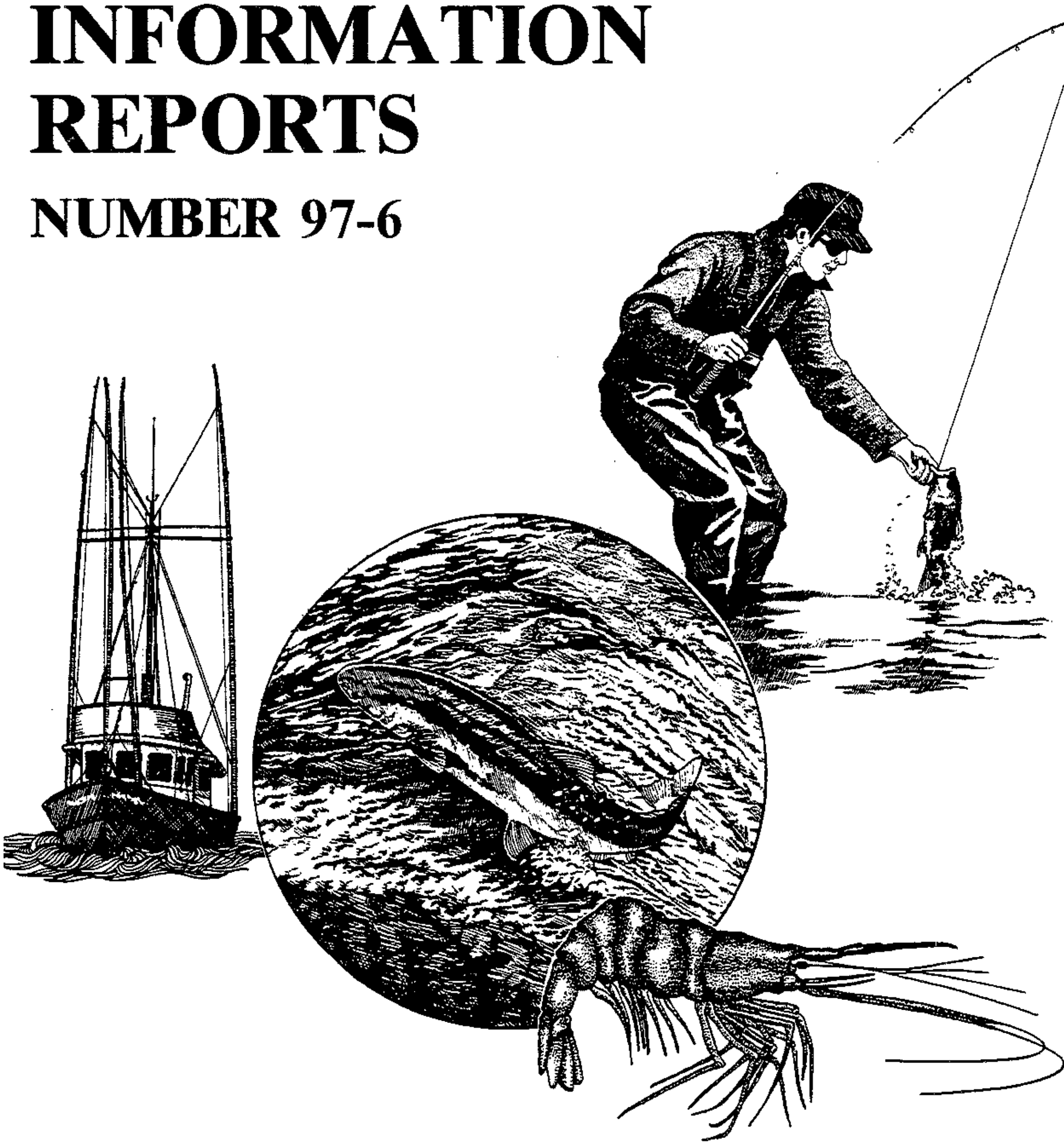

FISH DIVISION

Oregon Department of Fish and Wildlife

Evaluation of Methods Used to Estimate Geographic Stock Area for Ocean Shrimp (*Pandalus jordani*) From Logbook Data

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INTRODUCTION

Prior analysis of logbook data from the ocean shrimp (*Pandalus jordani*) trawl fishery has shown that the geographic area in which commercial concentrations of shrimp are found varies substantially between years, roughly in proportion to stock abundance (Hannah 1995). This variation in stock area has important implications for assessment of the ocean shrimp stock. For example, it indicates that catch per unit effort (CPUE), as it's commonly calculated, will not accurately index abundance (Beverton and Holt 1957, Winters and Wheeler 1985, MacCall 1990 and others). It also suggests that variation in stock area should be accounted for in developing accurate spawning stock and recruitment indices for ocean shrimp (Hannah 1993). The variation observed in the stock area of ocean shrimp probably stems from changes in the distribution of newly recruited year classes. These distributional changes may result from variation in larval transport or in the geographic pattern of larval survival (Hannah 1993, Hannah 1995).

My previous estimates of stock area for ocean shrimp relied on two key assumptions about the nature of the shrimp fishery (Hannah 1995). I assumed that the fishery was directed strongly enough at age one shrimp that the geographic distribution of successful catches would reflect the geographic distribution of these shrimp. This assumption was based on the age composition data presented by Hannah and Jones (1991) showing that age 1 shrimp dominated the trawl catch after about 1979. The second assumption was that variation in the rate at which logbook data were sampled would not create significant errors in the estimates of stock area. Sampling rates in the earlier study, based on the percentage of the total catch included in the logbook data sets, ranged from 25% to 47% (Hannah 1995). In this study, I critically evaluated these two assumptions about the shrimp fishery and then tried to develop a standard "best" method for estimating stock area from logbook data for ocean shrimp.

METHODS

Age Composition of The Catch

To determine, on a seasonal basis, when the shrimp catch was most heavily dominated by age one shrimp, I examined data on the monthly age composition of the catch for the years 1980-1995. The stock unit for this research included Pacific States Marine Fisheries Commission (PSMFC) statistical areas 82-88 (Figure 1). Age composition data were derived from samples of the commmercial catch landed into Oregon ports (Zirges et al. 1982, Jones and Hannah 1992, ODFW unpublished data). The collection and analysis of biological samples from the Oregon commercial catch has been previously described by Hannah and Jones (1991). Age composition data from Oregon samples was used in conjunction with estimates of total catch and effort for California, Oregon and Washington, tabulated by PSMFC statistical area, to estimate total catch at age, by area, for the years 1980-92 (Hannah et al. 1997). For the

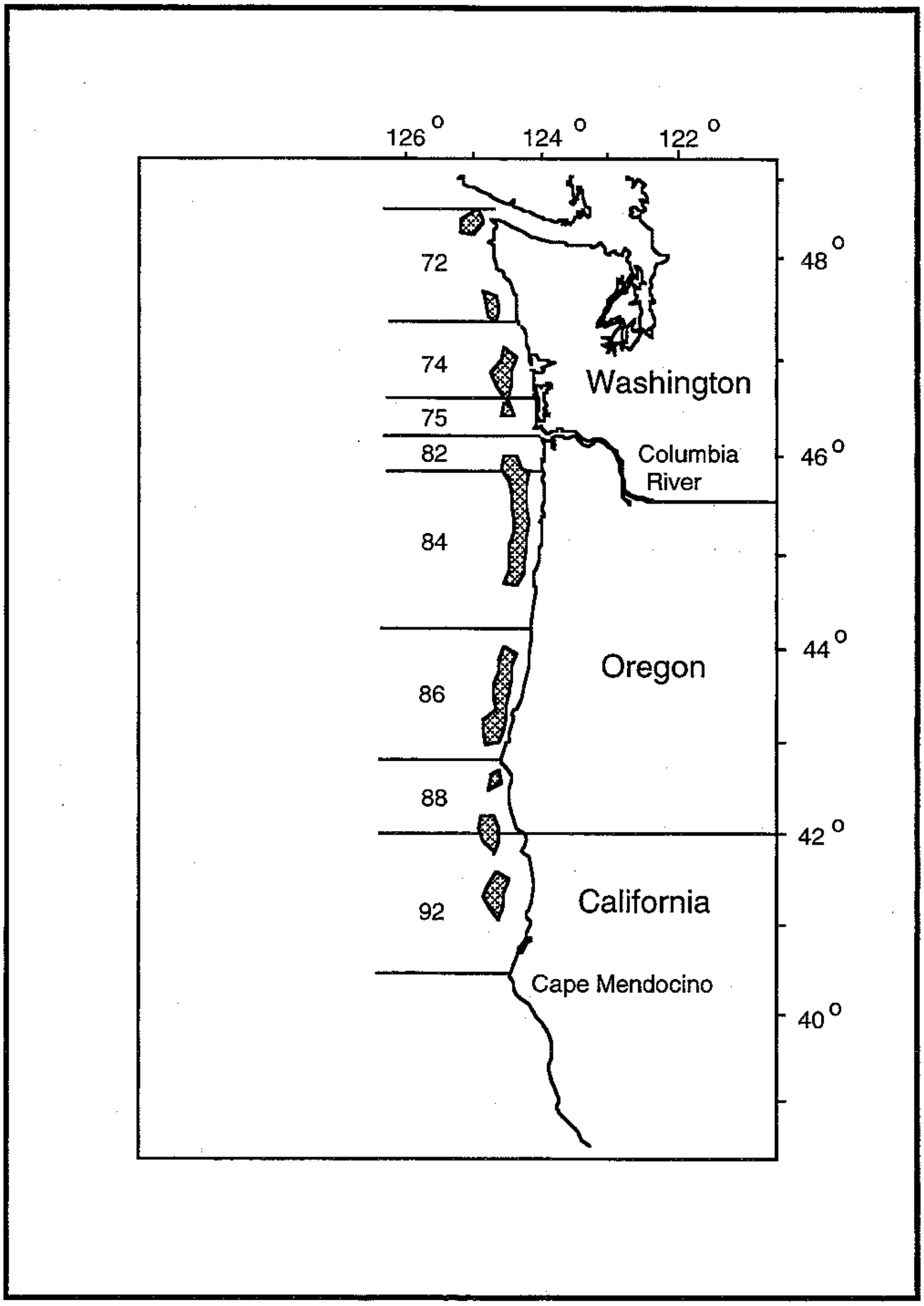

Figure 1. Location of commercial concentrations of pink shrimp *Pandalus jordani* along the U.S. Pacific coast (shaded areas) in PSMFC statistical areas 72-92.

years after 1992, location information for the shrimp catch landed into the states of California and Washington was not available. Accordingly, the age composition data presented here include California and Washington landed catch prior to 1993, but exclude these components for 1993-95. I assumed this would induce very minimal error in the age composition data for two reasons. First, Oregon landings comprise the majority of the removals of shrimp from statistical areas 82-88. Second, the states of California and Washington did not routinely collect samples from shrimp catches from areas 82-88, even in the earlier years. Age composition estimates for the years 1980-92 were calculated by applying biological data from the Oregon catch to the removal estimates from the Washington and California logbooks. Accordingly, the age composition of the catch should not be influenced much by this missing catch information. In instances where catch was recorded for a specific area and month but no biological samples were available, sample data from an adjacent area or month were used to estimate catch at age. I assumed this would have little impact on estimates of catch at age as strata with missing samples generally had low levels of catch.

Since about 1979, on an annual basis, age one shrimp have been the most frequent age class of shrimp in the commercial catch, followed by age 2 shrimp, with age 3 shrimp representing a minor component of the catch (Hannah and Jones 1991). Assuming that fishermen make decisions on where to fish based on the weight of catch obtained, active targeting of age one shrimp should occur only when these shrimp are frequent enough to comprise a large percentage of the catch by weight. Age one, two and three ocean shrimp weigh, on average, about 3, 6 and 9 grams, respectively (Zirges e tal. 1982). Accordingly, for age one shrimp to contribute in a major way to the weight of the catch obtained, they would have to comprise at least roughly 60-70% of the catch by number. For example, if catches were 60, 30 and 10 percent age one, two and three shrimp by number, respectively, then age one shrimp would comprise 40% of the catch by weight. Age two shrimp would also comprise 40% of the catch by weight, with age 3 shrimp comprising the other 20%. If the geographic distribution of successful hauls is to be related to the distribution of age one shrimp, the logbook data used should come from time periods in which age 1 shrimp comprised more than 60% of the catch by number. I examined the average age composition of the catch by month, for the years 1980-92 to determine the time period during which the catch was most dominated by age 1 shrimp. Then using this standard time period, I examined the age composition of the catch for each year from 1980-95 to determine in which years age one shrimp actually comprised at least 60% of the catch by number.

Analysis of Sampling Rates

The methods used to keypunch, standardize and error-check the 1980-89 logbook data have been described by Starr et al. (1989) and Fox et al. (1992). For the more recent years, a variety of similar quality control procedures were used. First, each logbook was examined to see if it was legible and complete. Next, prior to coding and keypunching, logbooks were systematically sub-sampled using port of landing, month and gear (single-rig or double-rig trawl) as strata. This was done to provide more uniform sampling across strata and to reduce the amount of data processed. After sub-sampling, the selected logs were keypunched, and the data were printed and verified against the original logbooks. Next, the starting locations of all tows were mapped and tows with locations well outside of the known shrimp grounds were deleted from the data sets. For example, individual tows which were located in water depths less than 40 fathoms or greater than 150 fathoms, or which were on high relief rocky habitat, were deleted. Finally, the data sets were reassembled on a "recruit year" basis. That is, they were edited and combined across calendar years to cover the months over which new recruits were, on average, most abundant in the catch.

Stock area was then estimated by "mapping" the shrimp tows onto a grid covering PSMFC areas 82-88 and summing the area of the blocks in which successful shrimp hauls originated. A successful haul was one with a non-zero shrimp catch. In the earlier study (Hannah 1995), I used 160 ha square blocks, while in this effort rectangular 320 ha blocks, roughly twice as long from north to south as east to west, were used. The choice of block size and shape was made in an attempt to match the blocks more closely to the trawling procedures used in the fishery. Trawling for ocean shrimp is generally parallel to the depth contours, approximately in a north-south axis in most of the study area (Figure 1) and hauls can extend over 7 km. Accordingly, a larger rectangular block, with the long axis oriented similarly to the axis along which most hauls are conducted, was chosen. I compared stock area estimates generated using 320 ha rectangles and 160 ha square blocks to evaluate the effect of using a different block size and shape on stock area estimates.

To evaluate the influence of variation in sampling rate on stock area estimates, I sub-sampled the data sets at various levels and graphed stock area versus sample rate. The sub-sample levels used ranged from 95% down to 5% of each original data set. The "true" sample rate for each sub-sample was calculated by simply multiplying the sub-sample rate by the original sample rate of the data set. The original sample rate was calculated from the total fishing effort (single-rig equivalent h) included in the logbook data set expressed as a percentage of the total fishing effort expended in the study area by vessels ultimately landing shrimp into Oregon ports. In this study, I based sampling rates on the percentage of fishing effort included in the logbook data sets, while in the previous study I used the percentage of the catch included (Hannah 1995). One problem with using catch to estimate sampling rate is that the large catches that sometimes occur on individual hauls can create added variance in estimates of sampling rate. This problem could be especially troublesome at low sampling rates and is avoided by basing sampling rate on fishing effort. I also used a form of "bootstrapping" to repeatedly select 10 replicate sub-samples, so that I could determine how the random selection of tows might be influencing the relationship between sampling rate and stock area. For each curve obtained via repeated sub-sampling, the change in stock area between the 95% sub-sample level and the original sample was also calculated, a quantity I'll refer to as the "marginal slope". This was done to determine how rapidly stock area was changing as sample size increased, at a point as close as possible to the actual sample rate for each year of data. Marginal slope was expressed as hectares of stock area per haul added to the data set (ha/haul). I next regressed the marginal slope estimates against the base sample rate for all years. In this case, a significant regression with negative slope was interpreted as evidence that as sample rate increased, stock area was approaching an asymptote (the marginal slope was declining as original sample rate increased). Next, I used non-linear least-squares regression to fit a curve to the sample rate and stock area estimates from the sub-sampling runs. This was done to determine if a family of curves fit the data well enough to allow stock area estimates to be adjusted for differences in sampling rate, either by interpolation or by moderate extrapolation. Based on inspection of the curves I selected a curve of the form:

$$A = 1/((1/a)+(b/R))$$

where, A = stock area,
R = sampling rate, and

a and b are estimated parameters describing the asymptote and the inverse of the curve slope at the origin, respectively.

Estimation of Stock Area by Other Methods

For years in which the fishery did not sufficiently target new recruits, another method of estimating stock area is needed. The strong relationship between stock abundance and stock area demonstrated previously (Hannah 1995) suggests that some form of abundance index might be used to estimate stock area for these years. To test this hypothesis, I compared the final stock area estimates from the years in which the fishery was clearly targeting new recruits to a simple virtual population estimate for the same year class. The virtual population was estimated by simply summing the catch at age across each cohort, ignoring variation in fishing or natural mortality. The resulting relationship was evaluated graphically and using linear regression to determine if it could be used to estimate stock area for years in which logbook data could not be used. In using this approach, I assumed that variation in natural and fishing mortality would not bias the relationship between stock area and the virtual population estimates. There is evidence to suggest that, due to the interaction between stock area and abundance, fishing mortality rates for ocean shrimp have not varied widely since 1980 (Hannah 1995). However, natural mortality clearly varies substantially between years, suggesting that any apparent relationship between the virtual population estimates and stock area is approximate at best.

RESULTS AND DISCUSSION

Age Composition

Data on the average age composition of the catch by number from 1980-92 (Figure 2) suggest that age one shrimp comprise over 70% of the catch by about June each year. These new recruits continue to dominate the fishery, on average, through the end of the season in October. By April of the following year, the influx of new age 1 recruits has reduced the relative abundance of the prior cohort to about 40% of the catch, however these shrimp now weigh about twice as much as they did during the prior spring. By May these older shrimp have declined to about 32% of the catch. Thus, logbook data from the months of June-October of year t and April-May of year t+1 should be combined to be most representative of fishing targeted at new recruits. Accordingly, all subsequent analyses were conducted on age composition data and logbook data sets covering a June-May "recruit year".

Examination of the average percentage of age one shrimp in the June-October catch, by year (Figure 3), shows that the catch during June - October was generally dominated by new recruits. This suggests that the first assumption of prior analyses (Hannah 1995), that fishermen target age one shrimp sufficiently that their logbook data provide information on the distribution of these shrimp, was reasonable. However, in 1990 and 1993 age one shrimp recruitment was low and vessels fished primarily on the remaining older shrimp. This suggests that for these two years logbook data are unlikely to give reliable information on the geographic distribution of new recruits.

Sampling Rates

A regression of "marginal slope" (Table 1) on sampling rate was statistically significant ($p<0.01$) with a negative slope (Figure 4). This suggests that, as sampling rate increases, the rate of increase in stock area slows. Random sub-sampling of the logbook data sets resulted in similarly shaped curves of stock area versus sampling rate for all years (Figure 5). The r-squared values for all curves were above 0.99 (Table 1), indicating that the random effects of sub-sampling had little effect on the fitted curve. The wide vertical spread of the curves in Figure 5 suggests that stock area varies widely between recruit years, even after correcting for differences in sampling rate. Most of the curves are nearly parallel at the sampling rates noted for the original data sets (Table 2), suggesting that differences in sampling rate have not induced large errors in estimates of stock area. A close examination of years with similar stock area estimates and disparate sampling rates indicates the relative magnitude of the errors generated by variation in sampling rate. For example, the minor difference in stock area between 1994 and 1982 is exaggerated by the wide spread in sampling rate. As a second example, the curves for 1981 and 1991 are virtually identical, suggesting that the apparent difference in stock area is almost completely due to how much logbook data was included in each sample.

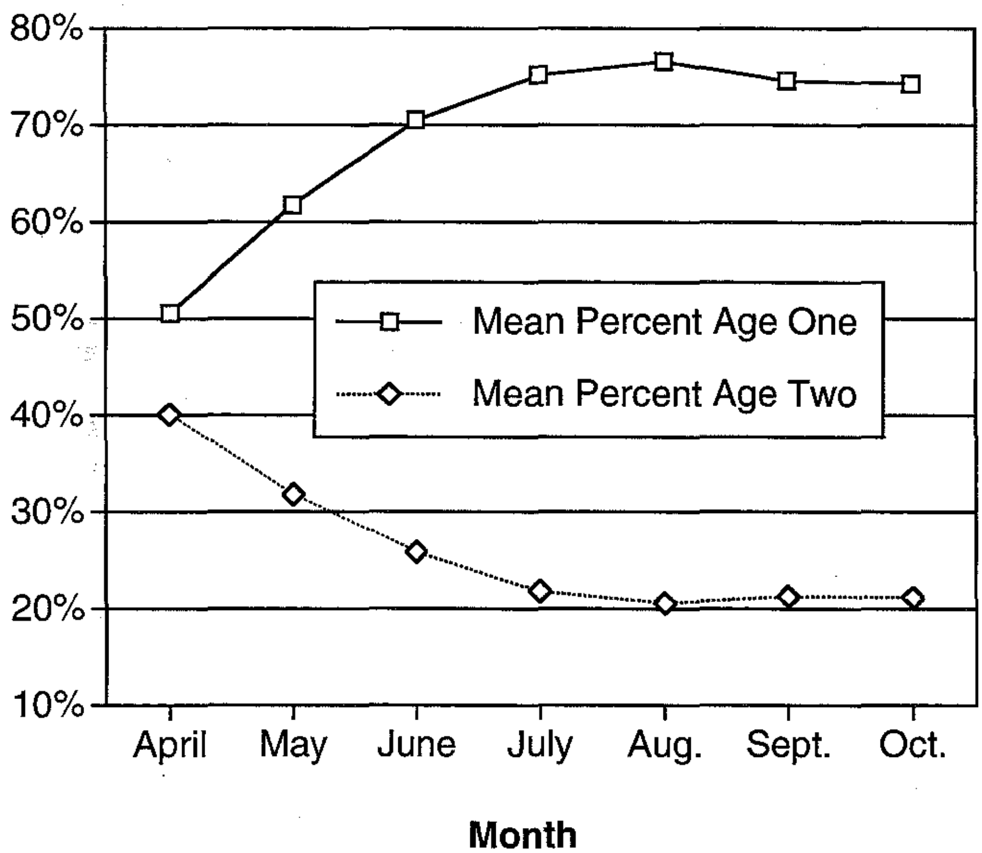

Figure 2. Mean percentage of age 1 and 2 ocean shrimp, by number, in the commercial catch from PSMFC statistical Areas 82-88, by month, 1980-92.

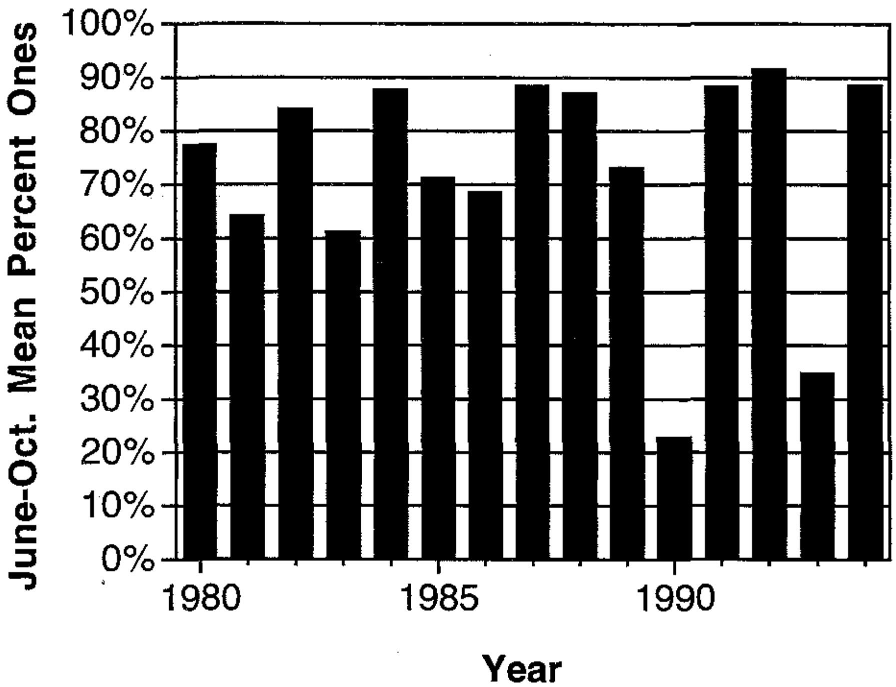

Figure 3. The mean percentage of age one ocean shrimp in the commercial catch from PSMFC statistical areas 82-88, for the months of June to October, 1980-94.

Table 1. Results of fitting curves by non-linear least squares regression to estimates of stock area(ha) and sample rate obtained from repeated random sub-sampling of the logbook data sets. The model is Area = 1/((1/a)+(b/Sample Rate)). For a definition of "marginal slope" see text.

Recruit Year (June-May)	a ($X 10^{-4}$)	b ($X 10^{-7}$)	r^2	Marginal Slope (ha/haul)	Stock Area (unadjusted ha)	Stock Area (adjusted to 50% Sample Rate)
1980	0.348	1.088	0.994	13.3	418,900	450,600
1981	0.545	1.705	0.998	18.7	443,200	477,200
1982	0.610	1.907	0.996	15.0	317,800	344,100
1983	1.761	5.502	0.996	12.2	162,200	172,900
1984	1.472	4.599	0.994	9.5	153,900	158,700
1985	0.860	2.687	0.994	10.8	323,800	319,400
1986	0.405	1.264	0.995	11.1	450,200	460,500
1987	0.331	1.034	0.998	6.9	450,900	464,600
1988	0.282	8.807	0.998	7.9	593,300	605,000
1989	0.307	9.594	0.998	5.7	591,000	585,100
1990	--	--	--	--	--	--
1991	0.496	1.549	0.997	7.3	484,200	478,100
1992	0.616	1.924	0.997	11.6	395,800	406,300
1993	--	--	--	--	--	--
1994	0.635	1.985	0.996	3.0	374,100	364,100

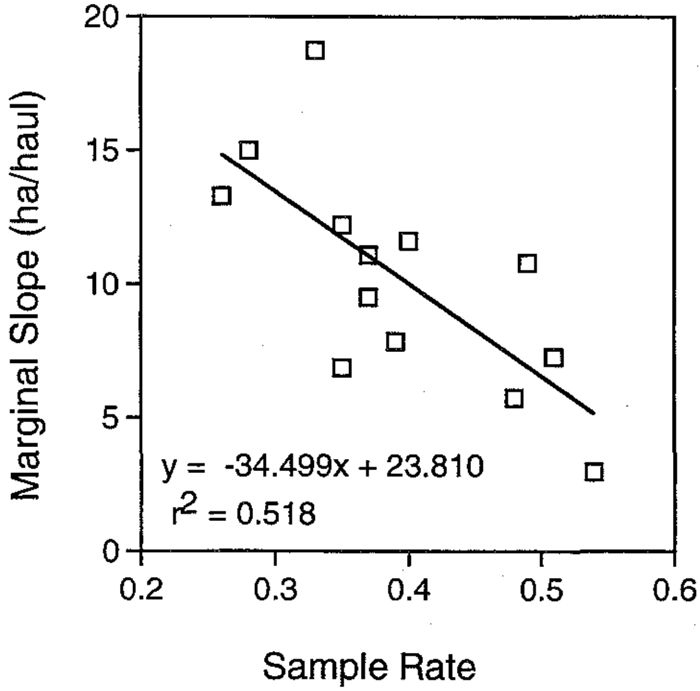

Figure 4. Linear regression of marginal slope (ha/haul) of sub-sampling curves (Table 1) on sample rate of logbook data sets, 1980-94. Sample rate is the proportion of total effort (sreh) expended to capture shrimp landed into Oregon ports that is included in the logbook data sets (see text).

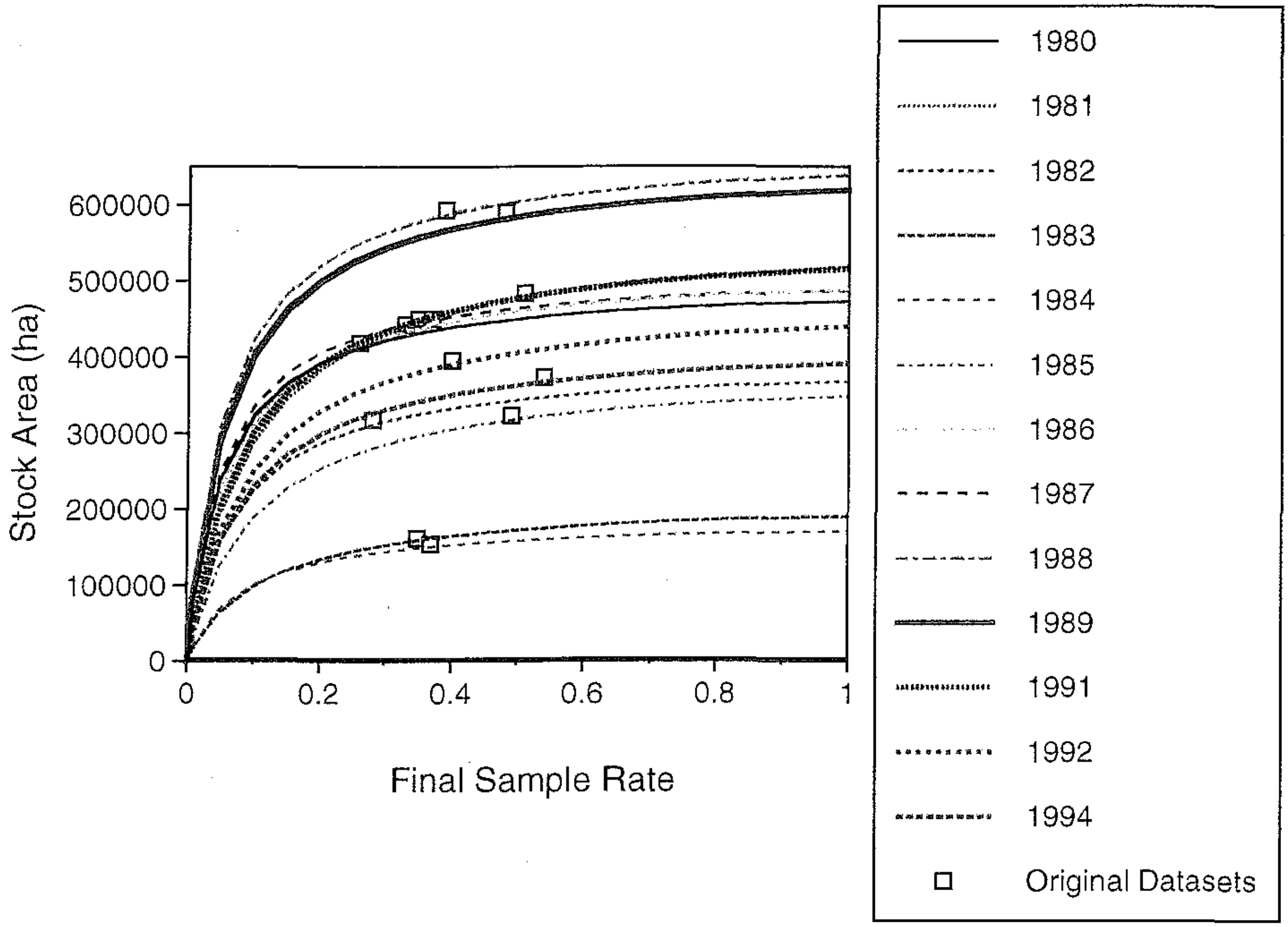

Figure 5. Sampling rates and stock area estimates for the original shrimp logbook data sets (small squares) and fitted curves of stock area (ha) versus sample rate resulting from repeated sub-sampling of the data sets at levels of 5% to 95%, 1980-94.

Table 2. Ocean shrimp stock area (ha) calculated from Oregon trawl logbooks, for PSMFC statistical areas 82-88, for recruit years 1980-94. Also shown is the amount of fishing effort (single-rig equivalent hours - sreh) expended in PSMFC areas 82-88 by vessels landing shrimp into Oregon and the percentage of this effort included in the logbook data sets.

Recruit Year (June-May)	Stock Area (ha)	Total Effort (sreh)	Effort Included (sreh)	Percentage of Total Effort Included
1980	418,900	127,519	33,146	26%
1981	443,200	76,413	25,025	33%
1982	317,800	72,221	20,161	28%
1983	162,200	23,600	8,357	35%
1984	153,900	24,909	9,212	37%
1985	323,800	43,249	21,154	49%
1986	450,200	96,808	35,538	37%
1987	450,900	106,755	37,385	35%
1988	593,300	119,060	46,555	39%
1989	591,000	111,209	53,100	48%
1990	--	96,893	--	--
1991	484,200	74,105	37,889	51%
1992	395,800	69,518	27,517	40%
1993	--	46,528	--	--
1994	374,100	63,331	33,958	54%

The significant regression of marginal slope on sample rate (Figure 4), in combination with the generally very close fit of the curves to the sample rate and stock area estimates (Table 1) suggest that the curves in Figure 5 can be used to correct stock area estimates for differences in sampling rates. In using this type of approach, there is a trade-off between added error from extrapolation and error reduction from correcting for variation in sampling rates. Inspection of Figure 5 suggests that standardizing stock area estimates to a sampling rate of around 50% would reduce the variation caused by different sampling rates while inducing minimal error from extrapolation. A comparison of the time series of the uncorrected and corrected stock area estimates confirms this (Table 1).

A comparison of the stock area estimates obtained by mapping logbook data into 160 ha square blocks and 320 ha rectangular blocks (Figure 6) shows that the choice of block size and shape can strongly influence the magnitude of the stock area estimate obtained. It's also clear that, for these data, the choice of block size and shape had little impact on the pattern of interannual variation in geographic stock area estimates. In this case, the use of a larger, rectangular blocks inflated the stock area estimates, probably because each block with only a single successful tow increased the stock area estimate by 320, rather than 160, ha. Since the logbook data contain only a point estimate of the start of each haul, and provides no information on the precise area trawled, it's not possible to pick a single "best" block size and shape for estimating stock area from logbook data. Virtually any block size chosen injects some bias into the estimates. Accordingly, stock area estimated from logbook data is appropriately used only as an index of how geographic stock area changes over time. As such, however, it should still be quite useful in calculating a recruitment index for ocean shrimp from catch and effort data.

Estimation of Stock Area By Other Methods

After standardization of stock area estimates at a 50% sampling rate, the relationship between stock area and a simple virtual population estimate appears strongly curvilinear (Figure 7). This was not entirely unexpected, since the relationship between stock area and catch described previously (Hannah 1995) showed a hint of curvature. Since years in which the fishery fails to target age one shrimp are generally also years of low recruitment, it is the left limb of this curve which is of most importance for estimating stock area. Considering only years with virtual population estimates below 3 billion shrimp, the relationship is approximately linear. A linear regression of stock area on the virtual population for the left limb of Figure 7 yields a significant linear regression equation ($p< 0.01$) with an r-squared value of 0.73. Using this relationship to estimate stock area for the years 1990 and 1993 results in stock area estimates of 208,800 and 200,800 ha, respectively. While these estimates seem reasonable, they fall very near the low end of the range of stock area estimates observed since 1980 (Table 1) and should be used with caution. The slope of the regression is also highly determined by the two lowest virtual population estimates. Since it's uncertain how variation in natural mortality rates

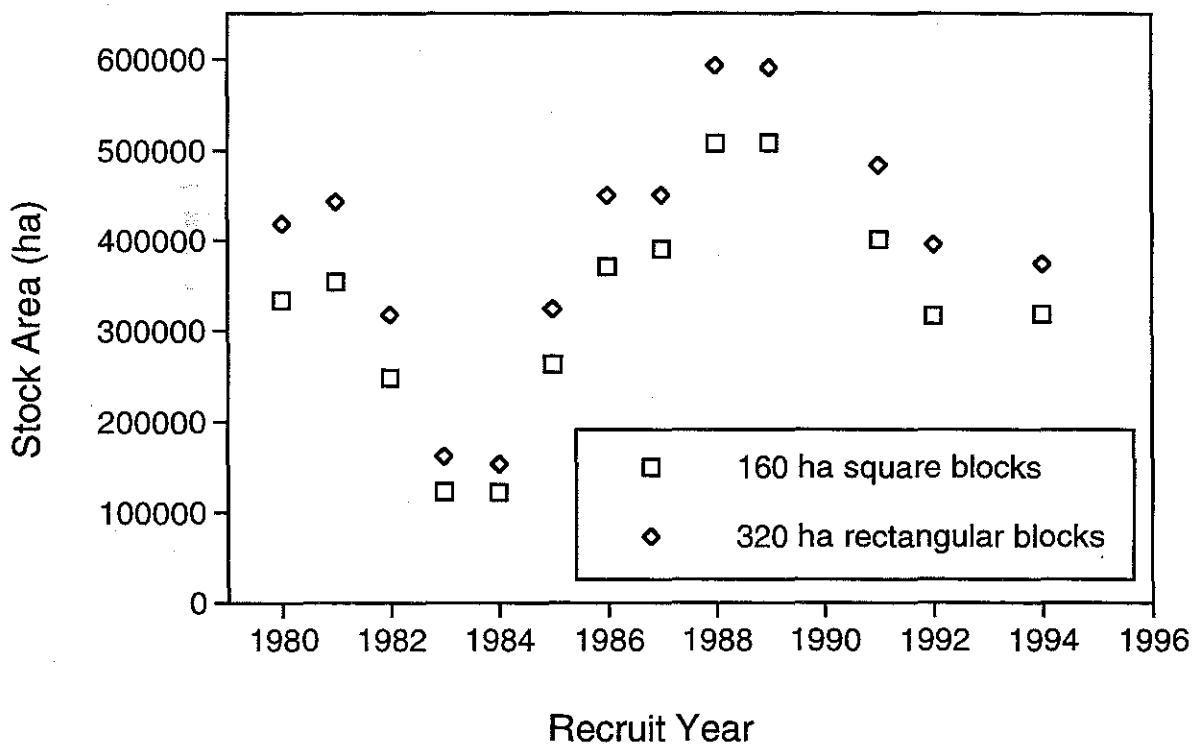

Figure 6. Comparison of stock area estimates derived from ocean shrimp logbook data using a grid of 160 ha square blocks and 320 ha rectangular blocks, 1980-94.

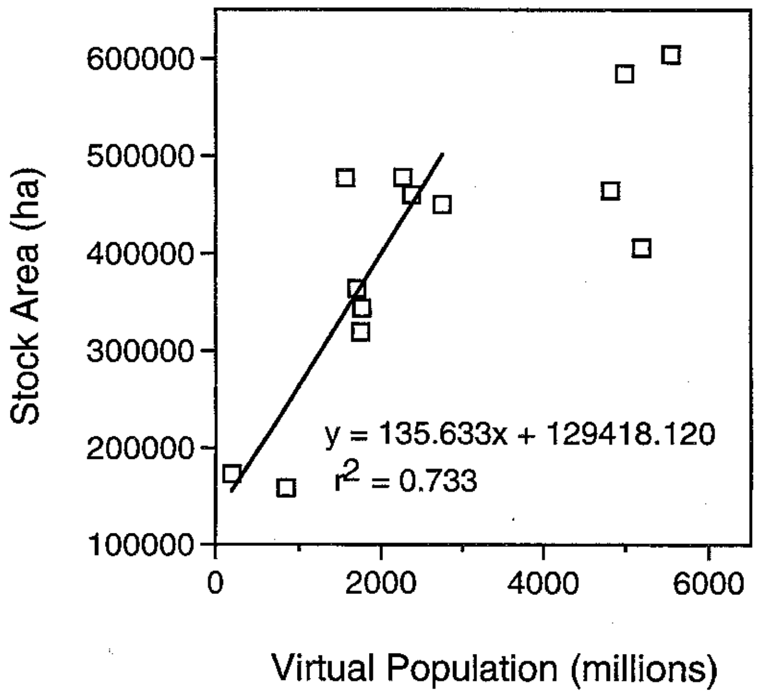

Figure 7. Stock area (ha) versus a simple virtual population estimate for ocean shrimp, 1980-94. Also shown is a linear regression of stock area on the virtual population for population estimates less than 3 billion shrimp.

could be influencing these estimates, this relationship should be considered approximate and preliminary until additional data can be added to better define the slope.

SUMMARY

1. The best "recruit year" for using shrimp logbook data to evaluate the geographic distribution of newly recruited age 1 shrimp is June of year t through May of year t+1.

2. As a general rule, the shrimp fishery targets age 1 shrimp during the "recruit year", however, during some years of very low recruitment, the fishery continues to target age 2 shrimp. Two recent examples of this were 1990 and 1993. In these instances, logbook data should not be used to estimate the stock area index.

3. Variation in sampling rate does influence stock area estimates, however, the asymptotic relationship between sample rate and stock area suggests that stock area estimates can be corrected for differences in sampling rate. Standardizing to a sample rate of 50% is suggested to balance the errors induced by extrapolation with those from variation in sampling rates.

4. The choice of block size and shape for "mapping" the successful tows has a major influence on the magnitude of stock area estimates. Accordingly, stock area estimates incorporate an unknown level of systematic bias, and are best used as an index of interannual variation in stock area.

5. The relationship between stock area and a simple virtual population estimate for each shrimp year class shows some potential as a tool for estimating the stock area index for years in which logbook data cannot be used for this purpose. Until more data points can be added to this regression, especially at low stock sizes, this regression should be considered approximate and preliminary.

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