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Impact of the Commercial Fishery on the Population of Bait Shrimp (*Penaeus* spp.) in Biscayne Bay 1986

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COVER PHOTO: Electrified shrimp sled trawl. Courtesy of Dr. Steven Berkeley, University of California

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Impact of the Commercial Fishery on the Population of Bait Shrimp (*Penaeus* spp.) in Biscayne Bay 1986

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ABSTRACT

Monthly population size of bait shrimp in the Bay was estimated from December 1984 to July 1985. Growth rates for male and female *P. duorarum* showed that pink shrimp exhibit a mean residence time in the nursery area (Biscayne Bay) of approximately 21 weeks. Monthly mortality rates were determined for each sex of pink shrimp. It was estimated that 23% and 26% of the male and female monthly population size, respectively, was absorbed by both the fishery and ecosystem monthly. Monthly proportion of the standing stock expected to die exclusively through fishing was 6.5% and 6.0% for males and females respectively. Estimates of emigration rates showed that approximately 4.0% of the population was lost from the Bay system each month. This surplus production was about 50% of the average monthly catch by the fleet. Fishing mortality represents only 8 - 9% of the losses to the shrimp population. The biggest source of loss is emigration, suggesting that most shrimp beyond the size at recruitment (to the fishery) are not utilized for food while in the Bay. Thus, it appears that the direct impact of the fishery on the bait shrimp population is relatively small.

1. INTRODUCTION

A small but valuable live bait shrimp fishery has existed in Biscayne Bay since at least the early 1950's. The commercial catch in 1983 was worth an estimated $1.1 million at dockside, and approximately $3.0 million at retail (Berkeley, 1984a). Berkeley *et al.* (1985) describe the commercial fishery and discuss the concerns which have been raised regarding the impact of the fishery on the biota and environment in Biscayne Bay. This study was undertaken to address one of these concerns, namely that the fishery's shrimp harvest represents a significant removal of food from the Bay thus indirectly reducing gamefish populations. Although it is not known what percentage of the shrimp population can be removed without significantly impacting the species which utilize them for food, it is assumed that if fishing mortality represents a small percentage of total mortality then the impact will be slight. Conversely, if the commercial harvest represents a high percentage or total mortality, then its impact can be considered potentially significant.

To determine the relative contribution of the commercial fishery to total mortality with sufficient accuracy to be useful, accurate estimates of population size are required. Thus, it was necessary to develop a quantitative sampling gear that would capture a high percentage or a relatively constant and known percentage of available shrimp. This would allow accurate estimates of shrimp density. If a sufficient number of stations in each habitat could be thus sampled, the density estimates could be expanded by the area represented by each station and summed to get a baywide population estimate.

Bait shrimp (*Penaeus duorarum* and *P. brasiliensis*) are nocturnal. During the day, they are inactive, burying themselves shallowly in the sediment. A type of gear that takes advantage of this inactivity would be ideal since net avoidance and escapement would be eliminated. Conventional sampling or commercial fishing gear (roller-frame trawl) is ineffective in the daytime and inefficient even at night. However, when subjected to pulses of direct current, shrimp involuntarily respond by flipping, tail first, from their burrows. The electrified trawl used in this study takes advantage of this behavior and allowed sampling during the daytime. Electrified otter trawls ("ticklers") have been tested in the Gulf of Mexico and were found to increase the daytime catch rate of shrimp from 2.4 to 30.3 times. At night, catch rates ranged from 50 to 109 percent of those by non-electric trawls (Seidel, 1969).

Total catch by the bait shrimp fleet was estimated monthly by monitoring the commercial fishery. With reliable estimates of both population size and commercial catch, the percent harvested by the fishery was estimated. These data also allowed us to estimate the rates of total mortality, fishing mortality, and natural mortality.

Total mortality consists of fishing and natural mortality. Fishing mortality is the portion of all "deaths" caused by harvest by the fishery, while natural mortality is the portion of all "deaths" due to predation, starvation, disease, and all other natural causes. By determining the relative contribution of fishing and natural mortality to total mortality, we can assess the impact of the fishery on the bait shrimp in the Bay, and, through inference, determine at least in a qualitative way, the impact of this harvest on the fish which utilize shrimp for food.

This study is a continuation of a previous two-year survey (Berkeley, 1984b) which studied the juvenile fish and macro-crustacean populations in Biscayne Bay. In addition, the results in this report provide supplementary information to some important points discussed in Berkeley *et al.* (1985) concerning the fishery and the ecology of Biscayne Bay.

2. MATERIALS AND METHODS

2.1. Gear

Daytime sampling was done on board a 20-foot Mako (R/V Bonito) using a modified electrified shrimp sled trawl. The sled was made of aluminum and was 1.7 m (5.5 ft.) long with a mouth opening of 1 m (Figure 1 and cover photograph). It was coated with epoxy paint to prevent its interference with the electrical field generated by the pulser system. Tarred netting of 3/8-inch stretched mesh was placed on the top and sides of the sled, and an 8-ft. long bag net of the same material was fitted to its tail end. Adjustable wooden depressor boards were mounted on the sled frame to insure that the gear remained on the bottom when being towed.

The electrical current was provided by a battery-powered electrical pulser unit leased from Ocean Harvester Corporation (Beaumont, TX). The unit consisted of four components: 1) a 36-volt battery source consisting of 3 small 12-volt batteries connected in series; 2) a control box mounted on board the sampling vessel; 3) a capacitor bank (pulser), mounted on the sled; and 4) an electrode array composed of three 14-inch stainless steel cables mounted on the sled in such a way that they were in contact with the bottom when the net was deployed.

The main battery bank furnished power to charge the pulser. The control box consisted of a timing circuit, powered by a 9-volt dry cell, a charging circuit, and a firing (discharging circuit. The function of the timing circuit was to turn on and off the charging, signal to the capacitor bank (pulser), and to turn on and off the discharging signal from the pulser to the electrode array. These signals were relayed to the pulser by their respective circuits through a 3-conductor cable assembly. The capacitor bank (pulser) stored the charge and discharged it into the electrode array at a frequency regulated by the timing circuit an the control box. Operation of the whole unit was monitored with the use of a beeper connected across the output terminals of the control box. The beeper produced an audible sound that varied in pitch and intensity with the voltage charge on the pulser. This indicated that the capacitor bank was charging and discharging properly. The output delivered by the electrode array produced a voltage drop of about 3-volts per pulse, at a rate of 4 pulses per second.

The electrical field preceded and lagged the length of the electrode array (50 in) by about 6 inches on each end. Hence, with the mean towing speed of approximately 0.5 m/sec, the period of time the shrimp were subjected to the electrical field was about 3.2 seconds.

2.2. Sampling Methodology

A line 50 meters long, anchored, and buoyed at both ends was laid at each sampling site. The trawl was lowered to the bottom as the boat approached a buoy. When the boat was alongside the buoy, the pulser was turned on and the tow continued until the buoy at the other end of the transect was alongside, at which point the pulser was turned off. The net was then pulled in, emptied into the sorting tray, and shrimp removed.

The shrimp were placed in a plastic bag with an identification tag containing pertinent information on the site sampled. Samples were stored in a cooler with ice until they were brought back to the laboratory for preservation in 10% formalin solution.

Taxonomic identification followed the diagnostic characters described in Perez-Farfante (1970). The carapace length (CL) of all shrimp was measured to the nearest millimeter using a standard vernier caliper. Total length was also recorded for a representative portion of the samples to determine the carapace length - total length conversion relationship:

Total Length (TL) in mm = 4.01 CL + 12.93

n = 255
r = 0.96
size range in samples:
8 - 31 mm CL
38 - 140 mm TL

2.3. Gear Efficiency

The effectiveness of the electrified shrimp trawl was tested by comparing density estimates from the trawl to estimates obtained from randomly placing a 1-m^2 mesh enclosure (throw trap) and removing all shrimp with a suction dredge. The throw trap-suction dredge method has been used effectively in sampling benthic organisms (Brook, 1975). This method was assumed to capture all shrimp within the 1-m^2 enclosure. A series of replicate samples were taken using both methods to determine gear efficiency, and the variance within and among habitat types. Within site and among area comparisons were performed on samples collected at six grass bed sites (Figure 2; sites A to F). Sites B and E were sampled more than once to enable us to estimate within site variance in shrimp distribution. Gear efficiency tests were performed for two basic bottom types; seagrass beds (of varying density) and barren bottom (mud and sand). The number of samples collected using the two methods varied depending on the consistency among replicates. Generally, a minimum of five 1-m^2 quadrats were sampled after which a minimum of three replicate 50-m tows were made with the electrified trawl. The efficiency of the trawl and necessary "raising factors" were then calculated for the different bottom types.

Fingerbars were installed on the sled frame in February 1985 because large amounts of dead seagrass blades, unattached algae (*Laurencia* and *Sargassum*), and assorted trash on the bottom sometimes clogged the net. Tests were conducted with and without fingerbars to adjust samples taken in December 1984 and January 1985. Clogging of the nets occurred only in seagrass beds and therefore tests were not done on other bottom types.

2.4. Sampling Regime

South Biscayne Bay was sampled monthly from December 1984 to July 1985. North Biscayne Bay was not sampled since the commercial fishery operates only south of Rickenbacker Causeway. The Bay was divided into 19 subareas (Fig. 2) based on a previously determined information on habitat, shrimp density (Berkeley, 1984b; and Campos, 1985), and types of bottom communities (DERM, 1983).

The sampling regime assumed that there is variance in shrimp density on several scales, and that shrimp are not randomly distributed. Density varies within a site, among sites within a subarea, and among subareas within the Bay. The variance within a site is relatively small compared to the variance among sites, and the variance among subareas is relatively greater than among sites. Thus, the best estimate of population size will be derived by taking as many replicates as possible from the subarea, not the site. In other words, based on this assumption, the most reliable density estimates are obtained by increasing the number of sites sampled within the subarea rather than increasing the number of replicates within sites. Therefore, each subarea was treated as a "station" and each site sampled within the subarea was treated as a "replicate" of the "station".

Generally, a total of 100 - 120 sites were sampled in the Bay in each sampling period. Allocation of sampling effort among subareas was based on the results of our previous study (Berkeley, 1984b), in which 22 stations were sampled monthly in South Biscayne Bay. These stations were classified as either West Bay or East Bay stations according to the general habitats described in the study. Sampling effort was stratified primarily by the mean density of shrimp in the West Bay area, weighted by the total surface area of subareas comprising the western half, relative to the mean density of shrimp in the East Bay area, weighted the same way. The resulting ratio was then used to allocate the number of samples in each half of the Bay. Further stratification within each half was done in the same manner except that the mean shrimp density (weighted) in seagrass beds was determined relative to those of barren bottom and hard bottom communities. The appropriate ratios were then applied to the number of samples originally allocated to each half of the Bay.

A grid was laid over a nautical chart of the Bay and points were marked every 30° latitude and longitude. For each sampling period, sample points within each subarea were picked randomly and their coordinates noted. A Sitex Loran - C unit (Model 787c) was used to locate chosen sample points in the field.

The sampling regime was made flexible so that the allocation of effort could be adjusted to follow known seasonal distribution patterns of bait shrimp in the Bay. Because of low shrimp abundance in May 1985, tow lengths were increased to 100 m in subareas with low densities, and more effort was expended in subareas where shrimp were abundant. Sampling in January, March, and July was incomplete because of boat breakdown and equipment failure.

Nine sets of samples were collected between December and July 1985. Sampling was monthly from December 1984 to April 1985, and in three week intervals thereafter to allow additional estimates of population size prior to recruitment of the next year class. Because of time constraints, sampling effort was reduced by half in June and July. Most samples were collected along the western portion of the Bay where shrimp were more abundant, while fewer but longer (100 m) tows were made in the eastern portion where shrimp densities were lower.

2.5. Population Size Estimates

Density estimates were standardized to number of shrimp per square meter and multiplied by the appropriate raising (gear efficiency) factors. Population size estimates were computed by multiplying adjusted mean density estimates by the surface area of the subarea(s) sampled. These expanded numbers were then summed to get the bay wide population size estimate in each sampling period. The 95% confidence limits of the mean population size were calculated by multiplying the lower and upper 95% confidence limits of the unadjusted density estimates by the appropriate lower and upper confidence limits of the raising factors.

In July, only the western portion of the Bay was sampled because of equipment failure. Total population size for this month was approximated by calculating the mean proportion of the population which came from the east bay areas during the previous eight sampling periods. This ratio was then used to approximate population size for July.

2.6. Commercial Fishery

Monthly effort was determined by thrice weekly boat counts (AM and PM) at the three commercial bait shrimp docks: Virginia Key, Dinner Key, and Black Point. Sampling dates for boat counts were picked randomly. Night counts were done to insure that all boats fishing that night were out. The difference between night counts and morning counts (after all boats had returned) gave the number of boats fishing that night.

Catch information from September 1984 through July 1985 was derived from three sets of logbooks provided by truckers and wholesale dealers. Logbook information contained 1662 records of number of shrimp caught per boat per night. Mean catch per boat-night was calculated by month and expanded by the estimated total number of boat-nights to derive total monthly catch.

2.7. Population Parameters

Growth rates were determined by fitting the von Bertalanffy growth function (VBGF) to size frequency data. This model expresses growth as:

$$L_t = L_\infty \, (1 - e^{-k(t-t_o)})$$

where:

L_t = carapace length (CL in mm) at age t (months)
L_∞ = theoretical maximum CL
K = growth coefficient
t_o = theoretical age (in months) at CL equal to zero

Growth parameters K and L were calculated using a modified FORTRAN version of the computer program ELEFAN I (Pauly *et al.*, 1980). Shrimp size frequencies varied among subareas within the Bay. Thus, size frequency distributions utilized the estimated numbers at size after expanding by subarea(s). Expansion was done by multiplying the number of shrimp in each size class with an expansion factor expressed as the total surface area (in m^2) of the subarea(s) divided by the surface area (m^2) covered by ail samples taken within the subarea(s). The von Bertalanffy growth function was fitted to monthly length frequency data separately for male and female pink shrimp. The size frequency distribution for July 1985 was not included in the computation of growth parameters and mortality rates since, with the absence of samples, the size distribution would be biased towards sizes of shrimp representative of the middle and western portions of the Bay.

In order to determine the absolute age of shrimp at a given length, t_o was estimated as follows (Pauly, 1980):

$$\log_{10} t_o = -0.3922 - 0.2752 \log_{10} L_\infty - 1.037 \log_{10} K$$

where the parameters t_o, L_∞, and K are defined above.

Instantaneous total monthly mortality rate (Z) was estimated using two methods: 1) by fitting an exponential curve of the form

$$\log_e N_t = \mathrm{Log}_e N_o - Z_d t$$

where:

N_t	population size at time t
N_o	initial population size at time to set at September 1st.
Z_d	instantaneous total mortality rate per day, thus $Z_d \times 30 = Z$
t	time in days

to monthly baywide population estimates, and 2) from the relative abundance of successive age groups through catch curve analysis.

The age distribution of the population was determined by rearranging the VBGF to the form

$$\frac{t = \log_e (1 - L_t/L_\infty + t_o)}{-K}$$

and using the estimated growth parameters to calculate the relative age (t in months) of shrimp of a given carapace length. Catch curve analysis was performed following the method described in Pauly *et al.* (1981).

Total mortality has two components, mortality due to fishing and mortality due natural causes (predation, starvation, disease, etc.). Independent estimates of instantaneous natural monthly mortality rate (M) were calculated in two ways: 1) M = Z - F, using two different estimates of Z as derived above, and 2) by using the empirical regression equation of Pauly (1980):

$$\log_{10} M_y = 0.0066 - 0.279 \log_{10} L'_\infty + 0.6543 \log_{10} K' + 0.4634\ T$$

where:

M_y =	instantaneous natural mortality rate (annual), thus $M_y/12 = M$
L'_∞ =	theoretical maximum total length (cm)
K' =	growth coefficient
T =	mean environmental temperature, T = 24.8 °C

Species composition and sex ratios were determined monthly from data collected during this study. These percentages were then used to allocate catch data into numbers of each species by sex. Instantaneous fishing mortality rate (F) was estimated using catch and effort data from the commercial fishery with the relationship from Ricker (1975),

$$F = C / \bar{N}$$

where:

C = total catch by the bait shrimp fleet in each month

$\bar{N}$ = mean monthly population size

Monthly total catch by the fleet during the months of September 1984 through November 1984, and August 1985 were estimated by multiplying mean catch per boatnight (from logbooks) with the mean daily effort (17.3 boat-nights per day), times the number of days in the respective months.

Exploitation rate (u) was calculated using the following equations from Ricker (1975):

$A = 1 - e^{Z}$ where: A = actual total mortality rate (monthly)
Z = instantaneous total mortality rate (monthly)

$u = \frac{F \cdot A}{Z}$ where: F = instantaneous fishing mortality rate (monthly)
u = rate of exploitation

Total catch of bait shrimp by the fleet was also expressed in terms of percent of the standing stock for each month.

3. RESULTS

3.1. Gear Efficiency

3.1.1. Comparisons Within and Among Areas

The results of within site comparisons are shown in Table 1a. At site B, (Chicken Key; see Fig. 2), variances among the three sets of samples were homogeneous at the $\alpha = 0.05$ level, and the mean number of shrimp per m^2 was not significantly different (ANOVA, $p > 0.05$). While in site E (west Featherbed Banks), the two sets of samples had unequal variances, but mean densities were not significantly different (t'-test; $p > 0.05$).

Among site comparisons were performed for the western and eastern portions of the Bay to examine the density distribution of shrimp within areas of similar environmental conditions, i.e. west bay and east bay grass beds described by Campos (1985). The results are shown in Table 1b. In the west bay area, sites A, B and C showed homogeneous variances and similar mean shrimp densities. Likewise, variances and mean densities among sites D, E, and F in the east bay area were not significantly different. However, significant differences were found in variances and mean densities between areas (Table 1c). No comparisons were performed between grass beds and barren bottom (mud and sand) since all suction dredge samples collected in mud and sand bottom were empty.

3.1.2. Efficiency Factors and Confidence Limits

Mean density of shrimp in seagrass beds was 0.321 per m^2 (±0.253) based on 67 throw trap samples. The mean density determined from trawl samples was 0.1101 (±0.082) shrimp per m^2 (n = 39). Using the throw trap/suction dredge, 67 m^2 of surface area was sampled while 2150 m^2 (including four 100-m tows) was sampled with the trawl. The mean efficiency of the electrified trawl in seagrass beds was 0.301/0.821 = 36.7%. This corresponds to a mean raising factor of 2.723, with lower and upper 95% confidence limits of 0.568/0.383 = 1.483 and 1.074/0.219 = 4.904, respectively, for trawl samples collected in seagrass beds. This raising factor was used for samples taken in December 1984 and January 1985, before fingerbars were installed on the net. Fingerbars were tested to determine any change in efficiency before permanent installation. Without figerbars, the mean density was 0.273 shrimp per m^2 (n = 3), whereas a mean density of 0.440 shrimp per m^2 (n = 3) was estimated with fingerbars. Although these mean densities were not significantly different (t'-test; $0.10 > p > 0.05$), this was probably due to the small sample size, thus we assumed the difference was real. The fingerbar factor for seagrass beds was 0.440/0.273 = 1.612. Since the gear efficiency tests were conducted without the use of fingerbars, the mean raising factor for samples collected in seagrass beds with fingerbars (beginning in February) was thus 2.728/1.612 = 1.692, with lower and upper 95 confidence limits of 0.920 and 3.042 respectively.

A total of 12 throw trap samples were taken on mud and sand bottom (sites G and H on Fig. 2). No shrimp were recorded in any of these samples (12 m^2). In contrast, a total of 14 shrimp were caught (0.040 shrimp per m^2) in seven 50-m net tows. Net efficiency on barren bottom was therefore assumed to be 100%. The same efficiency was assumed for other unvegetated, hard bottom areas, although no tests were conducted in these habitats.

3.2. Monthly Population Size Estimates

A one way ANOVA was performed for all months combined (excluding July) comparing mean shrimp densities among the 19 subareas. Data were first transformed into $\log_e (X + 1)$ in an attempt to make the variances homogeneous. However, despite transformation, variances remained unequal among subareas but mean densities were significantly different ($p < 0.001$). Duncan's multiple comparison test was run to determine subareas having similar shrimp densities. Four general areas of similar shrimp densities were formed by this test (Fig. 3). Baywide population estimates were therefore derived from expanded densities in these four subarea clusters. Mean shrimp densities, standard deviation, number of samples, surface area sampled, and total surface area for each subarea cluster per sampling period are shown in Table 2.

Estimates of mean population size from December to June, along with their 95% confidence limits, are presented in Table 3 and Figure 4. Shrimp abundance was highest in January and lowest in May. The mean proportion of the total population coming from east bay areas from December 1984 to June 1985 was 17.5%. The total number of shrimp coming from the west and mid-bay areas in July was 33,617,520, or 82.5% (presumably) of the standing stock. Total population size for July was therefore approximated to be:

$$(33{,}617{,}520)/(0.825) = 40{,}748{,}509$$

3.3. Catch and Effort by the Commercial Fishery

The mean number of boats fishing each night and monthly total effort (boat-nights) for the three shrimp docks during the study period are presented in Table 4. A maximum number of 33 vessels were recorded fishing in the Bay during the study in February 1985, while 24 vessels was the maximum recorded fishing in any night. A total of 4208 boat-nights were expended by the fleet from December 1984 through July 1985.

The monthly mean catch per boat-night and estimated monthly harvest by the fleet are shown in Table 5. Highest catch rates occurred in January when shrimp abundance was high, while the lowest catch rates were in July when shrimp abundance was low (Figure 4). Similarly, mean effort was high in January and February, and low in April and June.

3.4. Growth

The growth parameter estimates derived for pink shrimp were:

males $K = 0.134$
$L_\infty = 33.2$ mm CL
$t_o = -1.13$ months

females $K = 0.143$
$L_\infty = 43.4$ mm CL
$t_o = -1.08$ months

Growth curves providing best fits to the respective size frequency distributions are shown in Figures 5a and 5b. These results show that, while in the Bay, juvenile pink shrimp grow, on average, about 4 mm carapace length (CL) in males and 5 mm CL in females per month. Using the carapace length - total length conversion formula previously described, the average monthly growth in total length is about 29 mm for males and 33 mm for females.

3.5. Total Mortality

Instantaneous total mortality rate (Z) was estimated indirectly by catch curve analysis, and directly from monthly change in estimated population size. From the resulting monthly age frequency distribution, a catch curve was computed for each sex (Figs. 6a and 6b). The slope of the line fitted to the descending portion of each graph corresponds to the instantaneous total monthly mortality rate (Z). Exponential curves fitted to estimated monthly population sizes for each sex were (Fig. 7a and 7b):

males $\log_e N_t = 13.5398 - 0.0089t$
$r = -0.9846$

females $\log_e N_t = 18.8339 - 0.0100t$
$r = -0.9297$

Since t in the above equations is in days, the corresponding slopes are instantaneous total daily mortality rates, and are 1/30th of the monthly rates. The independent estimates of Z derived from the two methods were:

	Males	Females
a) catch curve	0.831	0.838
b) exponential curve	0.267	0.300

3.6. Fishing Mortality

Monthly population size by sex, monthly total catch by sex, and monthly F estimates from September 1984 thru August 1985 are shown in Table 6. The mean (geometric) monthly F estimates were 0.074 for male, and 0.070 for female pink shrimp.

3.7. Natural Mortality

Independent estimates of instantaneous natural monthly mortality (M), along with estimates of Z, F, A, and monthly exploitation rates (u) are presented in Table 7. From the relation M = Z - F, M values calculated using estimates of Z from the exponential curve were 0.193 and 0.230 while, using Z values calculated from catch curves (Figures 6a and 6b), were 3.757 and 0.769 for male and female *P. duorarum*, respectively. Values estimated from the empirical formula were 0.249 for males and 0.250 for females.

3.8. Exploitation Rates

Monthly population size estimates show that the actual total monthly mortality rate (A) is 23.4% for males and 25.9% for females. The proportion of the monthly standing stock of shrimp caught by the bait shrimp fleet is not directly comparable to the fishery's impact on the population since a portion of the catch would have died of natural causes The contribution of each cause of death, fishing (= u) and natural (= v), using the two estimates of Z are presented below.

	MALES		FEMALES	
	u	v	u	v
a) catch curve	0.050	0.514	0.047	0.520
b) exponential curve	0.065	0.169	0.060	0.199

Monthly catches of the whole fleet were also expressed as the proportion of the monthly population size of all bait shrimp from December 1984 thru June 1985. Table 8 shows the estimates of mean population size in the Bay for each month, the monthly catches of all bait shrimp by the fleet, and the percent of the standing stock harvested. Population size for May 1985 is the mean of the two sets of samples collected in May. The percent of standing stock harvested varied from 6.6% in January 1985 to 12.4% in March 1985.

4. DISCUSSION

The bait shrimp population in Biscayne Bay is composed of two species, *P. duorarum* and *P. brasiliensis*. Pink shrimp comprised more than 95% of the identifiable shrimp in the samples in all months during the study, with an overall monthly relative abundance of 96.3%. Previous studies in Biscayne Bay noted the dominance of pink shrimp throughout the year, with the proportion of *P. brasiliensis* increasing during summer (Eldred, 1960; Saloman *et al.*, 1968). Data gathered in a recent study in the Bay showed the same results (Berkeley, 1984b). Thus, there appears to have been little change in species composition since at least the 1960's. Since pink shrimp is consistently the dominant species, analysis of its population dynamics and abundance should reflect the dynamics of bait shrimp in the Bay.

As previously mentioned, an integral component of this study was the development of a sampling gear that would capture a high percentage of the shrimp present and/or a relatively constant and known percentage of the available shrimp to allow us to estimate absolute population size. Results of gear efficiency tests showed that in grass beds, the electrified trawl caught an average of 36.7% of the available shrimp, ranging between 20.6% and 66.7% (95% confidence limits). Data collected in a previous study (Berkeley, 1984b) using a roller frame trawl were compared to shrimp density estimates obtained during the present study. Although the two sets of data were collected at different times (about 2 years apart) comparison of mean CPUE from the commercial fishery between the 2-month period of August 1984 thru July 1985 ($\bar{x}$ = 6733) and the 13-year period (1971 - 1983) in Berkeley *et al.* (1985) ($\bar{x}$ = 6182) showed that although the former was 8.9% larger, this difference was not significant (t-test; $p > 0.05$). In the area of Chicken Key (stn 8 previous study; site B this study), mean catch per m^2 of bottom trawled using the electrified trawl was 0.33 shrimp per m^2, while that for the roller frame trawl was 0.04; approximately 8.2 times greater using the electrified trawl. The electrified trawl provided two additional advantages over the roller frame trawl (the standard gear used in the fishery); 1) sampling could be conducted during the daytime, and 2) it caught a relatively consistent percentage (36.706) of the true density of shrimp available.

The sampling method was designed to allow reliable estimates of population size. Bait shrimp are contiguously distributed, with their densities varying on several spatial scales. Densities vary within a site, among sites within a subarea, and among subareas within the Bay. Data from the previous study (Berkeley, 1984b) showed that the within site variance was less than the between site variance. In the present study, our *a priori* assumption was that the variance within sites was less than the variance among sites and the variance within subareas was smaller than the variance among subareas, although the scope of the study did not allow formal testing of this assumption. On the basis of this premise the best estimate of population size will be from taking as many samples as possible from the subarea, rather than increasing the number of replicates in a site within a subarea. In other words, the subarea represents the station, and each sample within the subarea is considered a replicate of that station.

Mean monthly population size estimates and their 95% confidence limits are shown in Table 3. The estimated population size in December 1984 appears too low. Since more small shrimp were sampled in December than in January, the increase in the estimated population in January was not caused by a surge in recruitment. Likewise, the increase cannot be accounted for by an increase in *P. brasiliensis*. Furthermore, the sharp decrease in abundance from January to April, strongly suggests that the December sample under represented true population size. Thus, it appears most likely that the increase in abundance from December to January was an artifact of sampling caused by clogging of the net (with algae) prior to installation of fingerbars. Emigration of shrimp out of the Bay is reflected by the decrease in abundance from January to April. The increasing trend in May, on the other hand, reflects recruitment of the next year class into the Bay. It is known that penaeid shrimp in the tropics and subtropics exhibit extended, and oftentimes, year round spawning with peaks occurring during certain times of the year depending on the species and geographical location. Previous studies in Biscayne Bay noted that recruitment into the fishery peaks in November and December (Berkeley, 1984b; Berkeley, 1934b). These studies found that the minimum size of bait shrimp vulnerable to commercial fishing gear was 14 mm CL. Based on the growth parameters determined in this study, male pink shrimp of this size are 2.2 months and females 1.6 months old. It is reasonable then to set their time of arrival into the Bay at about 2 months before the peak recruitment into the fishery (i.e. September). Maximum population size was therefore presumed to occur in September. Monthly population abundance for the year class of *P. duorarum* was calculated by fitting an exponential curve to population size estimates for the months of January thru May (first sample) (Figs. 7a and 7b). Population parameters were then estimated in relation to these calculated values. Exploitation rates, however, were calculated in relation to both the year class of shrimp and the overall population. In other words, because bait shrimp are recruited into the Bay 12 months a year, total population numbers do not decrease in strict accordance with the exponential curves. With increasing numbers of post larvae entering the Bay beginning in June, population size starts increasing and reaches a maximum in September (presumably), as projected previously. Although the term "year-class" has little meaning in this sense, the term is used in this study to delineate that portion of the standing stock sampled during the study on the premise that although recruitment into the Bay was year-round, it peaked during the summer (1984) with a projected maximum population size in September. Hence the population available in September 1984 was followed for 12 months by extrapolating the exponential curve. As previously mentioned, the increase in numbers starting in the second May sample represented incoming postlarvae whose peak numbers would have occurred in September 1935, and hence represents another "year class".

Therefore, mortality rates were estimated as they pertain to the year class showing peak recruitment in September 1984 excluding small shrimp recorded during the last three months of the study (2 May to July). However, on a 12-month basis, the fishery catches shrimp from these overlapping "year-classes" and because of this, exploitation rates are expressed relative to both the year class and the standing stock.

The growth of *P. duorarum* as described by the VBGF indicates that during their juvenile and sub-adult phases within the Bay, males grow about 29 mm TL and females 33 mm TL, per month, on average. These values are well within the ranges of monthly juvenile growth rates (7 - 52 mm TL) reported by Costello and Allen (1970).

Although no clear relationship between shrimp size and emigration has been established, it is believed to be related to the onset of maturation and therefore related to size. From January 1985 to April 1985, five samples of emigrating shrimp were collected off the RSMAS docks to determine their size distribution. These samples were not examined for species or sex composition. The mean sizes of shrimp sampled were:

Jan. 7 '85	$\bar{x}$ = 23.3 mm CL (n = 56) SD = 3.1
Feb. 2 '85	$\bar{x}$ = 25.0 mm CL (n = 59) SD = 2.7
Mar. 4 '85	$\bar{x}$ = 25.1 mm CL (n = 412) SD = 3.2
Mar. 21 '85	$\bar{x}$ = 23.5 mm CL (n = 245) SD = 3.6
Apr. 4 '35	$\bar{x}$ = 23.0 mm CL (n = 433) SD = 2.3

The overall mean carapace length was 23.9 mm (SD = 3.3). Although these samples were not examined for species or sex composition, assuming that both sexes of pink shrimp emigrate at similar ages, we can assume migrating size for males at 1 SD (3.3) less and for females, 1 SD more than the mean size. Therefore at 21 mm CL (97 mm TL) males are about 19 weeks old, and at 27 mm CL (121 mm TL) females are 23 weeks old. Thus, pink shrimp in the Bay spend about 21 weeks in the nursery area prior to migrating into deeper offshore areas.

The percent of the actual monthly mortality rate due to fishing was 28% (= 0.065/0.234) for males and 23% (= 0.060/0.259) for females. The actual total monthly mortality rate (A) from change in monthly population size was 23% for males and 26% for females. However, mortality rates based on age distribution (catch curves) showed different results (i.e. males: A = 56%; females: A = 57%). Catch curves for male and female pink shrimp are shown in Figs.

6a and 6b. They show that for males, the descending portion of the curve starts at relative age t = 5 months, whereas in females it starts at t = 4 months (point B). These points correspond to the respective size class midpoints of 17.5 mm CL in males, and 18.5 mm CL in females. These lengths are very close to the mean size at emigration (24 mm CL) for combined sexes. Therefore, succeeding points used in the least squares regression correspond to the size classes of pink shrimp emigrating from the Bay. No quantitative sampling for emigrating shrimp was done in this study so total mortality (and natural mortality) includes emigration as a source of loss from the Bay. This suggests that the higher Z estimates derived from catch curve analysis include emigration.

The highest point on each catch curve corresponds to the minimum size of shrimp fully vulnerable to the electrified trawl. For females, point A is the highest point on the curve, but was not used in the regression since the line drawn from point B to the last point (Fig. 6b) provided a better fit. However, re-examination of the age distribution showed that from the minimum age of shrimp fully vulnerable to the gear (about two months), the line is not straight. In other words the right half of the catch curve (the descending limb) can be described by two straight lines (Fig. 8), a gradual one from points A to C, and a steeper one from points B thru D. The line A thru C having a slope of 0.210 represents the instantaneous rate of decrease in abundance of successive age groups whose sizes are less than migrating size (24 mm CL), while line B - D having a slope of 0.838 represents the instantaneous rate of decrease in abundance for migrating shrimp. The instantaneous total monthly mortality rate therefore increases when shrimp reach migrating size. In this sense, Z really measures the instantaneous rate of total monthly loss from the Bay, due to fishing, natural mortality, and emigration. Since the smaller Z (0.210) corresponds to age groups less than emigrating size, this value is believed to reflect the true instantaneous total monthly mortality rate of female *P. duorarum*, whereas the larger Z, derived from shrimp of emigration size is composed of fishing mortality (F), natural mortality (M), and loss due to emigration M. The age distribution for males (Fig. 6a) does not show as clear a curve as that for females. The top portion of the curve is flat. The reason for this is not known. However, data gathered from a previous study (Berkeley, 1984b) showed similar relationships (Figs. 9a and 9b). The Z values corresponding to non-migrating size shrimp were 0.276 for combined sexes in the trawl samples and 0.408 for male pink shrimp in the commercial samples. The catch curve for females in the commercial samples, however, showed a flat top portion. Furthermore, on the assumption that the relationship depicted by Pauly's equation for instantaneous natural mortality rate provides reasonable estimates of M, then from the relationship $Z = F + M$ we have

males $Z = 0.074 + 0.249 = 0.323$

females $Z = 0.070 + 0.250 = 0.320$

These Z values are much closer to those estimated by the exponential curves (0.267 and 0.300 respectively) than to those calculated from catch curves (0.831 and 0.838 respectively).

It is thus most likely that the difference in Z values calculated from the exponential and catch curves in the present study is due to the inclusion of emigration (U) in the catch-curve derived rates. Estimates of total mortality rate using exponential curves should represent the true total mortality rates for *P. duorarum*, without emigration, and the difference between the two estimates should be an estimate of the instantaneous monthly emigration rate. If this is the case, then the instantaneous emigration rate for *P. duorarum* from Biscayne Bay in 1984 - 85 was:

males $0.831 - 0.267 = 0.564 = U$

females $0.839 - 0.300 = 0.538 = U$

with an average rate of 0.551 for combined sexes. This means that, on average, 42% (= 1 - e^{-U})of pink shrimp of migrating size (24 mm CL) leave the Bay each month. Since these shrimp do not enter the food chain of the Bay and almost certainly are not the source of recruitment for the subsequent year class, this represents a true loss to both the ecosystem (Biscayne Bay) and to the fishery. However, this "surplus production" (42%) pertains only to that portion of the total population that is comprised of migrating size shrimp. In terms of the whole population, this loss represents an average of 4.0% and ranges between 1.8 and 6.0 percent. This percentage of the population represents the amount of shrimp lost to the system aside from the amount taken out by the fishery and the amount absorbed by the system through predation, starvation, disease and other natural causes. Thus, at the present rate of fishing mortality, an average of 4.0% of the pink shrimp population in Biscayne Bay survives to migrate to offshore areas.

The local commercial fishery for bait shrimp was described by Berkeley *et al.* (1985). The fishery operates on a per-order basis and, as such, total effort reflects both market demand and trends in shrimp abundance. Boats fish to fill orders. Because of this, working hours are generally less at times of high shrimp abundance, while boats normally fish the whole night during the spring and summer when abundance is low. It is unlikely then that the present fleet size is harvesting at its full capacity.

A Beverton and Holt yield per recruit analysis assuming a mean size at first capture of 14 mm CL and natural mortality rates from the exponential curve (Table 7) indicated that maximum yield would be realized at a fishing mortality rate of F = 0.24 to 0.29 for males and about F = 0.23 for females. Present fishing mortality is approximately F = 0.074 for males and F = 0.070 for females. To maximize yield per recruit, fishing mortality would have to increase about 300 to 400% from its present level. If we assume the higher estimates of M derived from the Pauly equation (M = 0.249 males; M = 0.250 females), then maximum yield per recruit would occur at fishing moralities 400% greater than current levels. Maximum yield is not a desirable goal, however. From the standpoint of the fishery, bait shrimp are sold by the piece (number) not by weight, and thus increasing the weight yield would not necessarily increase the returns to the fishery. From the standpoint of the ecology of the Bay, shrimp are most likely a sufficiently important food source for many species of fish that maintaining the harvest at low levels is the more prudent strategy. It seems unlikely, however, that a moderate increase in fishing effort (fishing mortality rate) would adversely impact the species which utilize shrimp for food.

At present, the maximum number of vessels fishing in the Bay occurs during the winter when boats, otherwise operating in the Keys and along the Florida west coast move in to fish in the Bay. During this study, the largest number of vessels operating was 33 in February 1985. Shrimp abundance was also high in winter (Fig. 4). It was estimated that the fishing fleet, on average, harvested 7.4% of the monthly population of bait shrimp during the winter (December to February) (Table 8). This increased to an average of 9.4% during the next four months when abundance was low.

At the present rate of exploitation, the rate of fishing mortality (F) appears to be small compared to natural mortality M, and much smaller than U + M. Thus the fishery apparently does not significantly decrease the food resource available to fish populations.

From the standpoint of juvenile fish mortality resulting from their, incidental catch by the commercial bait shrimp fishery, any increase in fishing effort will increase this mortality. However, the significance of this mortality is unknown and without quantitative estimates of size of juvenile fish populations in the Bay, the magnitude of mortality caused directly by the fishery can only be superficially addressed. Although quantitative estimates of the species composition and numbers of gamefish in the by catch were documented by Berkeley *et al.* (1995), population size and total mortality estimates of juvenile fish are not available. In addition, since most fish are not in a self-contained system (Campos, 1985) their stocks are not limited to Biscayne Bay. The fishery's impact would have to be evaluated on its effect stock-wide. Delineating Stock size and distribution is a monumental task. Some gamefish species inhabit the Bay from juvenile through adult stages (e.g. spotted sea trout). Such populations are relatively self-contained in the Bay and knowledge of their population dynamics would provide meaningful data on the impact of the fishery on juvenile fishes.

5. SUMMARY AND CONCLUSIONS

Monthly population size of bait shrimp in the Bay was estimated from December 1984 to July 1985. Growth rates for male and female *P. duorarum* showed that pink shrimp exhibit a mean residence time in the nursery area (Biscayne Bay) of approximately 21 weeks. Monthly mortality rates were determined for each sex of pink shrimp. It was estimated that 23% and 26% of the male and female monthly population size, respectively, was absorbed by both the fishery and ecosystem monthly. Monthly proportion of the standing stock expected to die exclusively through fishing was 6.5% and 6.0% for males and females respectively. Estimates of emigration rates showed that approximately 4.0% of the population was lost from the Bay system each month. This surplus production was about 50% of the average monthly catch by the fleet (Table 8).

Of the three sources of loss, their instantaneous rates are:

MALES	FEMALES
F = 0.074	F = 0.070
M = 0.193	M = 0.230
U = 0.564	U = 0.538

Fishing mortality represents only 8 - 9% of the losses to the shrimp population. The biggest source of loss is emigration, suggesting that most shrimp beyond the size at recruitment (to the fishery) are not utilized for food while in the Bay. Thus, it appears that the direct impact of the fishery on the bait shrimp population is relatively small.

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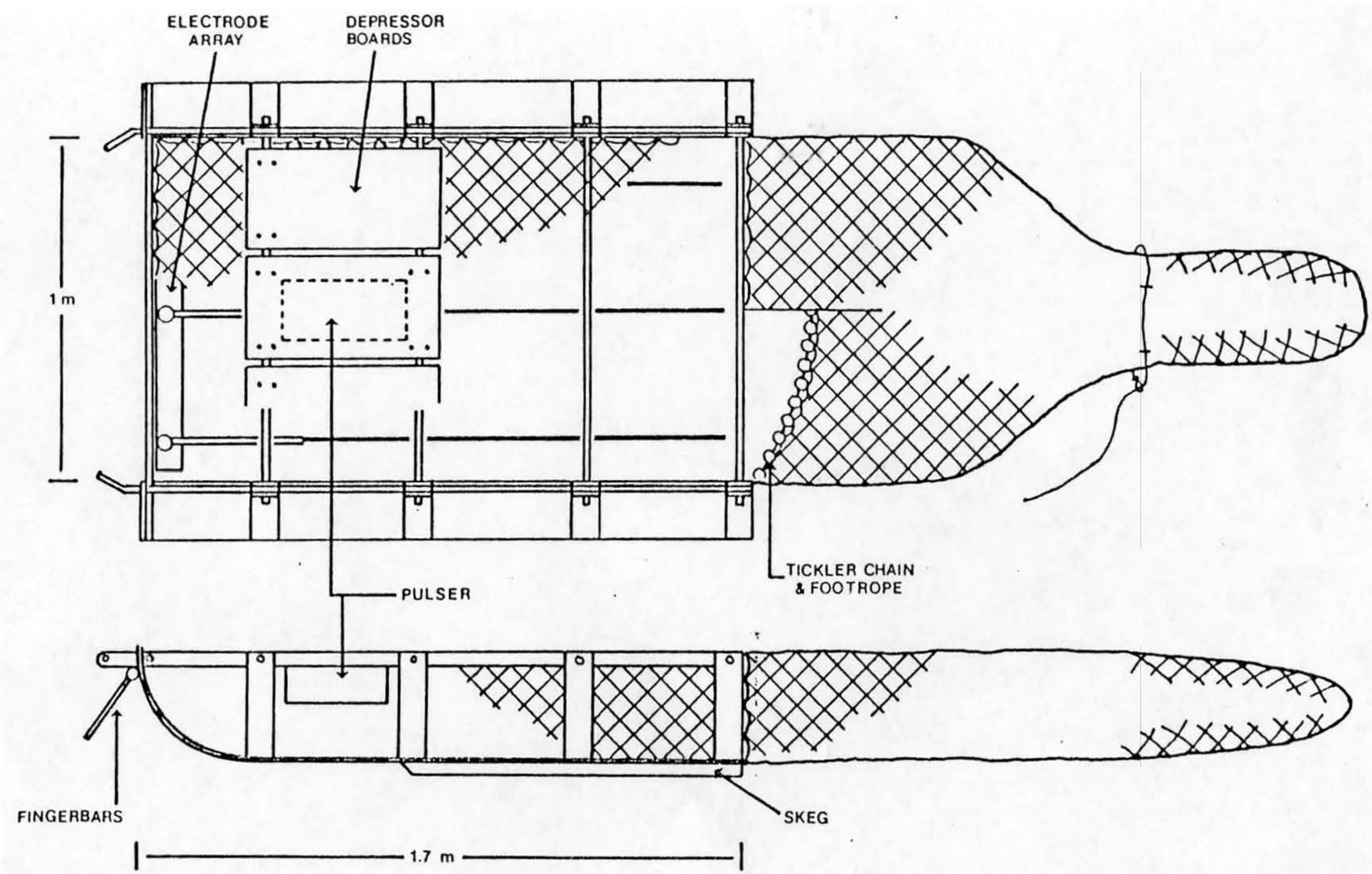


Figure 1. Electrified shrimp trawl.

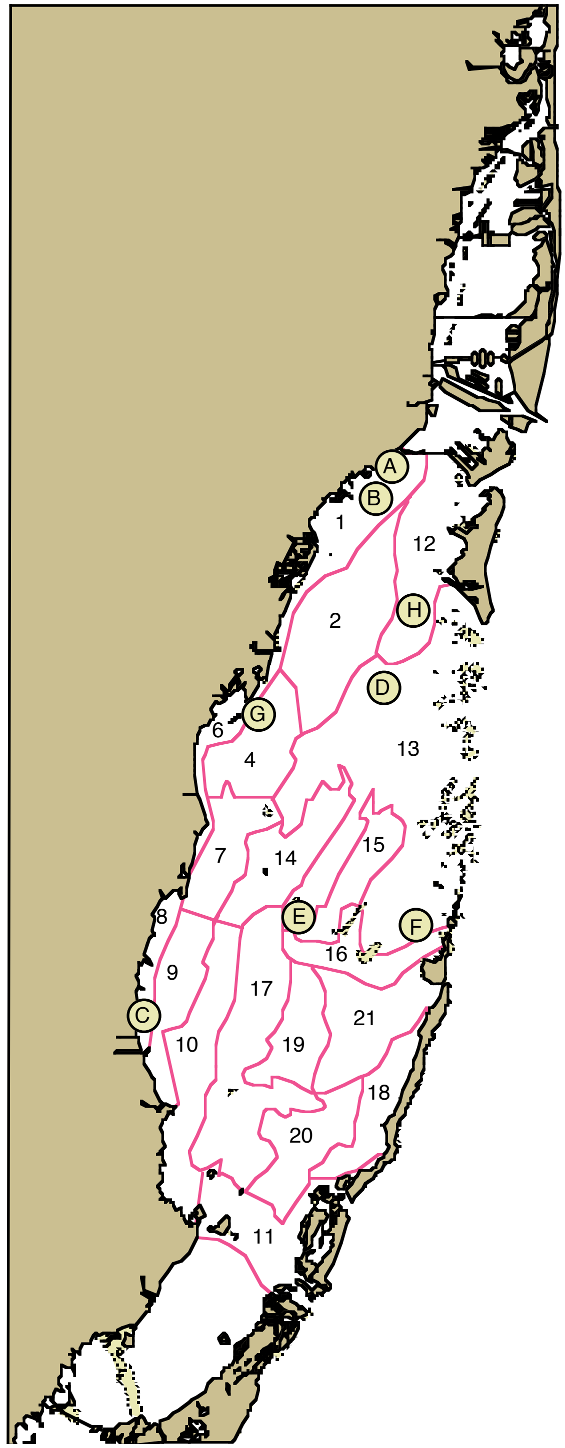


Figure 2. Eight sites (A to H) used in gear-testing and 19 subareas (1 to 21) sampled in south Biscayne Bay from December 1984 to July 1985. [NOTE: Current charts were used in all figures. Dodge Island (Port of Miami) and other areas in the Bay have changed since 1983.]

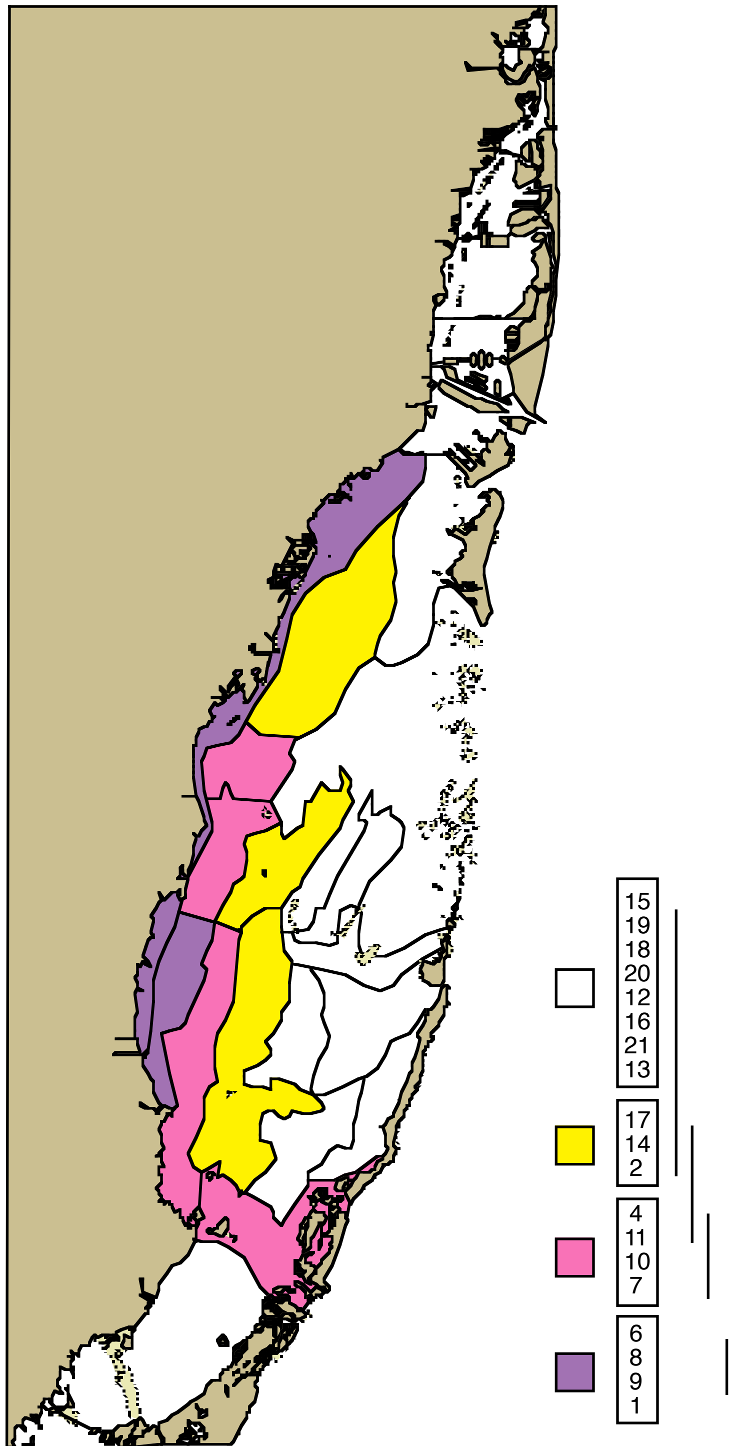


Figure 3. Map showing four clusters of subareas with similar shrimp densities and the results of Duncan's multiple comparisons test (= 0.10). [NOTE: Current charts were used in all figures. Dodge Island (Port of Miami) and other areas in the Bay have changed since 1983.]

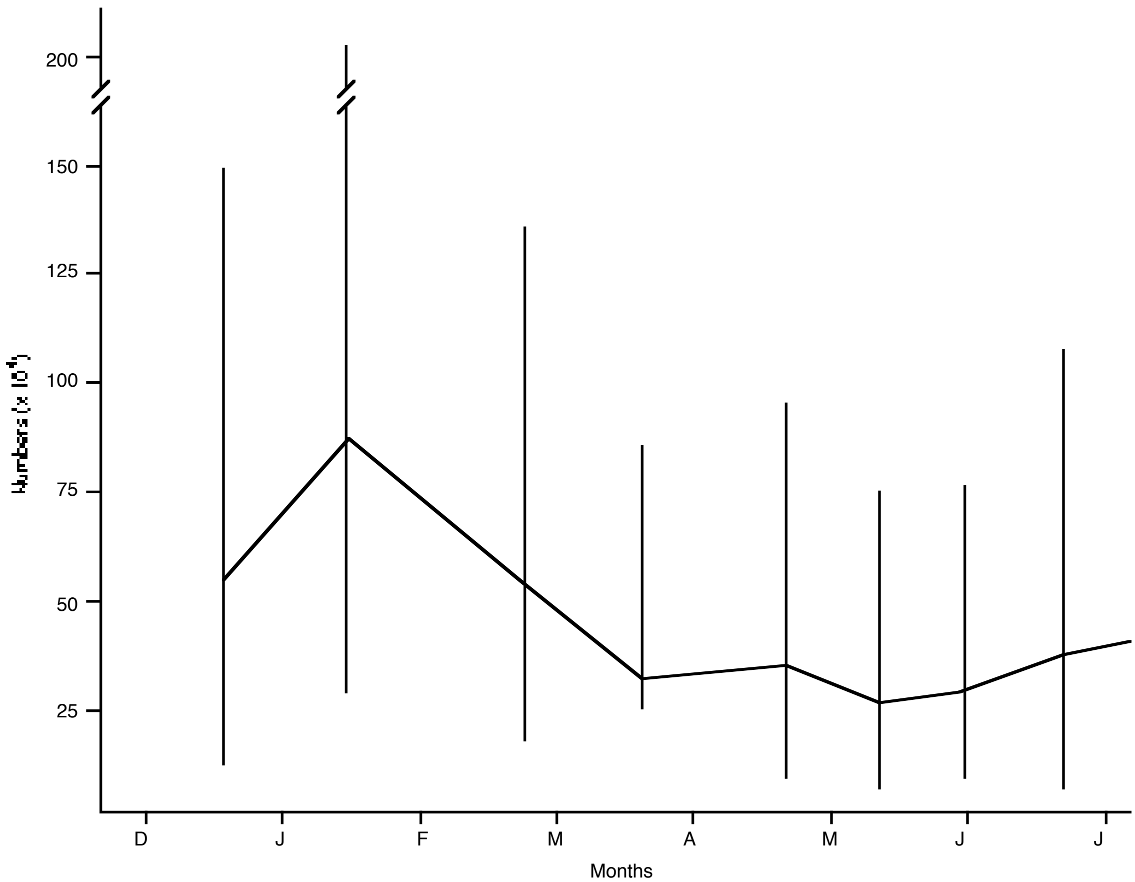


Figure 4. Mean and 95% confidence limits of population size of bait shrimp, (December 1984 to July 1985).

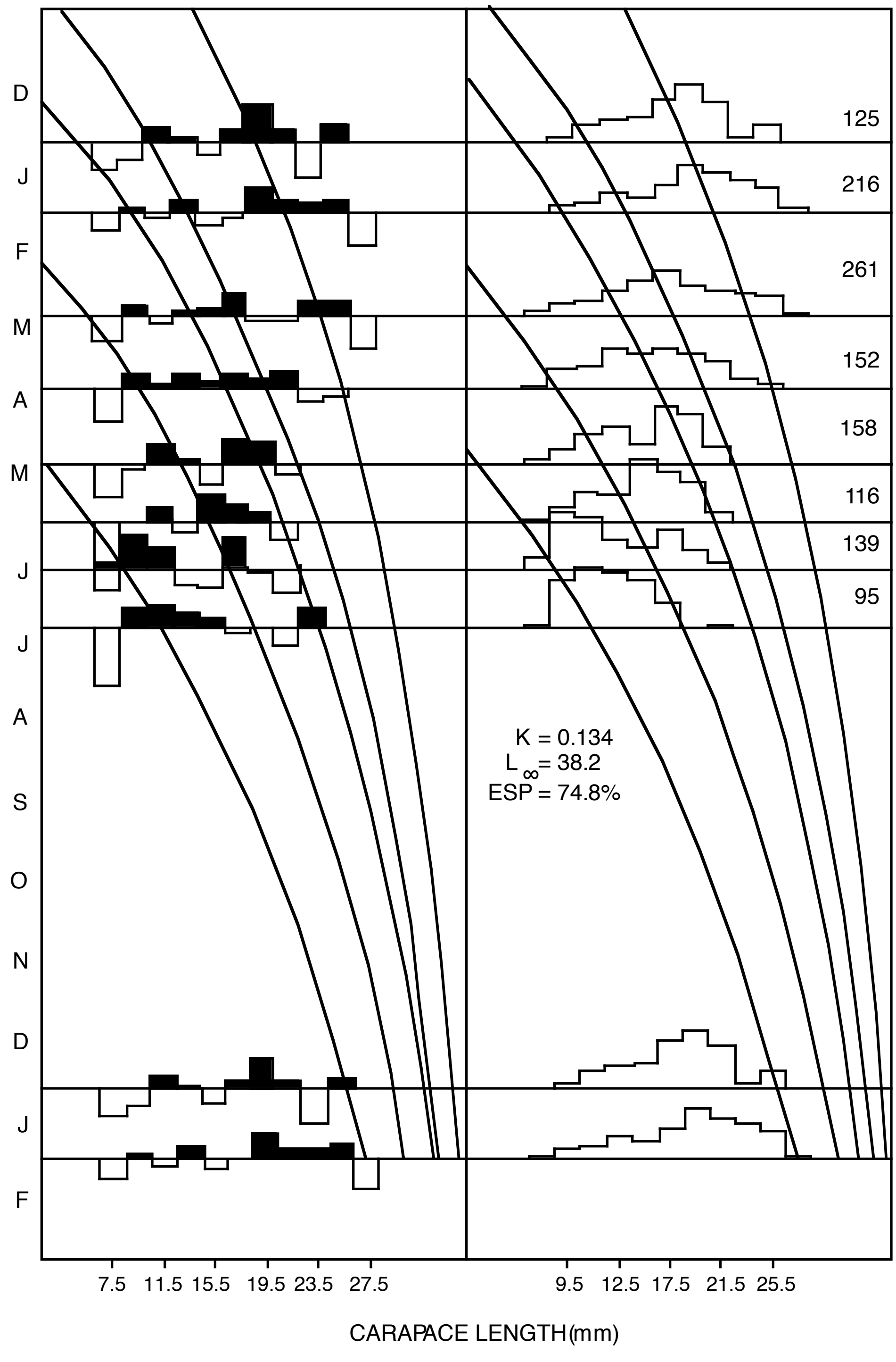


Figure 5a. Growth curves superimposed on percent (right) and restructured (left, Pauly *et al.*, 1980) length frequency distribution of male *Penaeus duorarum* in south Biscayne Bay, (December 1984 to June 1985).

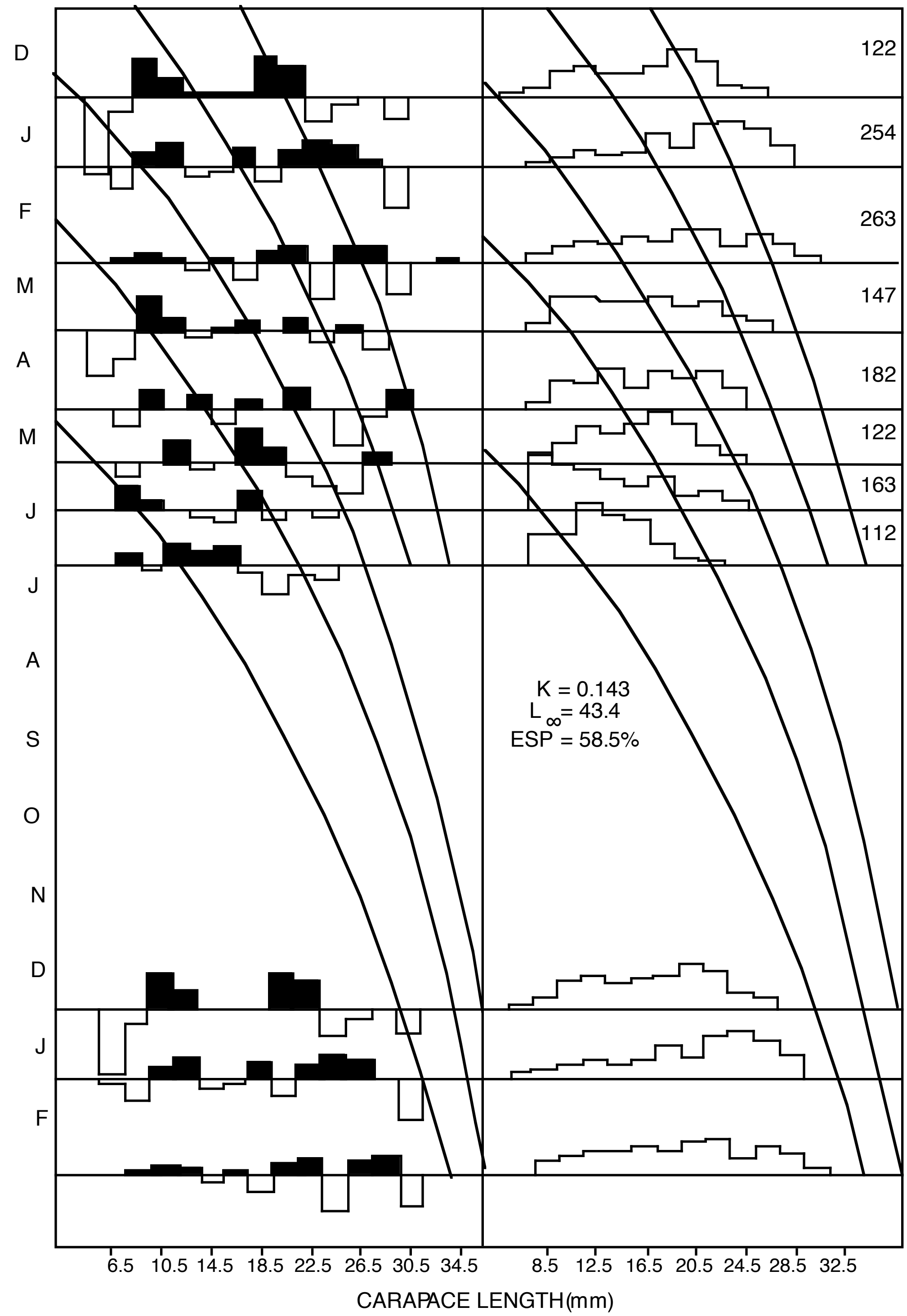
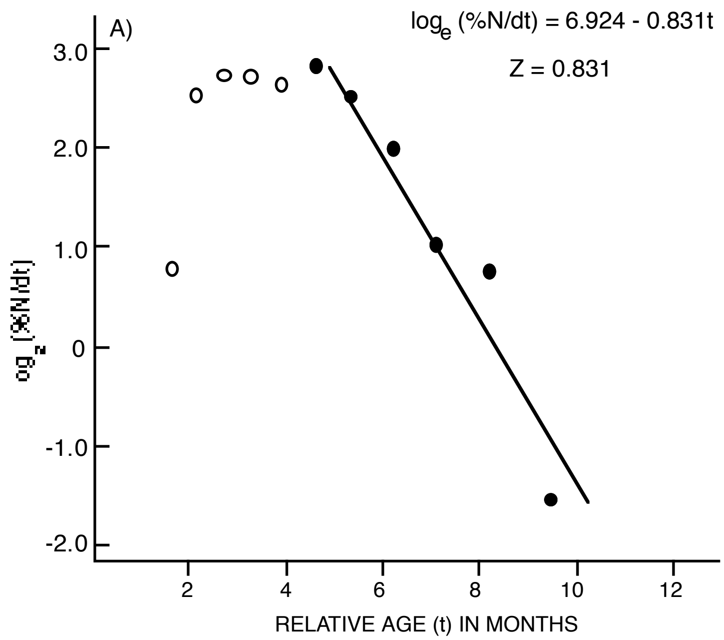


Figure 5b. Growth curves superimposed on percent (right) and restructured (left, Pauly *et al.*, 1980) length frequency distribution of female *Penaeus duorarum* in south Biscayne Bay, (December 1984 to June 1985).



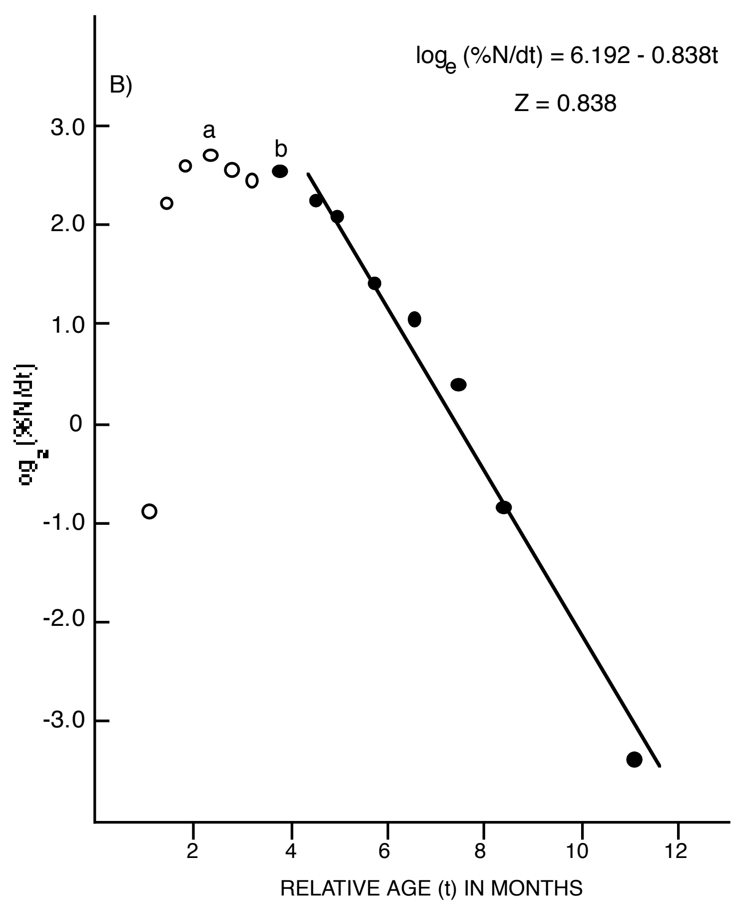


Figure 6. Catch curves for A) male and B) female *P. duorarum* in south Biscayne Bay, December 1984 to June 1985. Solid circles show points used in the least-squares regression.

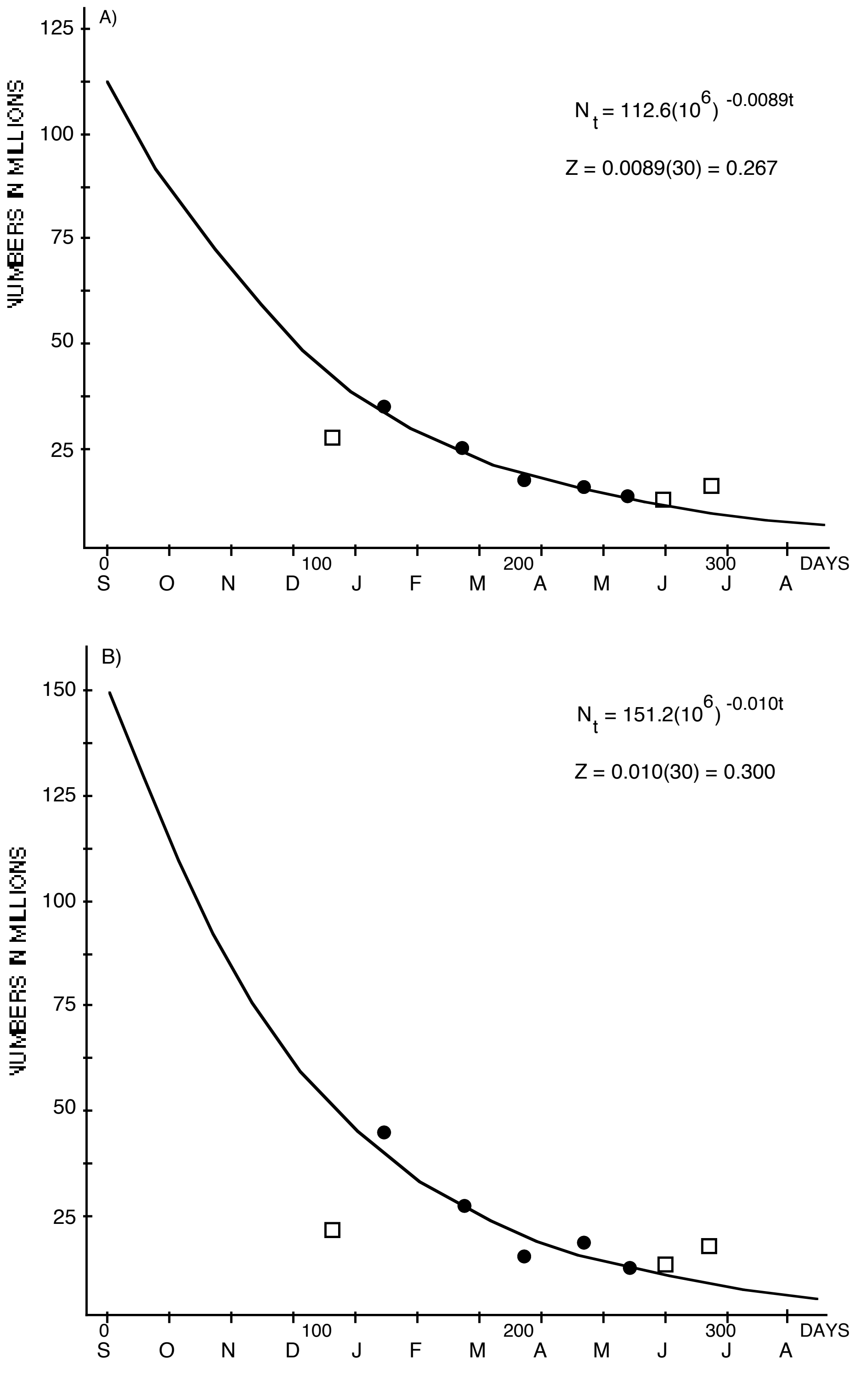


Figure 7. Exponential curves fit to mean population size estimates of A) male and B) female *P. duorarum* in south Biscayne Bay. Solid circles show points used in curve fitting. Open squares are points not used in curve fitting.

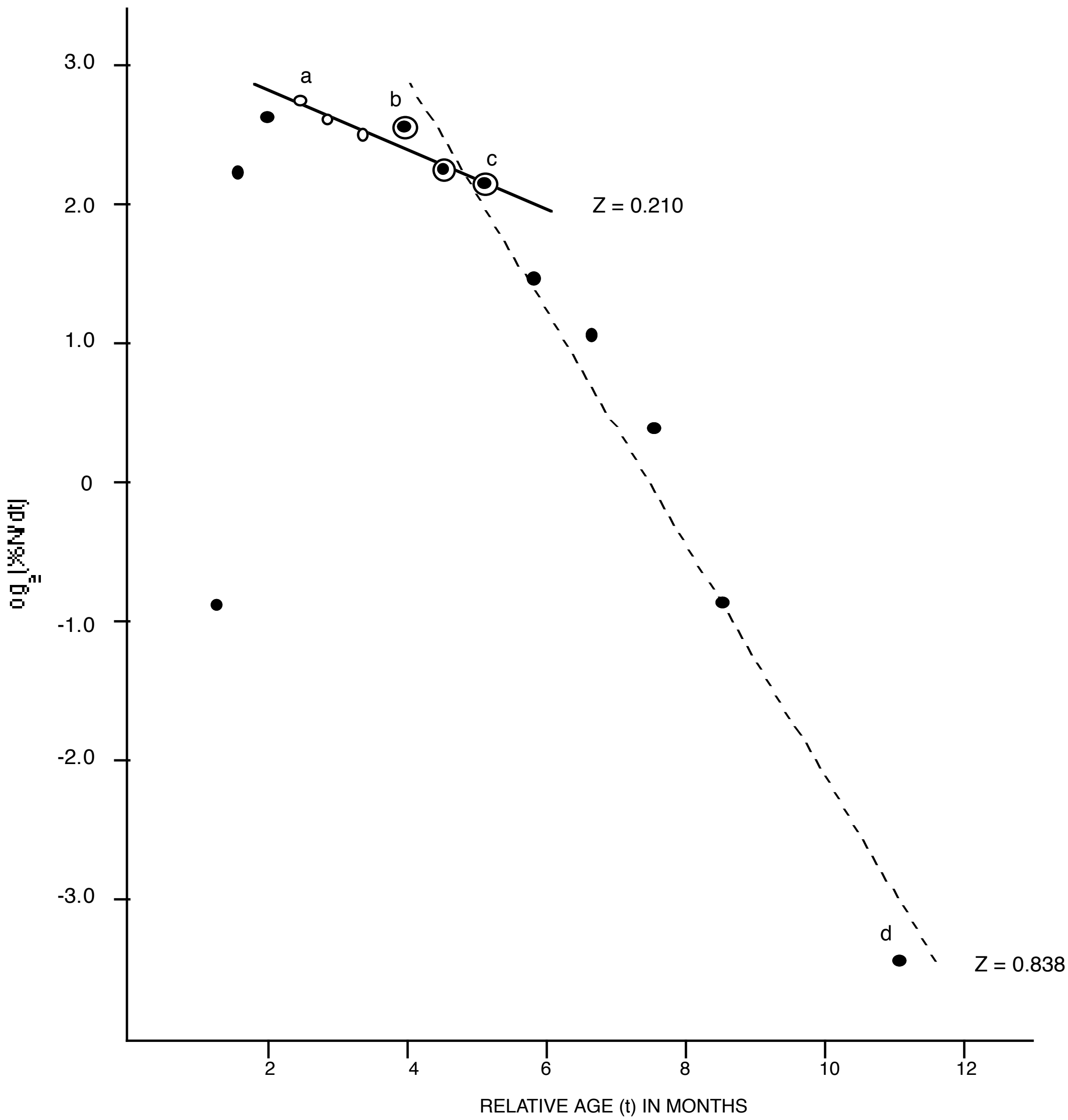


Figure 8. Catch curve for female *P. duorarum* depicting change in rate of total loss (December 1984 to June 1985).

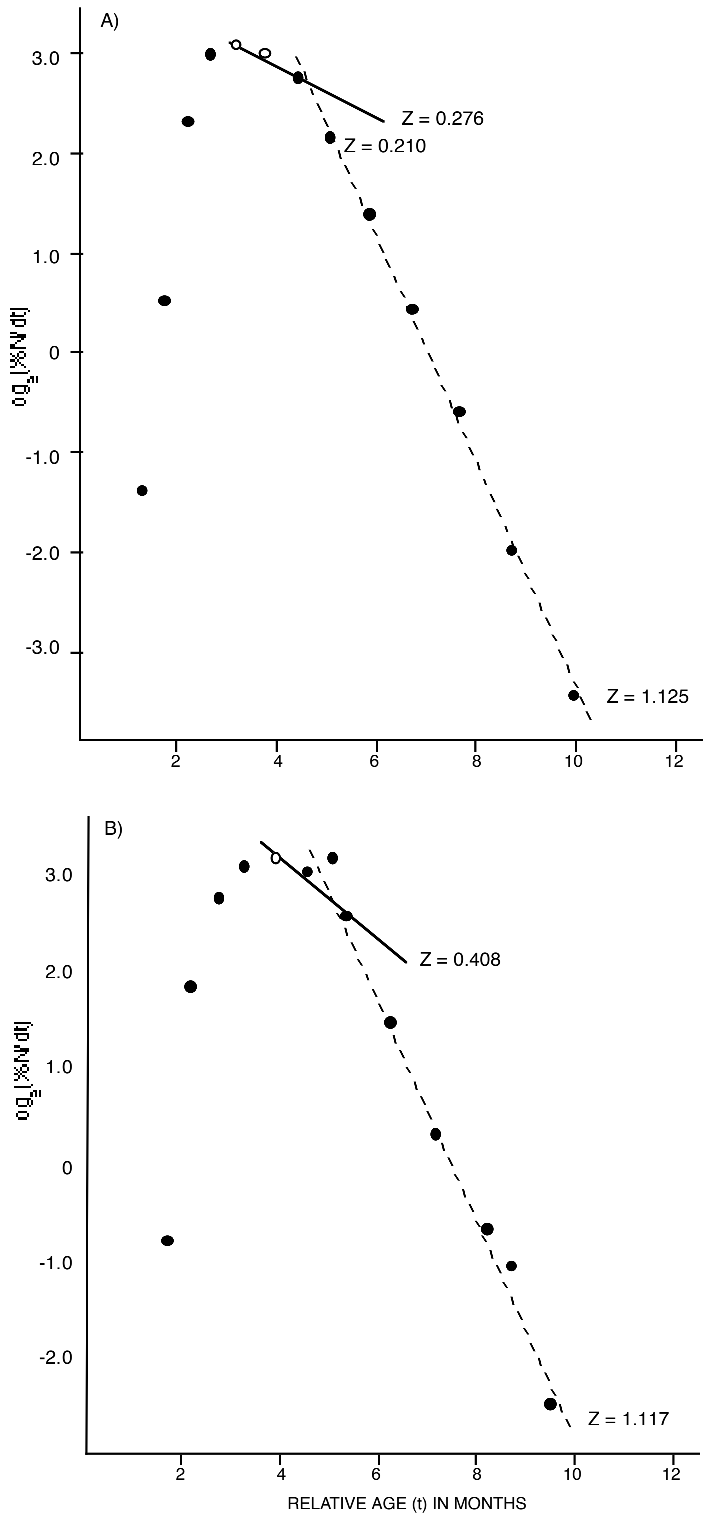


Figure 9. Catch curves showing change in rate of total 10S5 of *P. duorarum*. A) trawl data for combined sexes (April 1982 - March 1983). B) commercial samples for males *P. duorarum* (December 1981 to November 1983).

Table 1. Within-site, among-site (within-area), and among-area comparisons of mean shrimp density from throw trap/suction dredge samples collected at six grassbed sites in Biscayne Bay in November 1984.

a) Within-site comparisons

set	n	x	sd	Barlett's test	ANOVA	set	n	x	sd	F-test	V-test
			SITE B						SITE E		
1	6	1.33	0.82			1	5	0.60	0.89		
				b=1.12	F= 1.16					F=8.00	t'=1.21
2	17	1.06	1.44	(p>0.05)	(p>0.05)	2	10	0.10	0.32	(p< 0.0 1)	(p>0.05)
3	4	2.00	1.41								

b) Among-site comparisons (within-area)

			WEST BAY						EAST BAY		
A	7	1.14	1.46			D	6	0.33	0.52		
				b= 1.90	F=0.61					b=0.43	F=0.08
B	27	1.26	1.13	(p>0.05)	(p>0.05)	E	15	0.27	0.59	(p>0.05)	(p>0.05)
C	7	0.71	0.95			F	5	0.20	0.45		

c) Among-area comparison

area	n	V	5d	F-test	t'-test
WEST BAY	3	1.04	0.29	F=21.00	t'=4.50
EAST BAY	3	0.27	0.06	(p<0.05)	(p<0.05)

Table 2. Mean density of bait shrimp, standard deviation, number of samples, and surface area sampled in four subarea clusters in Biscayne Bay, from December 1984 to July 1985.

Month	Cluster[Δ]	Mean Density ($\#/m^2$)	Standard Deviation	No. of Samples (n)	Surface Area Sampled (m^2)
December 1984	I	0.319	0.540	27	1350
	II	0.134	0.171	28	1400
	III	0.067	0.094	17	850
	IV	0.055	0.073	28	1400
January 1985	I	0.335	0.272	25	1746
	II	0.303	0.188	19	1489
	III	0.111	0.135	16	835
	IV	0.109	0.098	23	1998
February	I	0.372	0.382	28	1400
	II	0.154	0.113	31	1550
	III	0.106	0.108	19	950
	IV	0.034	0.038	43	2150
March	I	0.216	0.252	24	1200
	II	0.132	0.099	31	1550
	III	0.044	0.039	18	900
	IV	0.018	0.020	33	1650
April	I	0.243	0.425	28	1400
	II	0.107	0.078	31	1550
	III	0.081	0.065	19	950
	IV	0.012	0.021	42	2100
1 May	I	0.185	0.328	28	1400
	II	0.082	0.071	31	1550
	III	0.066	0.073	19	950
	IV	0.011	0.022	42	2100
2 May	I	0.202	0.206	28	1400
	II	0.105	0.103	31	1750
	III	0.053	0.089	19	1250
	IV	0.012	0.020	42	4150
June	I	0.233	0.153	19	950
	II	0.084	0.076	15	750
	III	0.075	0.126	10	600
	IV	0.034	0.068	14	1350
July	I	0.192	0.220	19	950
	II	0.090	0.091	15	750
	III	0.134	0.153	8	400
	IV	---	---	--	--

[Δ] Total surface area (in km^2) of each cluster are: I = 57.906, II = 88.480, III = 108.352, IV = 253.911.

Table 3. Estimates of mean population size of bait shrimp, and their lower and upper confidence limits at the mid-point of each sampling period from December 1984 to July 1985. Mean population size for July 1985 was approximated (see text).

Sampling Period (mid-point)	Mean Population Size	Lower Limit	Upper Limit
December 17, 1984	51,657,064	12,207,152	145,529,517
January 13, 1985	85,836,148	27,966,810	204,063,722
February 21	55,268,453	17,453,732	134,014,652
March 21	33,395,253	9,722,180	84,140,953
April 20	35,391,074	7,711,240	94,386,718
1 May 12	27,859,708	7,174,381	74,845,825
2 May 30	29,822,245	8,600,056	76,464,303
June 22	37,756,837	7,040,527	106,509,168
July 6	40,748,509	---	---

Table 4. Monthly mean number of boats fishing per night from each shrimp dock (number of samples in parentheses), for all docks combined, and monthly total effort in boat-nights from December 1984 to July 1985.

MONTH	VIRGINIA KEY$^{\Delta}$	DINNER KEY	BLACK POINT	ALL DOCKS COMBINED	DAYS IN THE MONTH	MONTHLY TOTAL EFFORT
December '84	1.6	5.5 (4)	8.5 (2)	15.6	31	483.6
January '85	1.6	7.6 (11)	10.6 (9)	19.8	31	613.8
February	1.6	9.0 (11)	10.0 (23)	20.6	28	576.8
March	1.9 (14)	7.6 (14)	8.5 (13)	18.0	31	558.0
April	1.7 (12)	6.3 (9)	6.8 (10)	14.8	30	444.0
May	1.8 (11)	7.8 (14)	8.1 (15)	17.7	31	548.7
June	1.5 (10)	6.2 (12)	7.8 (12)	15.5	30	465.0
July	1.3 (3)	6.6 (5)	8.8 (5)	16.7	31	517.7
Total						4207.6

$^{\Delta}$ Mean effort was used for December, January and February

Table 5. Mean catch per boat-night (CPUE), standard error, sample size, and monthly total catch of bait shrimp by the fleet in Biscayne Bay from September 1984 to August 1985.

Month	Sample Size	Mean CPUE	Standard Error	Monthly Total Catch
September 1984	91	6385	200	3,321,279
October	86	5936	135	3,190,627
November	85	7162	242	3,725,548
December	175	7476	211	3,615,253
January 1985	143	9194	277	5,643,314
February	176	8224	204	4,743,851
March	181	7442	266	4,152,630
April	212	6248	166	2,773,952
May	199	5436	149	2,982,558
June	209	5752	141	2,674,861
July	105	5410	229	2,800,508
August	---	6759◊	---	3,633,156
Total	1662			

◊ Overall mean CPUE

Table 6. Estimates of mean population size ($\bar{N}$) derived from fitted exponential curves, monthly catch by the fleet (C), and instantaneous monthly fishing mortality rate (F) for male and female *P. duorarum* in Biscayne Bay from September 1984 to August 1985.

	MALES			FEMALES		
Month	Derived Estimate of Mean Population Size ($\bar{N}$)	Monthly Catch By Fleet (C)	$F = C / \bar{N}$	Derived Estimate of Mean Population Size ($\bar{N}$)	Monthly Catch By Fleet (C)	$F = C / \bar{N}$
September 1984	98,572,216	1,572,615	0.016	130,111,200	1,642,051	0.013
October	75,474,092	1,510,751	0.020	96,388,745	1,577,457	0.016
November	57,276,444	1,764,035	0.031	70,696,032	1,841,923	0.026
December	43,855,031	1,972,531	0.045	52,372,908	1,524,865	0.029
January 1985	33,281,092	2,453,362	0.074	38,412,750	3,109,817	0.081
February	25,256,649	2,238,713	0.089	28,173,715	2,330,090	0.083
March	19,685,640	2,098,965	0.107	21,293,236	1,876,348	0.088
April	14,939,212	1,226,257	0.082	15,617,459	1,451,161	0.093
May	11,438,552	1,383,925	0.121	11,569,698	1,496,018	0.129
June	8,758,192	1,226,347	0.140	8,571,043	1,377,363	0.161
July	6,705,911	1,326,031	0.198	6,349,585	1,384,581	0.281
August	5,089,041	1,615,776[Δ]	0.318	4,657,084	1,782,879[Δ]	0.383
			mean F = 0.074[◊]			mean F = 0.070[◊]

[Δ] Calculated from overall mean CPUE (=6759) x mean effort (=537.5) for the period September 1984 to July 1985.

[◊] Geometric mean

Table 7. Estimates of monthly mortality rates and exploitation rates for male and female *P. duorarum* in Biscayne Bay from September 1984 to August 1985.

		MALES		FEMALES	
		Exponential Curve	Catch Curve	Exponential Curve	Catch Curve
Instantaneous Total Monthly Mortality Rate	Z	0.267	0.831	0.300	0.838
Actual Total Monthly Mortality Rate $1 - e^{-Z}$	A	0.234	0.564	0.259	0.567
Instantaneous Monthly Fishing Mortality Rate	F	0.074	0.074	0.070	0.070
Exploitation Rate FA/Z	u	0.065	0.050	0.060	0.047
Instantaneous Natural Monthly Mortality Rate Z - F	M	0.193	0.757	0.230	0.768
Instantaneous Natural Monthly Mortality Rate (Pauly, 1980)	M	0.249		0.250	

Table 8. Estimates of mean population size of bait shrimp, total catch by the fleet, and percent total catch of mean population size for each sampling period in Biscayne Bay from December 1984 to July 1985.

Sampling Period (mid-point)	Estimate of Mean Population Size	Monthly Total Catch By Fleet	%
December 17, 1984	51,657,064	3,615,253	7.0
January 13, 1985	85,836,148	5,643,314	6.6
February 21	55,268,453	4,743,851	8.6
March 21	33,395,253	4,152,630	12.4
April 20	35,391,074	2,773,952	7.8
May 21◊	28,840,976	2,982,558	10.3
June 22	37,756,837	2,674,861	7.1
July 6Δ	40,748,509	2,800,508	6.9

◊ Mean population size of 2 sampling periods (1 May and 2 May).

Δ Mean population size approximated (see text).