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Abundance and Distribution of Pink Shrimp in and around the Tortugas Sanctuary, 1981–1983

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Abstract.—Size and abundance of pink shrimp (*Penaeus duorarum*) in and around the Tortugas sanctuary in the Gulf of Mexico were surveyed monthly from September 1981 through July 1983. Samples were not taken in April and June 1983. Shrimp size varied widely at most stations and abundance varied between stations, but the average size increased with increasing depth and abundance decreased with increasing depth. A large proportion of small shrimp (<103 mm total length) in all samples combined monthly were caught inside the sanctuary, but their abundance varied monthly and annually. Small pink shrimp dominated the catch from fewer than half the stations inside the sanctuary in September–December 1981 but increased in abundance and dominated half or more of the stations inside the sanctuary in January–December 1982 and February–May 1983. January and July were the only months in which catches from at least half the stations inside the sanctuary were composed mostly of shrimp at least 103 mm long in 1983. Recruitment was continuous but uneven throughout the survey. Peak months of recruitment varied annually, occurring in January and July–September 1982 and in January and March 1983. Small shrimp were less abundant outside the sanctuary but peaks in abundance at some stations outside the sanctuary, indicating strong recruitment, occurred in January and July–August 1982 and in March 1983. Conservative population estimates (±95% confidence intervals) for the Tortugas fishing ground for September 1982–July 1983 varied from 11.8 (±5.3) × 10^6 pink shrimp in July to 52.7 (± 12.8) × 10^6 pink shrimp in March. Although the trawlable area inside the southwestern sanctuary accounted for only 6% of the total trawlable area covered by the survey, the sanctuary contained an average of 36% of the total estimated pink shrimp population.

The Tortugas fishing ground (Figure 1) is a relatively small area of about 10,000 km^2 located north and west of Key West, Florida (Costello and Allen 1968). The area is the largest source of pink shrimp (*Penaeus duorarum*) in the United States, from which 4.5 million kg of tails, on average, were landed annually from 1960 through 1981 (Klima and Costello 1982). Unlike brown shrimp (*Penaeus aztecus*) and white shrimp (*Penaeus setiferus*) fisheries in the northern and western Gulf of Mexico and the south Atlantic Ocean, pink shrimp have a continuous but uneven recruitment throughout the year to the Tortugas ground and support a broad peak in commercial catches from October through April (Klima et al. 1982). Because the other shrimp fisheries generally have low production during the winter months, much of the shrimp fleet activity shifts to the Tortugas grounds; 600 or more vessels trawl in the area in some years (Klima and Costello 1982). In recent years, this fishing effort has been concentrated into a diminishing area in shallow water closer to Key West due to increasing fuel costs and decreasing shrimp abundance, causing widespread concern in the industry that the shrimp population may be declining.

The Gulf of Mexico Fishery Management Council (GMFMC), which has authority to regulate fishing in the Fishery Conservation Zone (FCZ), recommended in 1980 that a year-round shrimp sanctuary (Figure 1), closed to all shrimping, be established off southwest Florida in order to increase production on the Tortugas ground (GMFMC 1980). The proposed boundary was based on size-distribution data for pink shrimp from earlier research (Ingle et al. 1959; Iversen and Idyll 1959, 1960; Costello and Allen 1960; Iversen et al. 1960; Eldred et al. 1961; Iversen and Jones 1961) and was intended to protect small pink shrimp until they reached a total length of about 103 mm (69 tails to the pound). Research by Lindner (1966) and Berry (1970) on growth and mortality of pink shrimp indicated that yield would be maximized if harvest were limited to this size or larger. However, many individuals in the commercial shrimping industry, while agreeing to the need for a sanctuary east of the existing straight line extending southward from Cape Romano to protect nursery areas in Florida Bay (Figure 1), objected to the westward extension of the sanctuary to the Marquesas Keys (known as the "boot"). Earlier research indicated pink shrimp moved outside the boot to deeper waters as they grew larger than 103 mm, but many commercial shrimpers

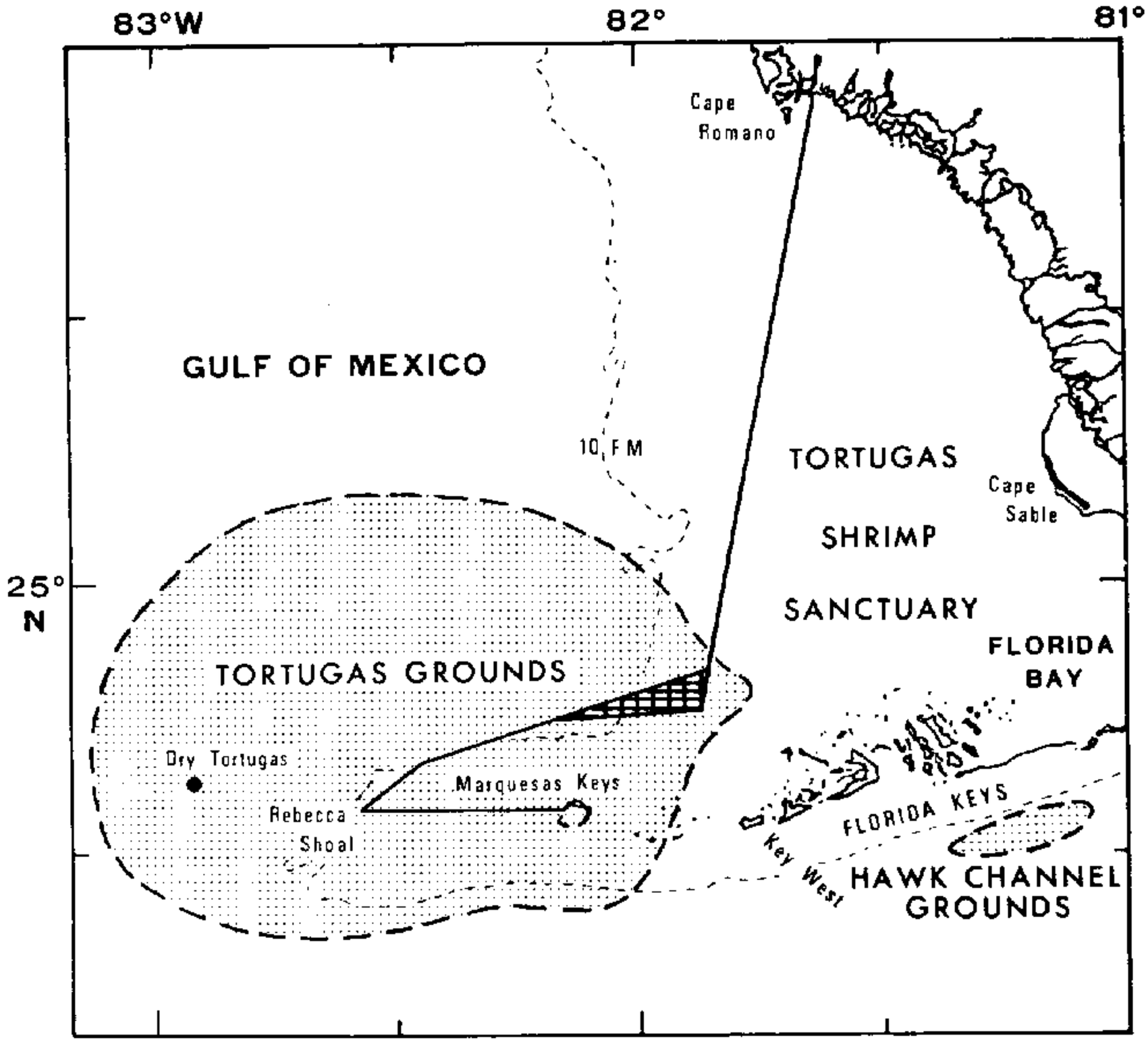

FIGURE 1.—The Tortugas fishing ground (enclosed by the dashed line) and the 1981 pink shrimp sanctuary (solid line). The northeastern part of the southwestern boot represented by cross-hatching was opened to commercial trawling April 15, 1983, and closed again on August 14, 1984.

and operators believed shrimp in the boot remained there, and that prohibition of trawling in the area would only decrease production and cause financial hardship. Another concern among some in the seafood industry over a prohibition of trawling for small shrimp was that modern technology enabled them to utilize smaller shrimp without waste; these shrimp had become more valuable to many of the smaller packing houses, and it was not in their financial interest to prohibit trawling inside the boot of the sanctuary.

The sanctuary was established on May 15, 1981. The National Marine Fisheries Service (NMFS) sampled the shrimp population in and near the boot from September 1981 through August 1982 to determine pink shrimp size and abundance distributions relative to the east–west sanctuary line so recommendations could be made to the council on whether the line should be moved north or south to provide better coverage of small shrimp. The area east of the north–south sanctuary line was not sampled regularly or extensively because of problems with crab traps and the rough sponge–coral bottom located throughout the shallow waters of Florida Bay. Before the survey was completed, an interim report (Roberts 1982) on the September–February results was presented to the council. The council extended the survey to July 1983 and enlarged it to cover all of the Tortugas fishing ground to (1) monitor the size and abundance distribution of pink shrimp inside the 1981 sanctuary, (2) determine the temporal and spatial range of small shrimp in the deeper waters of the fishing ground to the north and west of the boot, and (3) provide an estimate of the pink shrimp population on the ground. The council also opened a portion of the boot to commercial trawling (Figure 1) on April 15, 1983, but closed it again on August 14, 1984.

In this report, I describe pink shrimp size and abundance distributions in and near the sanctuary boot (1981–1982) and over most of the fishing ground (1982–1983) and estimate the pink shrimp population from September 1982 to July 1983. An analysis of the effectiveness of the closure is presented in Klima et al. (1986a, this issue) and a

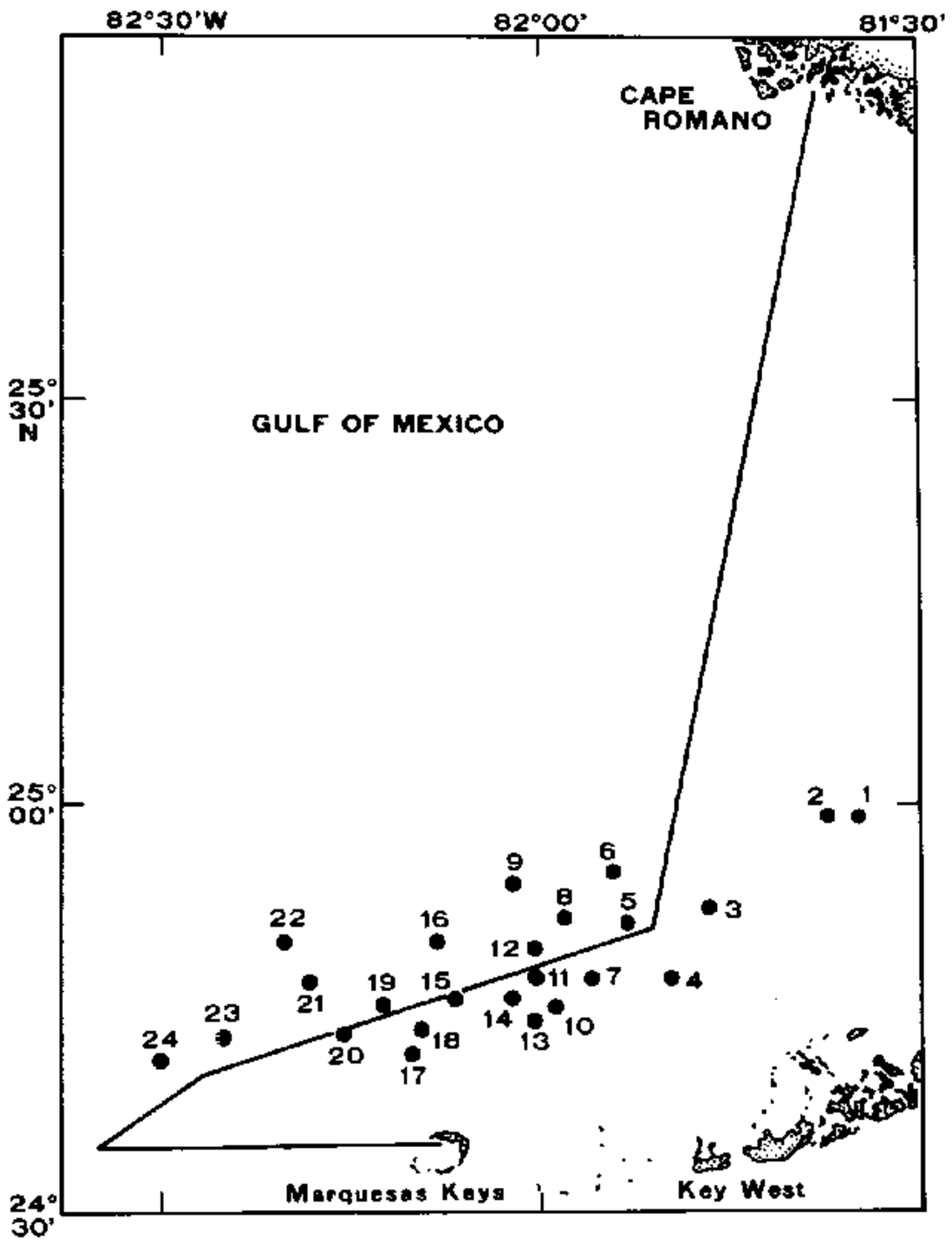

FIGURE 2.—The 1981 Tortugas sanctuary and the 24 stations selected for monthly sampling of pink shrimp, 1981–1982. Stations 1 and 2 were excluded from data analysis due to lack of data.

review of the actions taken by the GMFMC and NMFS is presented in Klima et al. (1986b, this issue).

Methods

Field Operations and Survey Design

1981–1982.—Twenty-four fixed stations ranging in depth from 11 to 25 m were sampled at night during a 1-week cruise once a month from September 1981 through August 1982 (Figure 2). Stations 1 and 2 were sampled infrequently due to the large number of crab traps scattered throughout the area and were later excluded from the data analysis. The M/V *Miss Virginia*, a 22.9-m commercial shrimp trawler rigged with four 12.2-m flat trawls, tickler chains, and 1.0 × 2.4-m doors, was used to sample the shrimp population. Four nets were used because of the difficulty in changing the rigging to tow only one or two nets as originally planned, and the extra nets provided backup data if one or more nets were fouled or damaged. The body of each net had 4.45-cm stretched mesh and the codend was made of 3.3-cm stretched mesh. The path of each 30-min tow and station position

TABLE 1.—Location and depths of Tortugas pink shrimp survey stations (September 1981–August 1982). Asterisks indicate stations inside the sanctuary.

Station	North latitude	West longitude	Depth (m)
1*	24°59′	81°35′	11
2*	24°59′	81°37′	11
3*	24°52′	81°46′	14
4*	24°47′	81°49′	16
5	24°51′	81°53′	16
6	24°55′	81°54′	16
7*	24°47′	81°56′	16
8	24°52′	81°58′	18
9	24°54′	82°02′	22
10*	24°45′	81°59′	16
11*	24°47′	82°00′	18
12	24°49′	82°00′	18
13*	24°44′	82°00′	16
14*	24°46′	82°02′	18
15*	24°45′	82°07′	20
16	24°50′	82°08′	23
17*	24°41′	82°10′	14
18*	24°43′	82°10′	18
19	24°45′	82°12′	20
20*	24°43′	82°15′	20
21	24°43′	82°19′	20
22	24°50′	82°20′	25
23	24°43′	82°25′	20
24	24°41′	82°30′	22

(Table 1) were recorded on each visit by a Loran C plotter, which has an accuracy in the Florida Keys of 30–60 m, to ensure that successive monthly tows were reasonably close to each other.

Because large sample volumes were collected by four nets towed simultaneously, only the total shrimp weight was taken from each outboard net. Data recorded from each inboard net included total catch (except large sponges), total fish weight, total shrimp weight, and miscellaneous weight (invertebrates). A random sample of 200 pink shrimp (or all of the sample if less than 200) was taken from the port inboard net for determinations of sex ratio and ovary development, and measurements of weight and total length (tip of rostrum to tip of telson). A random sample of 1.36 kg of shrimp was removed from the starboard inboard net to determine the shrimp count. This count was used to convert the total shrimp weight from all nets to the total number of shrimp caught at a station. Another 2.27-kg random sample of shrimp was removed from the starboard inboard net and frozen for return to the Galveston Laboratory where total lengths, weights, and detailed species composition were determined.

Surface and bottom water temperature and salinity were recorded at each station prior to trawl-

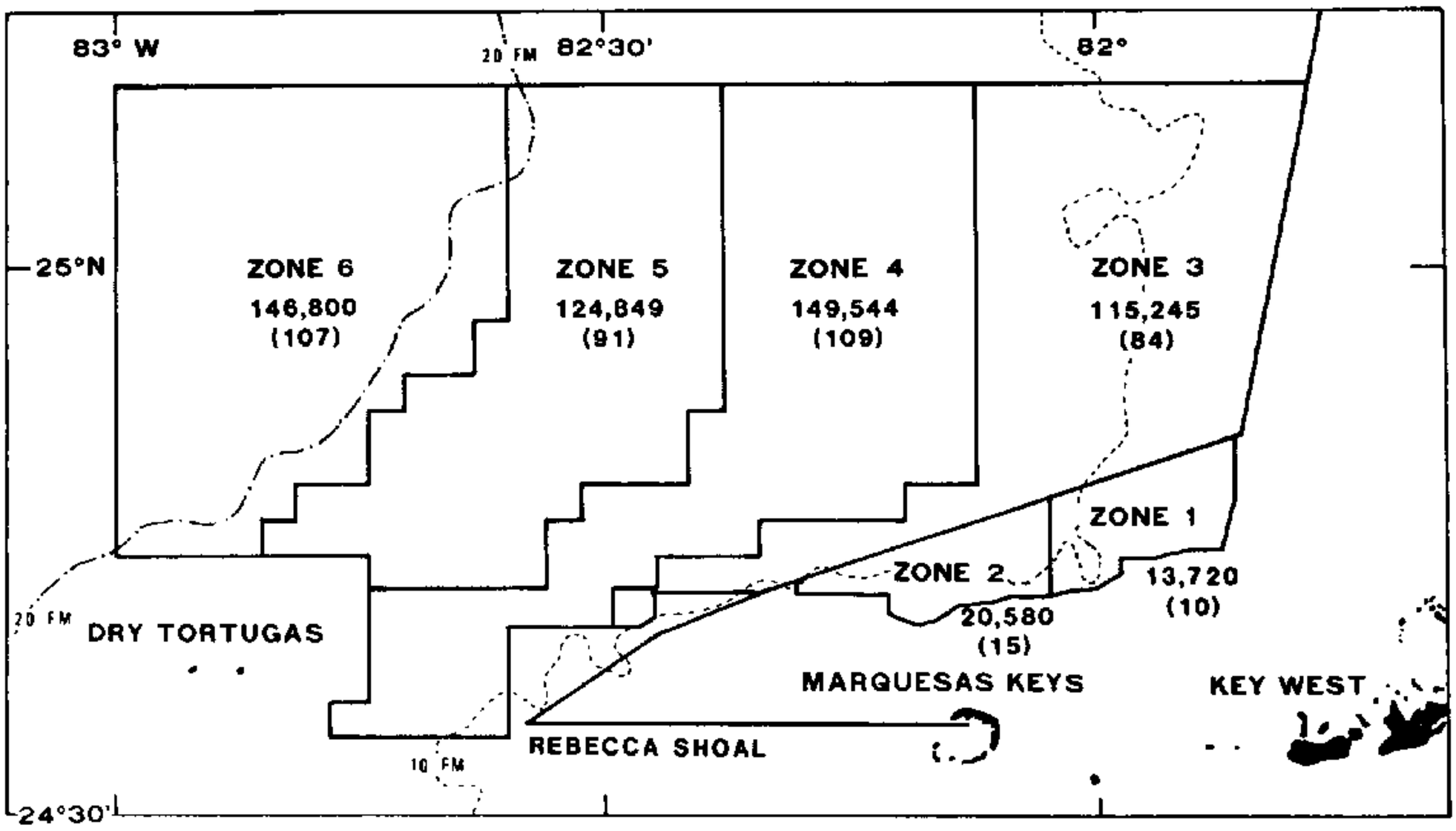

FIGURE 3.—The Tortugas survey area with the six zones used in 1982–1983 survey, trawlable areas in hectares, number of trawlable grids (in parentheses), the 10- and 20-fathom contours and the 1981 sanctuary boundary. The southern boundary of zones 1 and 2 is the reef line inside the sanctuary.

ing to document temporal or spatial changes in these variables during the study. A mercury thermometer (±0.1°C) and an optical refractometer (±0.5‰) were used to record them.

1982–1983.—The survey area was increased to cover more than 570,000 hectares of trawlable bottom in 1982–1983 (Figure 3). The area was bounded on the east by the north–south sanctuary line, on the north by 25°10′N latitude, on the west by 83°W longitude, and on the south between the Dry Tortugas and Rebecca Shoal by 24°34′N latitude and from Rebecca Shoal to the north–south sanctuary boundary by the reef line inside the sanctuary. Although pink shrimp occur along a narrow strip of continental shelf south of the Florida Keys, this area was not included in the survey because shrimp harvest is insignificant there, travel time is excessive, and numerous obstacles make trawling hazardous.

A stratified random sampling design was employed in the 1982–1983 survey because of time and budget limitations and the increased sampling area. Dividing the fishing ground into relatively homogeneous zones (strata) reduced the variance in sample weight, numbers, and pink shrimp length as well as the number of sampling stations necessary compared to a completely random design (Cochran 1977). Systematic errors due to shrimp avoidance or aggregation and periodic occurrences of shrimp near fixed stations were reduced by randomly selecting stations in a zone each month. Depth was used to delimit the zones outside the sanctuary based on previous Tortugas research, which found pink shrimp size to be directly related to depth and abundance (numbers or weight) to be inversely related to depth (Iversen et al. 1960; Eldred et al. 1961; Iversen and Jones 1961; Berry 1967). However, the number of zones or the depth interval for each zone needed to achieve homogeneity could not be determined from the earlier research; therefore, the area outside the sanctuary was divided arbitrarily into four zones. Zones 3–6 were designed to be as equal in area as depth contours allowed, and depth ranges were 16–22 m, 23–27 m, 28–35 m, and 36–51 m, respectively (Figure 3). The area inside the sanctuary was equally divided into an eastern and western zone based on an east–west shrimp size trend that occurred during part of the 1981–1982 survey, and on the high pink shrimp abundance and sample variance (numbers and weight) inside the sanctuary. Equal division of the sanctuary into zones about one-sixth the area of each zone outside the sanctuary provided a greater sample-to-area ratio, given an equal number of stations in each zone, which was needed for more efficient sampling in zones with large sample variance (Gulland 1966). The depth ranges of zones 1 and 2 were 14–20 m and 16–21 m, respectively.

Each zone was subdivided into consecutively

numbered grids 2′ of latitude square or about 1,372 hectares in area. The width of a grid was approximately the maximum distance of a 30-min trawl tow. Untrawlable grids were omitted from the random selection process, and the total trawlable area was reduced from 464 to 416 grids. Adjacent grids were sampled when an untrawlable bottom was encountered.

Five grids were chosen at random for sampling in each zone each month for a total of 30 grids. One 30-min tow was taken in each grid at night with four 13.1-m nets spread by 1- × 2.7-m doors rigged with tickler chains. The body of each net had 4.45-cm stretched mesh and the codend was made of 3.3-cm stretched mesh. The M/V *Capt. Eddie*, a 22.9-m commercial shrimp trawler, was used to collect the samples during a 1-week cruise each month from September 1982 through July 1983. No samples were taken in April and June due to budget limitations. Two nights for additional trawling were added later to the November–March cruise schedule to collect tagged shrimp released on the grounds during a concurrent study (Gitschlag 1986). These 2-h directed tows were made to increase trawling effort in an area of light commercial activity between the Dry Tortugas and Rebecca Shoal. If all stations and directed tows were completed before the end of the cruise, the captain was permitted to make commercial tows in any area of his choosing. The data from these commercial tows were compared later to station data from the same zone.

All trawl samples were processed according to procedures used in the 1981–1982 survey, except that a 2.27-kg sample of pink shrimp from each inboard net was counted to determine the total number caught at a station. Surface and bottom water temperatures and salinities were monitored as in the 1981–1982 survey for temporal and spatial changes.

Statistical Methods

1981–1982.—Length-frequency and catch-per-unit-effort data often show skewed distributions and have nonadditive components that prevent their use in some statistical tests (Steel and Torrie 1960). To correct these deficiencies, all length measurements (92,900 were made during the survey) were transformed logarithmically (base 10), and weight data were transformed by the square root as indicated by Taylor's (1961) test of the mean and variance relationship.

Analysis of variance (ANOVA) can indicate a significant difference between treatment effects (stations or months) but cannot determine which treatment effects are responsible for rejecting the null hypothesis. The Student–Newman–Keuls (SNK) stepwise multiple-range test, an a posteriori test, was used to distinguish and group nonsignificant treatment effects (stations) into a range of values (Sokal and Rohlf 1981). When many values are used in the SNK test, comparisons of all values from smallest to largest usually generate several overlapping ranges. Subjective judgement must then be used to separate overlapping ranges and reallocate those values found in more than one range to a single range. This was only a minor problem in most months and the SNK test provided general trends needed to show shrimp distribution in the sanctuary.

Among-net variability at a station was tested by ANOVA of shrimp weight, and homogeneity of length frequencies of the measured shrimp between the two inboard nets was tested by the *G*-test (Sokal and Rohlf 1981). There were no significant differences ($P > 0.05$) among nets for shrimp weight, but there were differences ($P < 0.05$) in length frequencies at approximately 22% of all stations tested over 12 months. Because of these differences, the proportion of pink shrimp larger or smaller than 103 mm was calculated separately for the starboard and port nets based on their respective length-frequency measurements.

A chi-square test for independence was used to determine whether or not the total number of small and large shrimp varied significantly according to location inside or outside the sanctuary. If the chi-square value was significant, shrimp size was not independent of location relative to the sanctuary.

In reference to general categories of shrimp size, the terms "small" and "large" are often used but are ambiguous. Therefore, small shrimp are defined here as pink shrimp less than 103 mm in total length (69 tails or more to the pound) and large shrimp are those equal to or greater than 103 mm. This division is based on research by Lindner (1966) and Berry (1970), which indicated that the maximum yield for commercial harvest is reached at a size of 103 mm or larger for pink shrimp.

1982–1983.—The primary emphasis in the second year of the study was not on between-net variability but on station, zone, and month variability in shrimp length, weight, and number to determine temporal and spatial variation in distribution. Between-net variability was checked, but all station data were reduced to an average value for one net as the unit of measurement at a station, as originally planned.

Analysis of variance indicated no significant differences in pink shrimp weight among nets at a station ($P > 0.05$), but G-tests indicated differences ($P < 0.05$) in length frequencies between the two inboard nets at more than 10% of the stations. Therefore, an overall mean length and variance was calculated for each station from the mean length in each inboard net, and the number of pink shrimp caught at a station (average for one net) was obtained by multiplying shrimp weights in starboard and port nets by the shrimp count from the adjacent starboard or port inboard net. Catch per unit effort in the form of mean weight at a station (one net towed for 30 min) was calculated from all four nets (or as many as were available).

Zonal and monthly station data were compared by ANOVA after a square-root transformation was applied. This transformation was indicated by Taylor's (1961) test of the variance-to-mean ratio and was sufficient to provide homogeneity of variances in lengths, weights, and numbers for most analyses. For those analyses with heteroscedastic variances (Bartlett's test), comparisons were made using the Games and Howell method (Sokal and Rohlf 1981). The station mean (of four nets) provided replicate samples for each treatment (months and zones) for the analyses. Furthermore, because there was a priori interest in identifying differences in the shrimp population inside the sanctuary and on the fishing ground, analyses of variance that compared zones were partitioned (between zone sums of squares) after the method of Sokal and Rohlf (1981) if there were significant differences in the means.

Population estimates for each zone each month were made by the "area swept" method described by Wilkins and Golden (1983). The area swept by one 13.1-m net towed at 4.6 km/h with approximately 75% spread (J. W. Watson, Jr., NMFS, Pascagoula, Mississippi, personal communication) was 2.27 hectares per tow. Because each grid has an area of 1,372 hectares, a conversion factor of 604 was used to convert the average number of pink shrimp caught in one net to an estimate of the population in a grid. The total population, variance, and 95% confidence interval of the survey area were derived from equations used by Cochran (1977) and Summers et al. (1983). A weighted population mean per grid ($\bar{Y}st$) was calculated by

$$\bar{Y}st = \Sigma\ W_h \bar{Y}_h \quad \text{(Cochran 1977)},$$

and this estimate was converted to the total population estimate by multiplying $\bar{Y}st$ by the number of trawlable grids (416). The untrawlable grids were not included because they had been dropped from the random selection process, and there was no way to estimate the number of pink shrimp in them. Variance (s^2) was calculated by the formula

$$s_{\bar{Y}st}{}^2 = \Sigma \frac{W_h{}^2 s_h{}^2}{n_h} - \Sigma \frac{W_h s_h{}^2}{N} \quad \text{(Cochran 1977)},$$

and a 95% confidence interval was derived from

$$N\bar{Y}_{st} \pm tNS_{\bar{Y}st} \quad \text{(Cochran 1977)};$$

N = total number of trawlable grids;
N_h = number of trawlable grids in a zone;
n_h = number of grids sampled in each zone h;
Y_{hi} = population estimate for a grid;
$\bar{Y}_h = \Sigma \frac{Y_{hi}}{n_h}$ = zone mean;
$s_h{}^2 = \frac{\Sigma(Y_{hi} - \bar{Y}_h)^2}{(n_h - 1)}$ = zone variance;
$W_h = \frac{N_h}{N}$ = zone weight.

The numerical data used in population estimates were not transformed because (1) these estimates were probably below the true population value, as will be explained in the Discussion, (2) untransformed data give symmetrical and wider confidence intervals that may come closer to containing the true population figure, and (3) no tests of differences between these estimates were planned.

Results

Size Distribution of Pink Shrimp

1981–1982.—Pink shrimp lengths were compared to determine the spatial and temporal size distribution at 22 stations inside and outside the boot of the Tortugas sanctuary. Because a two-way ANOVA of mean size by station and by month indicated significant differences in means between stations, months, and the interaction between stations and months ($P < 0.001$), grouping of similar stations by shrimp size with the SNK test was done separately for each month.

Station groups genrated by the SNK test for six representative months are shown in Figure 4. Stations were grouped by the mean sizes of all pink shrimp measured in the laboratory and the field. However, statistically distinct size ranges varied each month, and groups based on the critical 103-mm length occurred only by chance because the SNK test is not constrained to group by certain

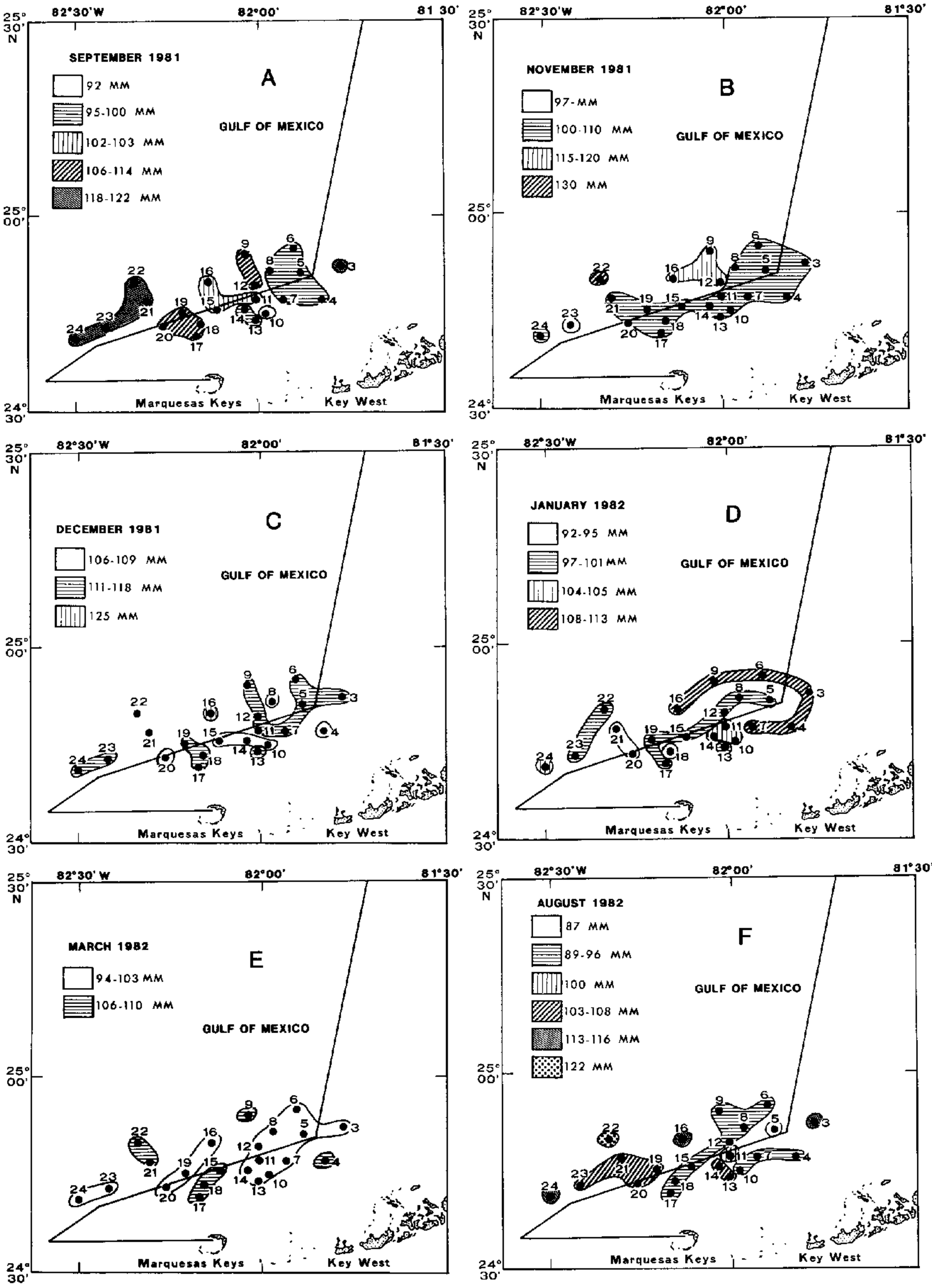

FIGURE 4.—Stations on the Tortugas ground grouped by mean length of pink shrimp by the SNK test for 6 of the 12 months (A–F) of the 1981–1982 survey. Stations 1 and 2 were excluded due to lack of data. Size groups in each figure legend were not always the same because the SNK test does not group by predetermined size category.

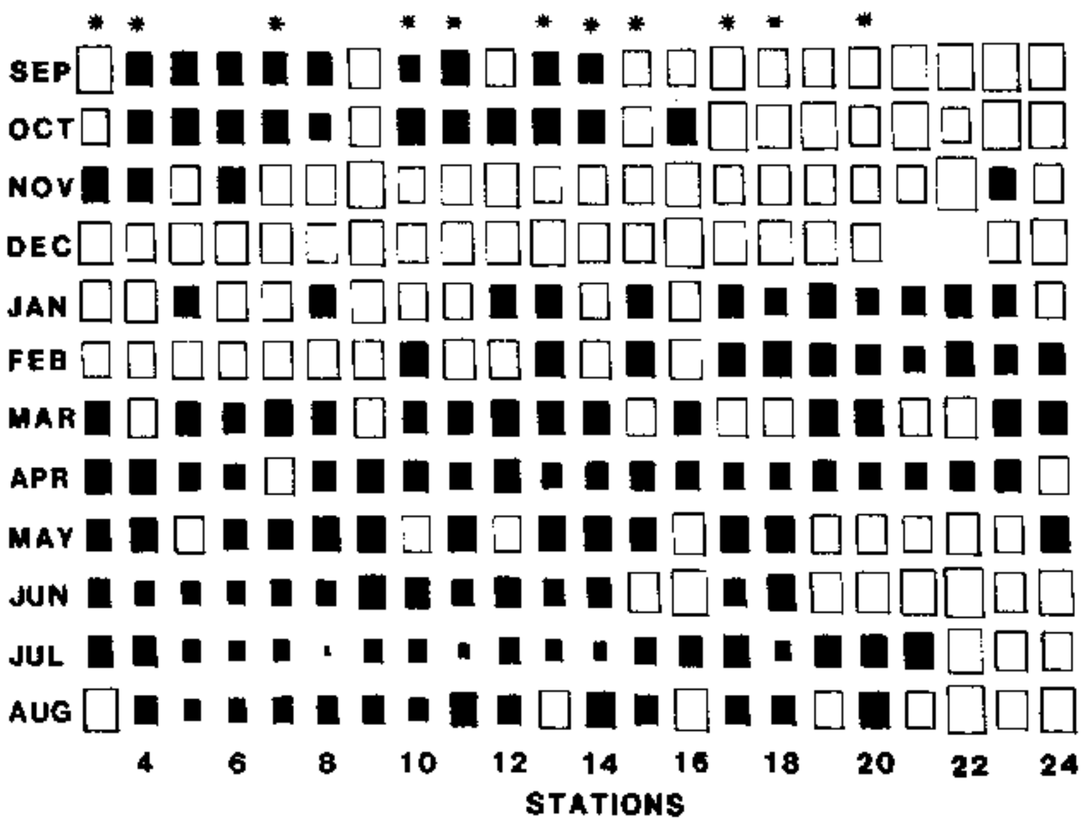

FIGURE 5.—A two-way plot of mean pink shrimp length at 22 stations (3–24) on the Tortugas ground for 12 months, 1981–1982. Each square is proportional to mean shrimp length—the smallest square is 81.0 mm (station 8, July 1982) and the largest is 130.3 mm (station 22, November 1981). Solid squares represent mean lengths less than 103 mm. There were no data for stations 21 and 22 in December. Stations inside the sanctuary are indicated by an asterisk at the top of the figure. Stations from left to right in the figure run in a general east-to-west direction in the survey area.

size categories. Because it was not always apparent (Figure 4) which stations in the smaller size categories were dominated by pink shrimp less than 103 mm, the mean length data also were arranged in a two-way plot of station by month (Figure 5) to emphasize stations dominated by small pink shrimp and their positions relative to the sanctuary.

The 12 months of the survey were divided into two groups based on the number and location of stations with a mean pink shrimp size less than 103 mm. In the first group, small pink shrimp were dominant at 2–11 of the 22 stations in September–December, whereas they dominated 11–20 stations in the second group in January–August (Figures 4, 5). In September and October, pink shrimp size increased in an east-to-west direction; more than half the large-shrimp stations were outside the sanctuary and over half the small-shrimp stations were inside the sanctuary. Station 3 was an exception to the east–west trend in September because it was the easternmost station of the 22 analyzed, yet contained pink shrimp with an average size of 120 mm. However, only 17 measurable pink shrimp were caught at station 3; therefore, the sample may not have been representative of the general shrimp population in the area. Another indication of the singularity of station 3 is that stations 1 and 2, which are east of station 3 and were successfully sampled in September, had a mean pink shrimp size under 90 mm (45 and 29 shrimp caught, respectively). The November and December size distributions differed from those in the first 2 months in that an east–west size trend was not evident and large pink shrimp were more widespread. Only four stations in November, two within and two outside the sanctuary, had pink shrimp averaging less than 103 mm long. December was the only month in the survey in which large shrimp dominated all stations; 106 mm was the smallest average length (at Station 4; Figures 4, 5). No data were taken at stations 21 and 22 in December due to excessive catches of jellyfish (*Aurelia* sp.) in the nets.

The January–August 1982 period represented a change from a predominance of large shrimp to that of small shrimp (Figures 4, 5). January and February size distributions were the reverse of those in September and October; large shrimp occurred at the eastern stations (except for station 24 in January) and small shrimp dominated the western stations. Seven of the 12 stations dominated by small shrimp were outside the sanctuary in January and 5 of the 11 stations with small shrimp were outside the sanctuary in February. March, April, and May differed from January and February in that there was an increase in size similarity among stations (fewer size groups), and small shrimp dominated more than half the stations inside and outside the sanctuary. June, July, and August showed a similarity to September and October in both a greater size dissimilarity among the stations than the other months and in the size distribution patterns, large shrimp being generally to the west and small shrimp to the east. Large shrimp were found at more stations outside the sanctuary than inside it in all 3 months and small shrimp occurred at more stations inside the sanctuary than outside it. In August, pink shrimp at station 3 again were an exception to the east–west trend in increasing shrimp size, as they had been the previous September, and averaged 115 mm. However, there was a larger sample in August (320) than in September (17). Stations 1 and 2 were not sampled in August so there were no data from the area east of station 3 for comparison.

1982–1983.—The 1982–1983 survey involved randomly selected stations over a large area, so a map of pink shrimp size distribution could not be drawn and only general trends were noted. Shrimp size at a station varied widely, showing ranges of 50–100 mm at most stations, but there was a general trend of increasing length with increasing depth

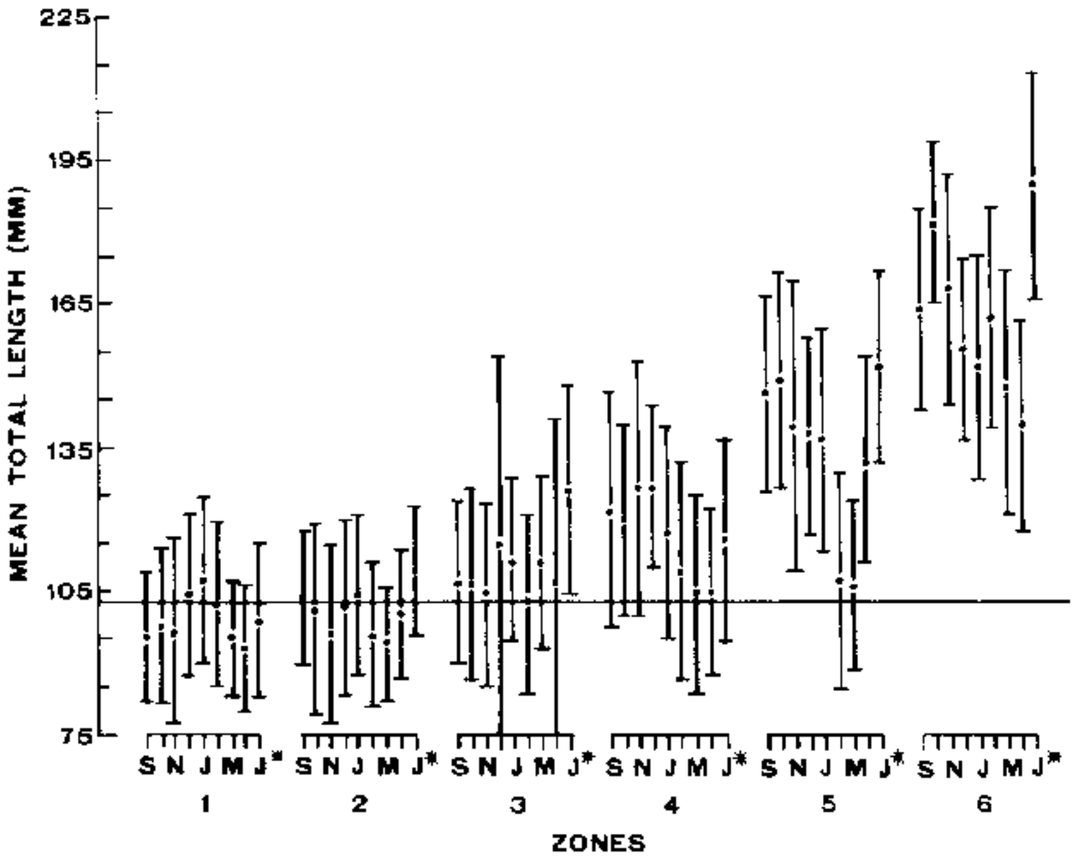

FIGURE 6.—Monthly mean pink shrimp lengths (±1 SD) averaged over all stations in each zone of the Tortugas ground, 1982–1983. The horizontal line is the 103-mm minimum length for optimum harvest. S = September; N = November; J = January; M = March; J* = July. Samples were not taken in April and June.

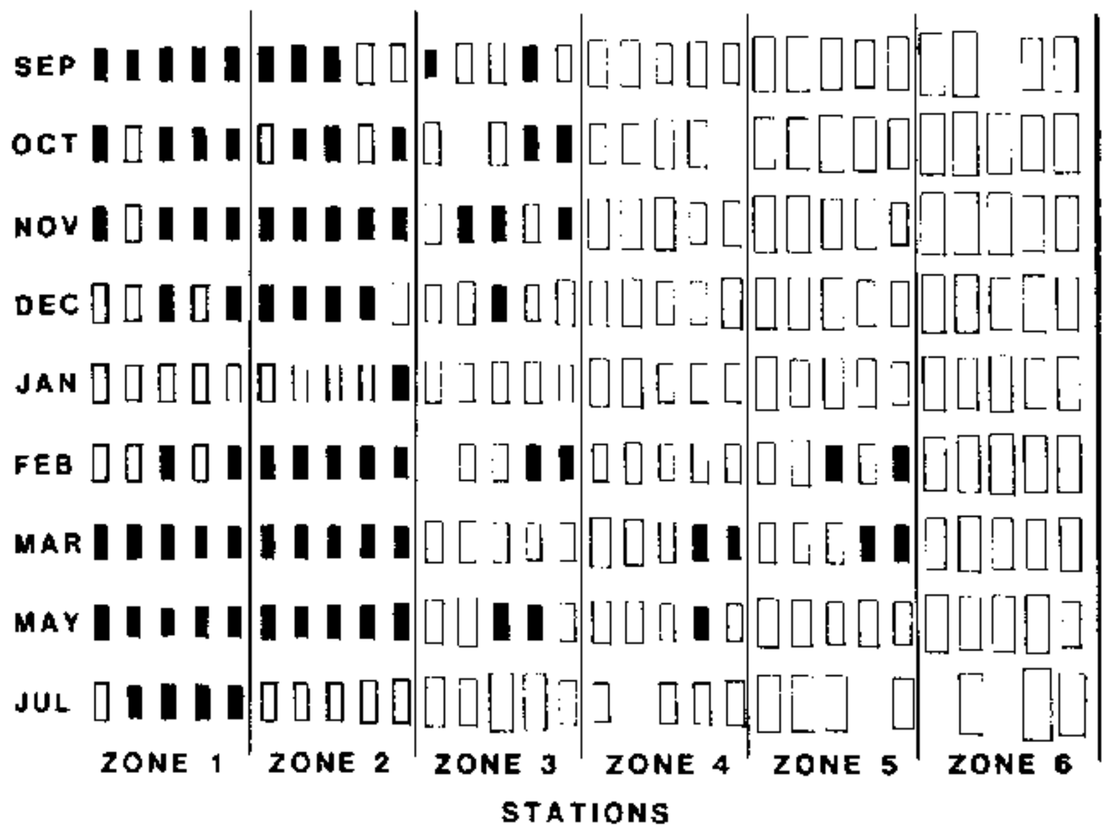

FIGURE 7.—A two-way plot of mean pink shrimp length at each station on the Tortugas ground (five stations/zone) for a total of 30 stations in each month, 1982–1983. Stations without shrimp were excluded. Each rectangle is proportional to mean shrimp length—the smallest is 86.1 mm (zone 3, September) and the largest is 220 mm (zone 6, July). Solid rectangles represent mean lengths less than 103 mm.

(Figure 6). Analysis of variance indicated significant differences in mean lengths between months within each zone ($P < 0.05$) and between zones for each month ($P < 0.001$). However, mean lengths were not significantly different between zones 1 and 2 within the sanctuary for any month ($P > 0.05$). A comparison of mean length inside the sanctuary to mean length outside (zones 3–6) showed a significant difference for each month ($P < 0.05$).

A two-way plot of mean pink shrimp size at each station in a zone by month is presented in Figure 7 to emphasize the distribution of shrimp less than 103 mm or at least 103 mm long in each zone. Shrimp less than 103 mm long dominated the samples taken at over half the stations inside the sanctuary in September–December and February–May. January and July were the only months in which large shrimp dominated most stations inside the line (compared to September–December in 1981). Small shrimp dominated at least one station in zone 3 beyond the sanctuary in all months sampled except January, March, and July, but their widest distribution outside the sanctuary occurred in February and March when they dominated stations as far west as 24°45′N, 82°41.3′W and as far north as 24°53′N, 82°23.7′W in zone 5.

Catch per Unit Effort (CPUE)

1981–1982.—The abundance of pink shrimp, as measured by CPUE (kilograms/net per 30-min tow), was examined for spatial or temporal changes with reference to the sanctuary boundary. There was no difference in the catch between nets at a station ($P > 0.05$), but there were significant differences between stations and between months (ANOVA; $P < 0.001$).

Initially, stations were grouped by CPUE for each month by the SNK test but no trends in density distribution were evident. Therefore, the average CPUE was compared between all 11 stations inside the sanctuary and the 11 stations outside the sanctuary (Table 2). Abundance was significantly higher inside the sanctuary for all 12 months (Mann–Whitney U-test; $P < 0.05$), averaging 1.8

TABLE 2.—Mean monthly catch per unit effort of pink shrimp on the Tortugas ground (kg/net per 30-min tow, ±1 SD) from all nets at a station, averaged over all stations inside or outside the sanctuary.

Month, 1981–1982	Inside sanctuary	Outside sanctuary
Sep	9.9±7.0	4.2±2.3
Oct	5.5±3.5	3.1±2.8
Nov	10.8±5.3	4.6±3.0
Dec	9.5±3.5	4.7±3.1
Jan	14.9±6.0	6.9±4.2
Feb	8.0±4.3	2.9±2.0
Mar	2.3±1.5	1.6±1.1
Apr	3.5±2.0	2.7±1.4
May	6.4±2.3	5.0±1.2
Jun	9.1±2.9	5.2±2.6
Jul	14.3±7.0	8.7±4.8
Aug	17.4±9.7	11.9±10.7

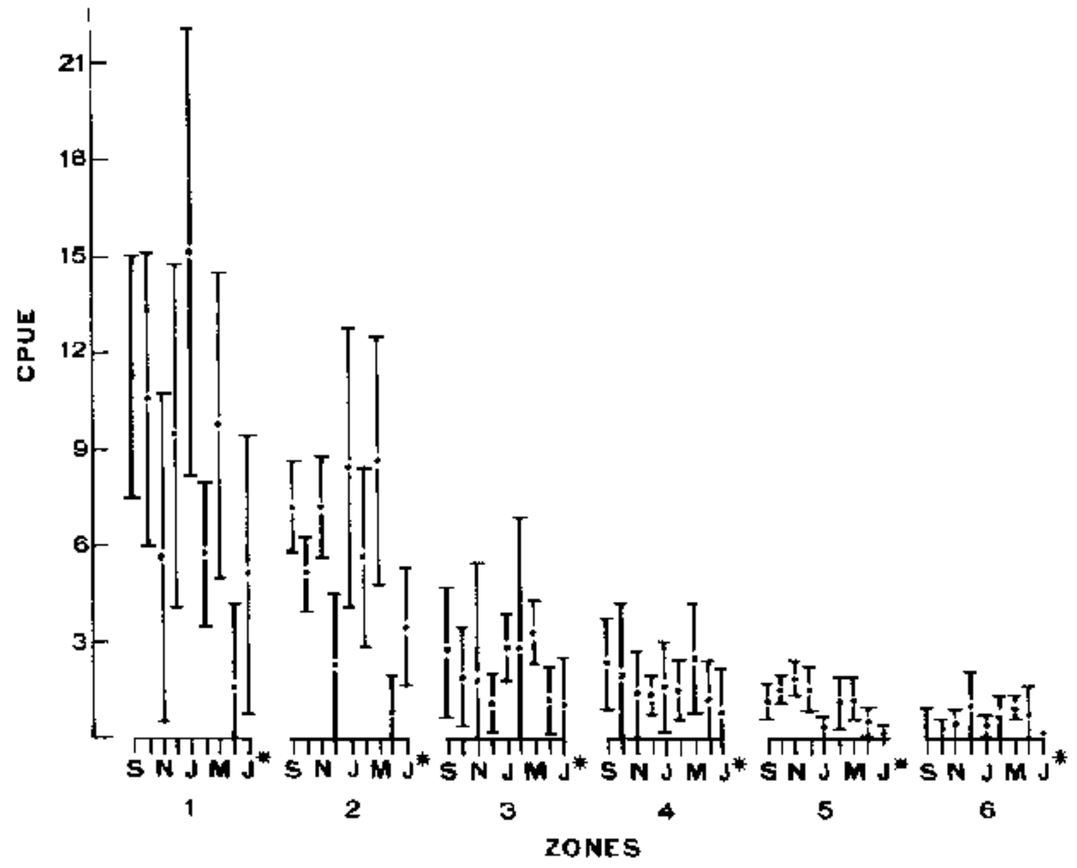

FIGURE 8.—Monthly average catch of pink shrimp per unit effort (CPUE: kg/net per 30-min tow, ±95% confidence intervals) in six survey zones on the Tortugas ground, 1982–1983. The CPUEs were averaged over nets at a station and then averaged over stations in each zone. S = September; N = November; J = January; M = March; J* = July. Samples were not taken in April and June.

times the catch outside the sanctuary. The lowest production inside the sanctuary occurred in March and April when the average CPUE fell below 5.0 kg. Outside the sanctuary, however, an average CPUE of less than 5.0 kg was recorded in 7 of the 12 months (September–December and February–April).

A comparison between the historical commercial catch record (1960–1979) and the survey data was made to determine if low catch rates occurred during the same months. The commercial catch record was standardized by Klima et al. (1982) to average catch per 24 h of fishing but did not account for vessel size and power or number of nets. The historical data showed that, although CPUE was stable at 225–270 kg/24 h for December–August and higher for September–November, the lowest CPUE for commercial catches occurred in February–June. For 1981, an unusually high production year, the low occurred only in February (Klima et al. 1982).

1982–1983.—Average survey CPUE at the random stations in 1982–1983 differed significantly in a two-way ANOVA of zones and months ($P < 0.001$). However, comparisons of zones by month (one-way ANOVA) indicated no significant difference in CPUE between zones in May ($P > 0.5$). There was a general decrease in CPUE with increasing depth (Figure 8); a significantly higher CPUE ($P < 0.001$) occurred inside the sanctuary than outside, except in May ($P = 1.0$). A comparison of CPUE between zones 1 and 2 inside the sanctuary indicated a significant difference ($P < 0.05$) in shrimp abundance in September, October, December, and January. The average CPUE was highest but more variable in zone 1, ranging from 15.2 kg in January to 1.6 kg in May. The deepest stations in the survey (zone 6) had the lowest average CPUE for all months and a range of only 0.05–1.0 kg.

Additional data collected during the survey by directed trawling (zones 4 and 5) and commercial trawling (zones 1 and 2) were standardized according to survey procedures for comparison to station CPUEs. The CPUEs for directed tows and commercial tows agreed with the trend in station CPUE: it was lowest outside the sanctuary and higher in zone 1 inside the sanctuary than in zone 2, except in May and July (Table 3). A CPUE below 5.0 kg occurred in all directed tows (Table 3) and in the survey station data (averaged over stations in a zone) in all months in zones outside

TABLE 3.—Monthly number of tows (N) in a zone, mean shrimp length, and mean catch per unit effort (CPUE) (kg/net per 30-min tow, ±1 SD) of pink shrimp caught in commercial tows (zones 1 and 2) and directed tows (zones 4 and 5) on the Tortugas ground.

Month, 1982–1983	Zone 1			Zone 2			Zone 4			Zone 5		
	N	Length (mm)	CPUE (kg)	N	Length (mm)	CPUE (kg)	N	Length (mm)	CPUE (kg)	N	Length (mm)	CPUE (kg)
Sep	2	96	9.3±0.03	5	103	6.1±1.6						
Oct	1	103	6.8									
Nov	3	96	5.2±2.4	3	97	4.6±1.1						
Dec	10	104	5.5±2.5	6	106	4.9±1.0				4	117	0.9±0.4
Jan	11	103	7.8±2.2	3	102	3.3±1.4	4	113	1.8±0.4	2	122	1.1±0.3
Feb	7	103	3.9±1.0	6	99	3.7±0.8	3	103	1.5±0.5	1	103	1.7
Mar	11	91	10.9±2.4	2	91	7.5±1.6	2	97	2.0±0	3	101	2.4±1.0
May	1	93	2.0	2	97	2.2±2.0						
Jul	1	101	2.0	7	113	7.1±4.3						

TABLE 4.—Total numbers of pink shrimp caught during the 1981–1982 Tortugas survey and the percentages of small shrimp (<103 mm total length) and large shrimp (≥103 mm) in the combined samples from 11 stations inside the sanctuary, 11 stations outside the sanctuary, and all 22 stations.

Month, 1981–1982	Inside				Outside				All stations			
	<103 mm		≥103 mm		<103 mm		≥103 mm		<103 mm		≥103 mm	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Sep	30,908	68	14,655	32	6,765	42	9,204	58	37,673	61	23,859	39
Oct	10,062	50	10,145	50	3,662	34	7,042	66	13,724	44	17,187	56
Nov	21,408	49	21,853	51	7,328	45	9,123	55	28,736	48	30,976	52
Dec	9,067	28	23,461	72	3,494	23	11,464	77	12,561	26	34,925	74
Jan	38,818	62	24,058	38	22,349	68	10,547	32	61,167	64	34,605	36
Feb[a]	17,363	55	14,183	45	6,641	56	5,304	44	24,004	55	19,487	45
Mar[a]	6,061	63	3,571	37	4,806	63	2,770	37	10,867	63	6,341	37
Apr	16,781	81	4,047	19	10,541	74	3,754	26	27,322	78	7,801	22
May	19,661	63	11,392	37	11,601	54	9,852	46	31,262	60	21,244	40
Jun	32,865	69	14,774	31	12,672	56	9,980	44	45,537	65	24,754	35
Jul	79,250	82	17,478	18	48,247	81	11,180	19	127,497	82	28,658	18
Aug	65,183	73	23,818	27	46,850	77	14,342	23	112,033	75	38,160	25

[a] The proportions of small and large shrimp are independent of location inside or outside the sanctuary (chi-square; $P > 0.25$).

the sanctuary (Figure 8). Low CPUE was less common in the commercial tows inside the sanctuary, occurring in February, May, and July in zone 1 and in November–February and May in zone 2. Low CPUEs at stations inside the sanctuary occurred only in December in zone 2 and in May and July in zones 1 and 2.

Pink Shrimp Recruitment

1981–1982.—Recruitment of pink shrimp to the Tortugas ground from the nursery area was indicated by the presence of small pink shrimp at the stations. However, size at recruitment varies with season and area (Iversen and Idyll 1960; Eldred et al. 1961; Tabb et al. 1962) and with author (Kutkuhn 1966, 107 mm; Costello and Allen 1970, 90–100 mm). Because there is no universally accepted size, I will use lengths less than 103 mm to indicate recruitment.

The high proportion of small shrimp in the length-frequency data of 1981–1982 (Table 4) suggested an almost continuous recruitment of pink shrimp from the shallow nursery area of Florida Bay into the deeper waters of the survey stations. However, recruitment level and time of recruitment, as indicated by the proportion and number of small shrimp, varied between stations inside the sanctuary and those outside. The highest levels of recruitment occurred in September, January, and June–August at stations inside the sanctuary, but only in January, July, and August outside the sanctuary. Numbers of small pink shrimp at all stations were lowest in February–May and highest in July and August, although numbers were higher inside the sanctuary than outside it. A chi-square test for independence showed that, for all months except February and March, there was a significantly higher proportion of small shrimp inside the sanctuary than outside ($P < 0.01$).

1982–1983.—Recruitment during the 1982–1983 survey was continuous but uneven in area and months (Table 5). Abundance of small pink shrimp was generally highest in the eastern half of the sanctuary (zone 1) than in the western half (zone 2) and was lowest in the deeper waters (zones 3–6). The highest levels of recruitment occurred inside the sanctuary in September, October, January, and March in zone 1 and in November and March in zone 2. Outside the sanctuary, numbers of small shrimp were much lower; peaks in abundance occurred in September–November and January–March in zone 3 and February–May in deeper waters. The total number of small pink shrimp was high inside the sanctuary in September 1982 but less than half the total number caught inside the sanctuary in August 1982 (in the first survey), indicating declining recruitment for the fall season. Abundance continued to decline until January, except for a small increase in November in zone 2. Recruitment increased in January 1983 and peaked in March inside the sanctuary. March apparently was a very strong recruitment period outside the sanctuary also, because small pink shrimp accounted for 53% of the combined samples at all stations in zones 4–6 and appeared in the March commercial landings (Klima et al. 1986a). Recruitment declined in the survey area after the March peak, reached a low in May, then increased slightly in July but only inside the sanctuary (Table 5).

TABLE 5.—Numbers and percentages of small (<103 mm total length) and large pink shrimp (≥103 mm) caught inside the Tortugas sanctuary (10 stations) and outside it (20 stations) each month, 1982–1983. An area factor was not calculated so that the numbers were not affected by differences in zone size and could be directly compared. Zone 3 (five stations) was separated from zones 4–6 because it was adjacent to the sanctuary and had a higher number and proportion of small shrimp than the other zones outside the sanctuary.

Month, 1982–1983	Inside sanctuary											
	Zone 1				Zone 2				Both zones			
	<103 mm		≥103 mm		<103 mm		≥103 mm		<103 mm		≥103 mm	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Sep	18,261	67	9,089	33	6,287	44	8,081	56	24,548	59	17,170	41
Oct	11,260	47	12,565	53	4,624	44	5,920	56	15,884	46	18,485	54
Nov	8,128	69	3,617	31	11,183	69	4,956	31	19,311	69	8,573	31
Dec	8,553	50	8,575	50	1,778	50	1,785	50	10,331	50	10,360	50
Jan	12,062	45	14,987	55	7,458	49	7,860	51	19,520	46	22,847	54
Feb	6,860	61	4,346	39	8,173	72	3,173	28	15,033	67	7,519	33
Mar	18,955	80	4,742	20	17,457	83	3,673	17	36,412	81	8,415	19
May	3,442	82	767	18	999	60	655	40	4,441	76	1,422	24
Jul	7,898	67	3,834	33	1,591	30	3,697	70	9,489	56	7,531	44

Month, 1982–1983	Outside sanctuary											
	Zone 3				Zones 4–6				All zones			
	<103 mm		≥103 mm		<103 mm		≥103 mm		<103 mm		≥103 mm	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Sep	1,861	39	2,876	61	462	14	2,948	86	2,323	29	5,824	71
Oct	1,306	43	1,729	57	287	11	2,323	89	1,593	28	4,052	72
Nov	1,466	52	1,337	48	416	14	2,492	86	1,882	33	3,829	67
Dec	441	32	926	68	123	4	2,839	96	564	13	3,765	87
Jan	1,197	31	2,665	69	537	22	1,912	78	1,734	27	4,577	73
Feb	2,093	57	1,589	43	1,692	44	2,152	56	3,785	50	3,741	50
Mar	1,879	36	3,360	64	3,869	53	3,458	47	5,748	46	6,818	54
May	972	51	943	49	1,441	44	1,808	56	2,413	47	2,751	53
Jul	102	11	853	89	288	26	811	74	390	19	1,664	81

Population Estimates

The average number of pink shrimp caught in one net for each station in a zone in 1982–1983 differed significantly for all zones in all months ($P < 0.001$) except May ($P > 0.1$), when the number of shrimp inside the sanctuary was low enough that no detectable difference appeared across zones. As did the CPUE, shrimp numbers showed a general decline with increasing depth (Figure 9), and shrimp were significantly more abundant inside the sanctuary than outside ($P < 0.001$) except in May ($P > 0.05$). Even within the sanctuary, shrimp abundance differed significantly ($P < 0.05$) between zones 1 and 2 in September, October, December, January, and July.

The pink shrimp population in each zone was estimated from the average number caught in one net at each station times an area factor (Table 6). These estimates were variable by month and zone and were conservative. Although zones 1 and 2 had a combined trawlable area that was only 6% of the total trawlable area in the survey, the pink shrimp population inside the sanctuary accounted for as much as 50% of the total population in July and as little as 12% in May (mean of 36% for 9 months). The total population was highest in March at 52.7 (±12.8) × 10^6 pink shrimp and lowest in July at 11.8 (±5.3) × 10^6 pink shrimp.

Salinity and Temperature

Salinity and, to a lesser degree, temperature were relatively stable among stations during both surveys. Salinity ranged from 34 to 36‰ between surface and bottom at all stations and months in 1981–1982, and from 34 to 36.5‰ in 1982–1983. Temperature fluctuated the most between months during both surveys due to seasonal changes; the highest temperature was recorded in August 1982 (31°C) and the lowest in February 1983 (19.2°C). For any month in the 1981–1982 survey, temperature varied more between surface and bottom (maximum of 3°C) than among stations. For the

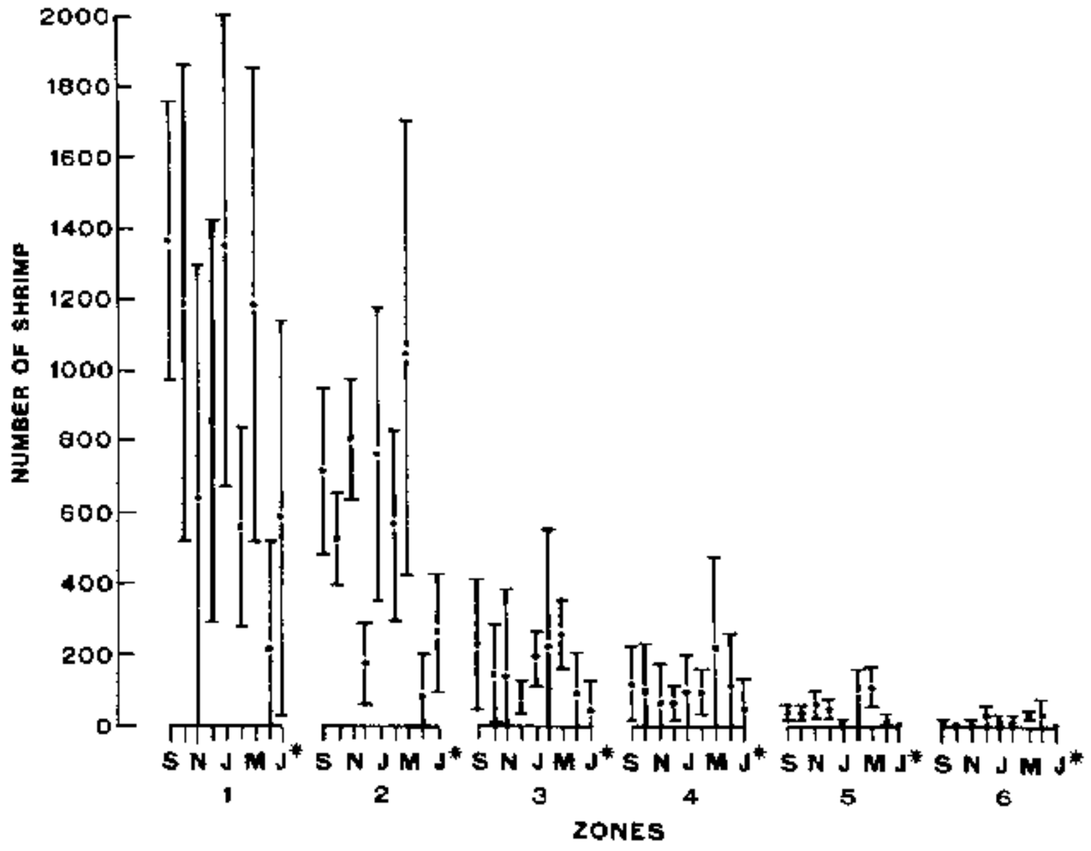

FIGURE 9.—Monthly average number of pink shrimp caught in one net, with 95% confidence intervals, for six survey zones on the Tortugas ground, 1982–1983. The numbers of shrimp were averaged over nets at a station and then averaged over stations in each zone. S = September; N = November; J = January; M = March; J* = July. Samples were not taken in April and June.

1982–1983 survey, the greatest temperature change occurred among stations (maximum of 5.5°C) rather than between surface and bottom.

Discussion

Two surveys of pink shrimp on the Tortugas ground and sanctuary in 1981–1983 that involved standard trawling techniques found monthly and annual variation in size and abundance patterns, particularly inside the permanent shrimp sanctuary. However, such estimates of size and abundance distributions and population estimates can be biased by such uncontrollable factors as trawl efficiency, between-sample variance that affects the number of samples needed to estimate a variable, shrimp behavior (burrowing and avoidance), and increased mortality (e.g., increased commercial trawling). Of the variables measured, the number of shrimp caught at a station probably was most affected. I assumed that although the trawl was not 100% efficient, especially for shrimp less than 60 mm long, efficiency was constant under similar conditions and sample length frequencies for shrimp longer than 60 mm were representative of the population at a station.

Trawl efficiency is affected by a trawl's operating characteristics (how it tends the bottom) and shrimp behavior. Most trawls operate with the footrope about 10–15 cm above the bottom. This distance is regulated by loops of chain on the footrope and characteristics of trawl doors, and the space allows much of the trash on the bottom as well as shrimp to pass under the net (J. W. Watson, Jr., NMFS, Pacagoula, Mississippi, personal communication). However, even if the net worked directly on the bottom, it would miss the many pink shrimp that remain buried in the sediments even during peak times of activity at night (Penn 1984). The effects of burrowing behavior are illustrated by the results of a study on the effectiveness of electric trawls in catching pink shrimp and brown shrimp. Divers found that electric trawls caught 35–54% of marked groups of shrimp during the day in clear water, the percentage varying with trawl size and electric field strength (Watson 1976). The catch efficiency of the same trawls under the same conditions without electrical discharge was less than 1%. The effectiveness of a non-electric trawl with a tickler chain increased at night to 30–50% (J. W. Watson, Jr., personal communication).

Light is an important factor controlling the burrowing behavior of pink shrimp. It has been reported by captains of shrimp trawlers (Eldred et

TABLE 6.—Monthly population estimates of pink shrimp by sampling zone and for the total trawlable Tortugas survey area, with 95% confidence intervals (CI), 1982–1983. The estimates were made from the average number of shrimp caught in one 13.1-m net by the area-swept method and multiplication by a conversion factor. Total population estimates are the sums of the estimates for each zone.

Month, 1982–1983	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Total ± 95% CI
Sep	8,247,790	6,497,910	11,860,548	8,144,916	2,110,017	507,287	37,368,468 ± 8,424,894
Oct	7,184,110	4,768,470	7,684,404	6,883,895	2,312,037	278,842	29,111,758 ± 7,492,950
Nov	3,842,500	7,299,570	7,092,624	4,653,755	3,588,767	575,767	27,052,983 ± 10,455,869
Dec	5,164,720	1,610,370	4,321,044	4,472,270	2,885,064	1,741,318	20,194,786 ± 3,531,133
Jan	8,156,590	6,928,785	9,776,004	6,467,079	643,370	756,490	32,728,318 ± 6,527,830
Feb	3,379,250	5,130,390	11,650,296	6,743,176	4,181,632	833,851	31,918,595 ± 11,260,538
Mar	7,146,350	9,558,120	13,264,104	14,842,094	6,143,410	1,818,786	52,772,864 ± 12,845,144
May	1,249,110	747,180	4,840,920	7,612,451	1,044,043	1,752,981	17,246,685 ± 2,145,582
Jul	3,537,470	2,391,750	2,385,516	3,325,590	187,733	27,071	11,855,130 ± 5,269,555

al. 1961; Fuss 1964; Hughes 1968) and in experimental studies (Fuss 1964; Fuss and Ogren 1966) that pink shrimp reduced their nocturnal activity and burrowed deep into the sediments beyond the reach of nets or tickler chains during a full moon in clear water. On the other hand, even though they are normally nocturnal, pink shrimp have been known to be active during the day after a storm has increased water turbidity (Eldred et al. 1961; Fuss and Ogren 1966).

A full moon was present only during the December 1981 cruise in the 1981–1982 survey. However, the full moon probably had little effect on the number of shrimp caught because two cold fronts moved through the Tortugas area during the cruise and associated storms increased water turbidity. The number of shrimp caught at a station was more important during the 1982–1983 survey because this number was used to make monthly population estimates. A full moon was present during the March, May, and July 1983 cruises. Of these cruises, May was the only month when a full moon was present during the first 4 d of the cruise when most of the stations were sampled. May was also the only month in which there was no significant difference in abundance (CPUE or numbers) between all size zones due to the low number of shrimp caught at the shallowest stations (zones 1 and 2 inside the sanctuary; Figures 8, 9).

Further evidence that May samples underestimated the pink shrimp population is found in the September 1982–August 1983 commercial shrimp landings from NMFS statistical subareas 1–3, which covered the survey area (Table 7). The largest commercial landings occurred in March and April, which corresponds to the survey population "high" in March (Table 6), but May landings were the third largest of the 12 months and the May CPUE was the second highest. Except for November and December 1982, when commercial landings increased in opposition to the survey population estimates, the landings and survey data fluctuated in the same manner.

The mortality rate of pink shrimp, which includes fishing mortality, also affects population estimates but remains an unknown quantity. Nichols (1986) used an estimate of mortality for yield-per-recruit modeling but cautioned that mortality varies seasonally and annually. Fishing mortality, especially that due to illegal trawling inside the sanctuary, is unknown. Klima et al. (1986a) documented illegal trawling inside the sanctuary during the 1981–1983 survey period and gave an estimate by Charles Fuss of the NMFS Enforcement Office of about 65% for compliance by commercial trawlers. They further stated that it would be impossible to make a valid evaluation of the impact of the sanctuary if illegal fishing effort were substantial and unknown.

A calculation of the number of samples needed each month for estimates of size and abundance that would be within 20% of the true value with a 5% chance of error (see Summers et al. 1983 for methods) indicated the stratified random sampling design and number of samples taken (30/month) were adequate for length-frequency and CPUE estimates for pink shrimp but not for population estimates. Because of the variance between stations and zones, 73–209 stations were required to meet the above standard for population estimates each month, whereas 30 stations provided estimates of shrimp length and CPUE within 3–11% of the true value with a 5% chance of error each month. Thus, the pink shrimp population estimates for each month of the 1982–1983 survey were conservative and should not be construed as accurate population censuses.

Recruitment to the Tortugas ground, as indicated by pink shrimp size, is continuous throughout the year, but there are peaks in recruitment when the abundance of small shrimp increases. The timing of these peaks has varied in past surveys from January to June and September to December, but they usually occur sometime in the spring (March–May) and again in the fall (September–November), the fall peak usually being greater (Ingle et al. 1959; Iversen and Idyll 1960; Iversen et al. 1960; Eldred et al. 1961; Iversen and Jones 1961; Berry 1967). The 1981–1982 survey began too late to provide data on the spring peak in 1981,

TABLE 7.—The 1982–1983 commercial landings of pink shrimp (heads-off weight), the number of 24-h days fished, and the catch per unit effort (CPUE) for statistical subareas 1, 2, and 3 in the Tortugas area.

Month, 1982–1983	Commercial landing (kg)	Days fished	CPUE (kg/24 h)
Sep	146,456	838	175
Oct	124,343	1,062	117
Nov	214,632	1,220	176
Dec	258,023	1,453	178
Jan	357,240	1,977	181
Feb	344,112	1,781	193
Mar	540,605	1,864	290
Apr	531,078	2,032	261
May	387,207	1,379	281
Jun	218,246	1,114	196
Jul	117,502	610	193
Aug	82,947	443	187

but the percentages of small shrimp in commercial landings indicated that 1981 recruitment differed from the usual pattern. The spring peak extended over a longer period, March–June 1981, and was greater than the fall peak, which occurred in September and was below normal (Klima et al. 1982). Klima et al. (1982) were unable to attribute these differences in recruitment to the presence of the sanctuary and could only speculate on causes, such as illegal trawling inside the sanctuary.

An unusual recruitment pattern also was indicated in the 1981–1982 survey data. There was a short peak in September 1981 and again in January 1982, a weak recruitment period in the spring with low numbers of small pink shrimp in March–May, and a strong peak in June–August (Table 4). However, the June–August 1982 commercial landings data did not indicate any unusual recruitment of shrimp beyond the sanctuary because monthly landings and CPUE were average or below compared to 1960–1979. A decline in abundance of small shrimp at survey stations began in August 1982, the end of the first survey, and continued in the second survey until a low was reached in December 1982 (Table 5). Recruitment peaked again in January 1983, as in 1982, but the greatest abundance in the second survey occurred in March 1983 (the month when it was lowest in 1982). The lowest abundance occurred in May 1983, another increase starting in July. Except for July 1982, the 1981–1983 data agree with historic trends in abundance patterns.

In addition to variability in recruitment peaks, there were differences in the size distribution of pink shrimp during the 1981–1983 surveys, particularly inside the sanctuary. Large shrimp dominated most stations in and near the sanctuary from September to December in the first survey, the lowest proportion of small shrimp occurring in December. January–August 1982 were mostly "small shrimp" months, the highest percentages of small shrimp occurring in April, July, and August (Table 4; Figure 5). During 1982–1983, unlike in the first survey, small shrimp dominated stations inside the sanctuary in September–December as well as in February–May. They were also found in abundance at stations beyond the sanctuary in 7 of the 9 months of the survey, but their greatest distribution occurred in February and March, when they dominated stations as far from the sanctuary as zone 5 (Figure 7). The fewest stations were dominated by small shrimp in January 1983; the next fewest were in July (Table 5; Figure 7). Based on these results, small-shrimp distribution was highly variable from 1981 to 1983, but high proportions of small shrimp were contained within the sanctuary (mean of 68% of all pink shrimp less than 103 mm caught in 1981–1982 and 87% in 1982–1983).

Management Implications

The 1981 Tortugas sanctuary is not the first one established off southwestern Florida to protect small pink shrimp from overfishing. The State of Florida established the first sanctuary in 1961 and modified the boundaries in later years. Caillouet and Koi (1981) reviewed historical records for the Tortugas fishery from 1960 to 1978 to determine the value of previous Tortugas sanctuaries as management tools and to determine the causes of annual fluctuations in size composition of the catch. They found an increase in pink shrimp size in the 1962 catch following the 1961 closure. Size composition in 1963 was similar to that in 1961, but a trend of increasing size began in 1964 and continued through 1968. However, a shift toward decreasing shrimp size was noted in 1969 and 1970. The closure boundaries were redefined in 1970 and shrimp size again increased in 1971 and 1972. This trend of increasing size was reversed in 1973 and 1974, possibly due to fuel price increases that caused vessels to work closer to ports where shallower water and smaller shrimp predominated. There was a substantial decline in shrimp size in 1975 and this trend continued through 1979. Even with 19 years of commercial catch records, the data were insufficient for Caillouet and Koi (1981) to determine whether the observed shifts in size composition were related to changes in fishing regulations or to changes in distribution and amount of fishing effort. They did note that enforcement of the sanctuary was limited and illegal fishing, if substantial, would affect any benefit of a sanctuary.

Klima et al. (1986a) compared pink shrimp size in the commercial catch landed during the 1981–1983 sanctuary period with the historic record (1960–1979) to identify changes that may have occurred in the landings due to the new regulations. They found no consistent increase in pink shrimp size, as would be expected if the management measures were effective, nor could any increase in commercial catch be attributed to the sanctuary due to the variability in historic and recent landings data (catch, CPUE, and size composition). The commercial catch in 1981 reached a record 6.5 million kg, but over half of the total landings were produced in January–April just before the sanctuary was established. Production in

1982 was lower than any in the 1960–1979 period (2.9 million kg) and 1983 was only slightly better (3.1 million kg), indicating other factors may have had a greater effect on commercial production than the sanctuary. Klima et al. (1986a) attributed the variation in commercial landings, and the failure of the sanctuary regulations to increase shrimp size and yield, to high variability in 1981–1983 recruitment and to illegal trawling inside the sanctuary.

However, the 1981–1983 survey data indicated the 1981 Tortugas sanctuary accomplished a major goal of the management plan because it enclosed a high proportion of small pink shrimp (primarily in the small boot area) as they were recruited to the fishing ground. Furthermore, the boot area represents only 6% of the Tortugas fishing ground, yet it contained an average of 36% of the estimated pink shrimp population for the 1982–1983 survey period. Unfortunately, this provides considerable inducement for illegal trawling, which compromises any benefit of the sanctuary if it is a common practice. Nichols (1986) has estimated from yield-per-recruit models that without trawling in the sanctuary and with movement of larger shrimp to deeper waters there would be a 7–20% increase in commercial weight yield and a 25–64% increase in commercial value—an overall benefit to the shrimp industry.

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