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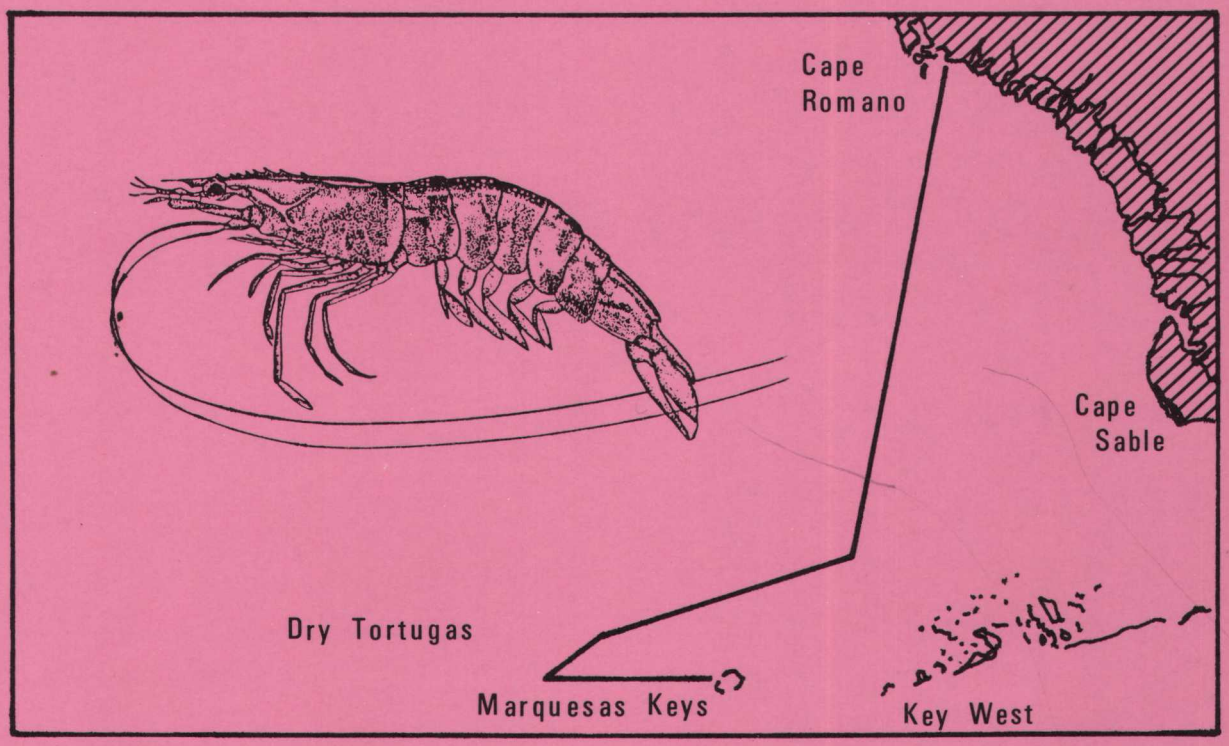
Three Reports Concerning the Tortugas Sanctuary Studies, 1981-1982



DECEMBER 1982

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Center
Galveston Laboratory
Galveston, Texas 77550

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Report I. The Tortugas Sanctuary Study, May 1981-February 1982; Edward F. Klima and Thomas Costello.

Report II. A Preliminary Analysis of Pink Shrimp (Penaeus duorarum) Size and Abundance During the Tortugas Shrimp Sanctuary Study, September 1981-February 1982; Terrell W. Roberts.

Report III. A Synopsis of the Tortugas Pink Shrimp Fishery, 1960-19681, and the Impact of the Tortugas Sanctuary; Edward F. Klima, Geoffrey A. Matthews, Frank J. Patella.

U. S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
Dr. John V. Byrne, Administrator

National Marine Fisheries Service
William G. Gordon, Assistant Administrator for Fisheries

DECEMBER 1982

REPORT I

THE TORTUGAS SANCTUARY STUDY

MAY 1981-FEBRUARY 1982

by

Edward F. Klima

Thomas Costello

INTRODUCTION

The Shrimp Fishery Management Plan for the Gulf of Mexico was implemented by the Secretary of Commerce on May 15, 1981. The Tortugas shrimp sanctuary was implemented concurrently on that date and regulations prohibited all trawling activity within that area. The objective of the Tortugas shrimp sanctuary is to optimize the yield of the shrimp recruited to the Tortugas fishery by establishing a cooperative closure with the State of Florida and the U.S. Department of Commerce to protect small shrimp until they have generally reached a size large than 69 tails/lb.* According to the plan, yield would be increased by protecting shrimp from fishing in an area where they were predominantly small and growing rapidly.

This overview report provides an evaluation of how well the objectives of the Totugas shrimp sanctuary regulation were achieved in 1981. The overview report presents the results of the individual research studies that have been undertaken in connection with the Tortugas shrimp sanctuary. The individual research reports are listed in Appendix A of this report. These specific research papers should be referred to for a detailed description of the data obtained and analytical methods used. Appendix B of this report also contains a cost summary of the research studies.

The Gulf of Mexico Fishery Management Council (GMFMC) requested the Southeast Fisheries Center (SEFC), National Marine Fisheries Service, National Oceanic and Atmospheric Administration to plan and initiate a program of sampling from September 1981 through February 1982 to determine whether adjustments of the Tortugas sanctuary area might be necessary to delineate the Tortugas shrimp nursery area more

*70 shrimp/lb, heads off.

precisely. This report specifically addresses the following questions:

1. What is the regulatory history of the Tortugas pink shrimp fishery?

2. What are the characteristics of the Tortugas fishery in the period of research including catch, effort, catch per unit of effort (CPUE) and fleet mobility?

3. What are the size ranges of shrimp inside and outside the sanctuary area during the study period.?

4. What is the effectiveness of the sanctuary line in protecting small shrimp from fishing compared to selected alternative positions of the sanctuary line?

QUESTION 1: What is the regulatory history for the Tortugas pink shrimp fishery?

Historic

Commercial concentrations of pink shrimp were discovered in the Tortugas Florida area by fishermen Felix Salvador and Everett Peterson in 1949. A fishery was developed in 1950 and has ordinarily produced annual catches of 8-12 million lbs, heads off.* The fishery is primarily based on a single species, Penaeus duroraum. Other species occur in trawl catches, notably Trachypenaeus similis, T. constrictus, Solenocera atlantidic, Penaeopsis goodei and some rock shrimp of the genus Sicyonia. These are of minor importance.

As early as 1955, widespread concern developed over the possibility that Tortugas pink shrimp, particularly small pink shrimp, were being overexploited. Most of the concern was expressed over large catches of very small shrimp which were not saleable and were therefore discarded at sea.

Studies by the Marine Laboratory of the University of Miami led to initial Tortugas management regulations enacted by the Florida State Board of Conservation in 1957. The 1957 session of the Florida legislature passed a law designating part of the Tortugas fishing grounds a "controlled area", i.e., an area that could be closed or open to shrimp trawling as appropriate (Figs 1 and 2). This "controlled area" is the forerunner of the present sanctuary (a sanctuary in various geographic forms has been in effect throughout the history of this fishery). The decision to open or close the "controlled area" was based on sizes of shrimp occurring in the area. When shrimp were predominantly smaller than 50 count, heads off, the area was to be

*Commercial landings are reported in lbs, heads off.

closed to trawling. In 1961 the Florida legislature modified the controlled area specifying one part to be permanently closed and designated a "nursery area". The remainder was designated as a controlled area to be opened or closed as appropriate based on sizes of shrimp in that area (Fig 3). An analysis of Tortugas shrimp sizes derived from sampling in the area is given by Ingle et al. (1959). A history of regulations relating to the Tortugas shrimp fishery is given by Costello (MS), and it has been discussed by Caillouet and Koi (1981) in the context of annual fluctuations in size composition of the catches from 1960 to 1978.

Deferred Harvest Rationale

Initially, the decision to establish a sanctuary for small pink shrimp in the Tortugas area was based on the assumption that deferred harvest of small pink shrimp would result in a benefit to the fishery. The background for the State of Florida management of the Tortugas fishery is clearly expressed in a letter of August 24, 1978 from Charles R. Futch to O. B. Lee. The letter in part stated "...We operate under the basic assumption that: it is desirable to catch the greatest possible number of pounds of shrimp, this desirability being enhanced as the sizes of shrimp are increased." The letter from Futch to Lee further explains Florida State management as follows: "...The shallow, brackish, grassy areas of Florida Bay serve as the nursery grounds for pink shrimp. As growth proceeds, shrimp seek progressively deeper water, resulting in west and northwesterly movements. A comparison of shrimp size with depth (Iversen, et al., 1960) demonstrated that, despite a size differential between sexes, size increased with increasing water depth. Females with a mean carapace length of 25 mm (corresponding to a count size of 67, heads on)

could be expected in depths of 7 fms or greater.

"Clearly, shrimp can be expected to be larger than 67-count/tails by the time they migrate into the open fishing area. The fact that the long northern leg of the line crosses the 7-fm contour presents no contradiction. Iversen et al. (1960) also noted a size gradient in a northerly direction irrespective of depth." The fact that Florida Bay estuaries serve as nursery areas for the Tortugas fishery was confirmed in a series of mark-recapture experiments (Costello and Allen, 1966).

Mortality Studies

Studies estimating rates of fishing and natural mortality for Tortugas pink shrimp (Costello and Allen, 1968; Berry, 1967; Parrack, 1980) supported the rationale for deferred harvest management of Tortugas pink shrimp. Lindner (1965) presented a clear summary of what we know about shrimp size and the Tortugas fishery. His paper further supports the view that protection of small shrimp would increase yield. Another study (Kutkuhn, 1966) did not support the rationale for deferred harvest management; however, mortality estimates in the study were based on small numbers of observations and possible bias in marking methods.[1]

The Department of Commerce Fishery Management Plan enacted in 1981 established a cooperative Tortugas sanctuary closure designed to protect small pink shrimp until they have generally reached a size range larger than 69 tails/lb. This sanctuary slightly modified the historic sanctuary established by the state of Florida. The original "controlled area", its location relative to the Florida keys, the historic State of Florida shrimp sanctuary and the

[1]Thomas Costello, Dept. of Commerce, NOAA, NMFS, SEFC, Miami, FL; personal communication.

current Tortugas sanctuary established in the Department of Commerce Shrimp Fishery Management Plan are shown in Figs 1, 2, 3 and 4.

QUESTION 2: What are the characteristics of the Tortugas fishery in the period of research including catch, effort, CPUE and fleet mobility? (This answer is based on information from Klima, et al. (MS)).

Commercial landings from statistical subareas 1, 2 and 3 in 1981 greatly exceeded landings in all of the years of the fishery since 1960. Average landings are approximately 10 million lbs/yr, heads off; however, in 1981 landings amounted to 14.5 million lbs of shrimp. The landings appeared to be stable during the 21-yr period with the exceptions of 1960 and 1981, which greatly exceeded the average and were larger than the standard deviation of this 21-year period (Fig 5).

The fishery basically begins each year in September/October with recruitment of small shrimp to the grounds with peak harvest in December, January and February and slight declines in March and April, tapering off considerably in the May-August period. It is evident that monthly landings in 1981 were markedly different than the monthly averages of the landings in the rest of the years (Figs 6 and 7).

Fishing effort did not fluctuate greatly over the 21-yr time frame and averaged 16.5 thousand days/yr. One fishing day is defined to be equivalent to 24 hrs of fishing time. Highest efforts were expended in 1961 and 1978. In 1981, the effort was below average but within one standard deviation of the 21-yr time span (Fig 8). Browder[2] indica-

[2]Browder, Joan; DOC, NOAA, NMFS, SEFC, Miami, FL; personal communication.

tes that 768 vessels trawled in the Tortugas-Sanibel grounds (subareas 1-4) in 1981. Over 72% of these vessels also trawled in other regions of the Gulf of Mexico that same year. The total activity of the fleet, according to the number of trips, reaches a peak in the winter in Tortugas-Sanibel and a peak in the summer in the rest of the Gulf of Mexico.

Furthermore, the relative abundance of pink shrimp as measured by CPUE for 24-hr fishing days is remarkably stable thorughout the 1960-1979 period, with an average of 603 lbs/24-hr day (Fig 9). The highest CPUE occurred in 1981 with a catch of 957 lbs/24-hr day. There were significant differences in the CPUE between 1981 and all other years in the fishery. Further, when comparing fishing effort versus catch, the catch appears to be relatively stable for all years except 1960 and 1981 (Fig 10).

Size distribution in 1981 was significantly different from that in the last 5 years (1976-1980) and the first 5 years (1960-1964) of the fishery. The difference between 1981 and the other years was a major recruitment of 50-count or smaller shrimp onto the fishing grounds in March and April 1981. This recruitment could be followed by their modal size classes through August. Historically, there is not a large spring recruitment; however, 1981 was different and this recruitment was easily detectable in the size categories of the commercial landings. In October-December 1981, larger shrimp were landed than for a similar time period from 1976-1980.

The catch and relative abundance, as well as the size distribution of the shrimp on the Tortugas grounds, was different in 1981 from all other years of the fishery except perhaps 1960. Landings were higher, CPUE was higher, and major recruitment of small shrimp which could be followed

throughout the fishery for several months occurred in March and April. The newly-established sanctuary line may have protected the small shrimp during the months of May-September and may have resulted in larger shrimp being caught in October, November and December. Subsequent recruitments of small young-of-the-year shrimp in the fall of 1981 was probably not as great as in previous years.

Unfortunately, it is not possible to make a clear determination from these data that the differences observed in the commerical catch statistics were attributed to implementation of the Tortugas sanctuary. The reason for this conclusion is that there was an unusually large shrimp recruitment into the Tortugas shrimp fishery that preceded establishment of the sanctuary line. However, the line may have contributed to the continued high CPUE and high landings as well as preservation of the dominant modal group, thereby resulting in harvesting of large shrimp from October-December 1981.

Furthermore, questions arise as to how many fishermen refrained from fishing inside the sanctuary, as 33 violations were documented from May 1981 through March 1982 (Fuss).[3] If considerable amounts of illegal fishing did occur, the catch results presented in this paper may be biased in terms of measures of CPUE. Thus the full benefits of the sanctuary would not be realized.

QUESTION 3: What are the size ranges of shrimp inside and outside the sanctuary area during the study period? (This answer is based on information from Roberts (MS)).

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[3]Fuss, Charles; DOC, NOAA, NMFS, Southeast Regional Office, St. Petersburg, FL; personal communication.

Research cruises were conducted from September 1981 through February 1981. Stations were placed both inside and outside the sanctuary line (Fig 11), with the objective to determine whether the line should or could be moved ±10% and still protect juvenile pink shrimp from fishing. Although sampling was not conducted throughout the entire fishing grounds, our stations adequately reflect the shrimp population in the vicinity of the sanctuary line. The answer to this question is based on the shrimp sampling stations and is discussed in detail by Roberts (MS).

The average monthly relative abundance of shrimp from the survey station data for the entire study area varied throughout the study period from a low of 8.8 lbs[4]/30-min tow for one net in October to a high of 23.5 lbs in January. However, the CPUE inside the sanctuary area was always higher than outside the area. Inside the sanctuary, shrimp catch rates ranged from over 30 lbs/hr in January to a low of 11 lbs/hr in October, whereas outside the area, catch rates ranged from 6.4 lbs/hr in October to a high of 15.9 lbs/hr in January (Fig 12; Table 1). To specifically look at the differences in relative abundance between the inside and outside sanctuary areas, we have constructed Table 2 listing the number of stations in which a minimum commercial catch of >8 lbs/30-min tow[5] for one net and the maximum

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[4]Catches and catch rates of the research cruises are given in heads-on weight.

[5]A catch rate of 8 lbs heads on/30-min tow for one net is equivalent to approximately 322 lbs heads-off shrimp per 8 hours fishing with four nets and is defined as "minimum commercial catch".

number of pounds caught in a given month were recorded. This table clearly indicates that the waters inside the sanctuary in the "boot" area (west of the sanctuary line, running north-south) are prolific. Also, the waters inside the sanctuary are significantly more productive than the areas outside the sanctuary. Good catches were experienced throughout the Tortugas grounds both inside and outside the sanctuary only in January.

With regard to size, Roberts (MS) found that shrimp averaging 70-count or smaller, heads off, occurred both inside and outside the sanctuary line in all months except December. Likewise, shrimp that averaged larger than 70-count were found inside and outside the sanctuary in all six months of the study period. These data clearly indicate that the sanctuary line is not a knife-edge division which separated small and large shrimp during the 6-mo study period.

To further substantiate this statement, Roberts examined the percentage size distribution of shrimp smaller than the 70-count found inside and outside the sanctuary line from September 1981 to February 1982 (Table 4; Figs 13 and 14). It is clearly evident that 50% or more of the shrimp found inside the sanctuary in all months except December were smaller than 70-count and that outside the line much larger shrimp were found, although 34% or more of the population outside the sanctuary were considered to be small in all months except December.

During this study, proportions of shrimp smaller than 70-count on the Tortugas grounds ranged from a low of 26% in December to a high of 62% in January. Inside the sanctuary, the percentage of shrimp smaller than 70-count ranged from a low of 28% in December to a high of 68% in September, whereas the percentage of small shrimp was always less out-

side the sanctuary except in January and February. In December, very few less-than-70-count shrimp were found on the grounds. In January, over 68% of the shrimp outside the line were smaller than 70-count, whereas inside the line only 62% were that size.

One important question is what proportion of the small size pink shrimp (smaller than 70-count) in the area sampled was inside the sanctuary line. Table 5 and Fig 15 provide this information on a monthly basis and it is evident that the sanctuary line does, in fact, protect small size shrimp during all months, as a predominant proportion of small shrimp in the population in the area sampled is found inside the sanctuary from September through February.

Further, it is also evident that some portion of the shrimp population is inside the sanctuary and shrimp are larger than 70-count. This percentage varies by month throughout the 6-mo period and ranges from a low of 23% in September to a high of 50% in December (Table 5). It appears that in December, over 50% of the shrimp larger than 70-count were inside the sanctuary. Conversely, in December only 19% of the shrimp smaller than 70-count were inside the line. The biomass of shrimp smaller than 70-count was lowest in October and December and almost five times greater in January (Fig 14).

Therefore, we conclude that the sanctuary line, although it does not protect all of the small shrimp, does protect a high percentage of the shrimp in the Tortugas area. Florida Bay has been identified as the major nursery area for juvenile pink shrimp that are recruited to the Tortugas fishery (Costello et al. MS). It should be recognized, however, that the deeper waters of the Tortugas fishery were not adequately sampled, nor were the very shallow areas where extensive loggerhead sponges are located. Conceivably,

larger shrimp could be found in deeper waters and small juvenile shrimp found in the loggerhead sponge areas. Therefore, the data presented here only represent that portion of the study area that was sampled for the 6-mo period of time. However, we feel it is representative of the Tortugas fishery and as such, is an adequate sample.

QUESTION 4: What is the effectiveness of the sanctuary line in protecting small shrimp from fishing compared with alternative positions of the sanctuary line?

The survey data reported by Roberts (MS) indicated that 63% or more of the total number of shrimp smaller than 70-count/lb were found inside the sanctuary but also 56% or more of all shrimp larger than 70-count were found inside the sanctuary line (Table 6; Figs 15 and 16). The reason for this is that the highest biomass of pink shrimp was always concentrated inside the sanctuary area and that outside the restricted area, the shrimp stock was at least at a 50% lower level of abundance in all months except perhaps October (Table 1).

The relative abundance of shrimp on the Tortugas grounds varied throughout the 6-mo period (Fig 14). Highest biomass occurred in January, next highest in September, closely followed by November. Lowest biomass was encountered in October and December. The biomass of shrimp smaller than 103 mm TL for all stations reflected the general overall biomass and indicated that again September, November and January were the peak periods of small shrimp abundance. It appears there was a major recruitment to the grounds in January 1982.

Inside the sanctuary area, biomass again reflected the same peak time frames of abundance and these data indicated that the sanctuary does protect a large proportion of the

small recruiting shrimp (smaller than 70-count) in all months of the study. High concentrations of small shrimp (70-count) were found in September, November and January inside the sanctuary. It should be pointed out that a large proportion of the shrimp smaller than 70-count were also found outside the sanctuary in the month of January.

The MISS VIRGINIA, a chartered commercial shrimp vessel, was allowed to commercially drag two nights per month in any area they desired. In each of the six months, the MISS VIRGINIA elected to drag inside the sanctuary line. Their shrimp catches were large, ranging from a low of 6 lbs/30-min tow/net to a high of 34 lbs/30-min tow/net (Roberts, MS). In reviewing the specific catches per tow, 6 of the 70 commercial tows averaged smaller than 70-count shrimp for the six months of this study. Further, there were only 27 of 70 stations in which more than 50% of the catch was smaller than 70-count shrimp. The count size of the catch by the MISS VIRGINIA varied from 48 to 101, heads off.

This information provides a great deal of insight into the mixture of both small and large shrimp inside the sanctuary area. It also provides a clear indication that high catch rates can be expected inside the sanctuary, probably because of the restricted fishing. Outside the sanctuary, fishing in all months appears to be relatively poor except for January; therefore, the deliberate fishing by the MISS VIRGINIA inside the sanctuary was a result of knowledge based on sampling as well as knowledge of the fishery in that the catch rates were considerably greater inside the sanctuary, which was protected from all commercial fishing during the study period.

The data collected from the survey studies and the commercial tows made by the MISS VIRGINIA clearly indicate the major portion of the shrimp biomass was located inside the

sanctuary and that shrimp smaller than 70-count were predominantly found in this area, along with larger shrimp. The sanctuary could effectively protect small shrimp from September through February. However, few small shrimp were found on the grounds in December and therefore, at least in this month, the fishery was prevented from catching 70-count or larger shrimp inside the sanctuary when few small shrimp were present.

Alternative Positions for the Sanctuary Line

The Gulf of Mexico Fishery Management Council and the Management Advisory Panel have suggested several alternate positions for the sanctuary line. Obviously there are numerous alternative positions for this line; however, we have selected five options based on the GMFMC's recommendations. These options are as follows:

1. Extend the vertical shrimp line to Snipe Point and eliminate the western sanctuary line, called the "boot".
2. Move the horizontal line farther to the south some 3-4 nautical miles.
3. Move the horizontal line farther to the north 3-4 nautical miles.
4. Leave the line as is.
5. Seasonal closure.

Option 1: If the sanctuary line were drawn vertically to Snape Point, it would close only the eastern portion of the present sanctuary zone to commercial fishing. In reviewing the basic information, most of the shrimp from stations in this eastern area were consistently small throughout the study period. Moreover, low catch rates were experienced east of the sanctuary line and this area obviously serves as a nursery. Costello et al. (MS) clearly indicated that Florida Bay serves as a nursery area for

juvenile pink shrimp. However, the preponderance of the shrimp are moving out of that area westward within the sanctuary. This option would permit fishing in the "boot" area, which has been identified as an area which has large concentrations of small pink shrimp as well as large pink shrimp. The concentration of shrimp is highest in this area as compared to all other areas on the Tortugas grounds. This option would likely considerably increase fishing intensity on small shrimp.

Option 2: Move the horizontal sanctuary line farther to the south approximately 3-4 miles. This would virtually eliminate all protection for the "boot" area because if the line was moved that degree, it would be almost on a parallel line to the reef areas where trawling is not possible.

Option 3: Move the horizontal line farther to the north 3-4 miles. This probably would protect a few more small shrimp, but it would also eliminate fishing on the large shrimp which are also found in this area and would considerably minimize the fishable bottom on the Tortugas grounds.

Option 4: Leave the line as is. This option has been thoroughly reviewed in the data presented in this report and reports by Roberts (MS) and Klima et al. (MS).

Option 5: Seasonal closure. The data presented so far indicates that the months of September, November and January are key months in terms of protecting small pink shrimp on the Tortugas grounds. Very few small pink shrimp were found within the sanctuary area in December and little protection is afforded to the small shrimp population by the sanctuary during this month. A flexible open season could be considered if an adequate monitoring program could be established to determine when few small shrimp are inside the sanctuary. At such times, the sanctuary could be open

to fishing either for a fixed period of time or until the monitoring program determined that small shrimp were abundant in the sanctuary.

Recommendations

Option 4 or 5 appears to be the most realistic recommendation at this time. However, because 1981 was very different from all other years in the fishery, we recommend that no action be taken at this time but that, after reviewing the data at a later date when a full year's data is available, serious consideration be given to selecting months when the sanctuary area could be open to fishing if it poses no threat to protecting small juvenile shrimp on the grounds.

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APPENDIX A

Klima, Edward F., Geoffrey A. Matthews and Frank Patella. MS. A synopsis of the Tortugas pink shrimp fishery, 1960-1981, and the impact of the Tortugas sanctuary.

Roberts, Terrell W. MS. A preliminary analysis of pink shrimp (Penaeus duorarum) size and abundance during the Tortugas shrimp sanctuary study, September 1981-February 1982.

APPENDIX B

COST SUMMARY

Data collection and research directed to the Tortugas sanctuary closure study were carried out by the Southeast Fisheries Center using funds in its FY82 base budget and funds supplied by the Gulf of Mexico Fishery Management Council. The following summary identifies the amounts and uses of the funds spent.

Item			Total Cost
1. Collection of resource survey data: Sept 1981-Feb 1982			
	Labor:	$74.2K	
	Other costs:	88.8K	$163.K
2. Analysis of catch and effort data:			
	Labor:	$10.6K	
	Other costs:	4.2K	$ 14.8K
3. Collection and management of catch and effort data (TIMS) (May-Dec):			
	Labor:	$64.1K	
	Other costs:	38.4K	$102.5K
4. Preparation of reports:			
	Labor:	$ 1.7K	
	Other costs:	0.5K	$ 2.2K
5. Total costs:			
	GMFMC:	$163.3K	
	SEFC:	119.5K	$282.8K

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Table 6. Percent of the pink shrimp population <103 mm TL occurring inside the sanctuary, and percent of the population ≥103 mm TL occurring inside the sanctuary.

Table 1. Mean CPUE (lb/30-min tow/1 net, heads on) of pink shrimp from stations inside and outside the Tortugas closure study area. Calculations are based on 46 tows (2/station) from which length measurements were taken.
STD = Standard deviation.

CRUISE		INSIDE	OUTSIDE	COMBINED
September 1981				
	CPUE	19.96	9.25	14.84
	STD	15.52	4.95	12.88
October 1981				
	CPUE	11.03	6.40	8.82
	STD	8.96	5.65	7.67
November 1981				
	CPUE	23.92	10.16	17.34
	STD	20.96	6.26	11.36
December 1981				
	CPUE	19.25	9.92*	14.68*
	STD	8.60	6.69	9.26
January 1982				
	CPUE	30.43	15.86	23.46
	STD	15.51	9.17	14.79
February 1982				
	CPUE	17.25	6.81	13.58
	STD	9.75	4.52	8.90

*2 tows were missing.

Table 2. Measure of relative abundance inside the Tortugas sanctuary in Area A (west of the vertical closure line) and Area B (east of the vertical closure line) and outside the sanctuary (column 1, the number of stations with 8 lb/30-min tow for 1 net over the total number of stations and column 2, the number in parentheses is the number of stations having the maximum catch per 30-min tow/net.

	Inside sactuary area				Outside sactuary area	
	Area A		Area B			
Month	(1)	(2)	(1)	(2)	(1)	(2)
September	8/9	(2) 40 lbs	1/1	--	5/11	--
October	6/10	(2) 20 lbs	3/3	--	4/11	(1) 20 lbs
November	9/10	(6) 24 lbs	2/2	(2) 24 lbs	6/11	(1) 24 lbs
December	9/10	(3) 27 lbs	1/2	(1) 27 lbs	4/9	--
January	10/10	(9) 21 lbs	1/3	--	8/11	(4) 21 lbs
February	99	(2) 30 lbs	1/2	(1) 30 lbs	2/11	--

Column 1 gives the number of stations with ≥8 lb/30-min tow for one net (net before slash) and the total number of stations sampled (number after slash). Column 2 gives the number (in parentheses) of stations having a catch/30-min tow/net as large as or larger than the given value.

Table 3. Number of stations sampled for pink shrimp according to average size group (<103 mm TL and ≥103 mm TL) and location (inside or outside the sanctuary area).

Month	Average size <103 mm TL		Average size ≥103 mm TL		Total No. Stations Sampled
	Inside	Outside	Inside	Outside	
September	X	X	X	X	21
October	X	X	X	X	23
November	X	X	X	X	23
December			X	X	21
January	X	X	X	X	23
February	X	X	X	X	23

Table 4. Percentage of pink shrimp <103 mm TL and ≥103 mm TL occurring at sampling stations inside and outside the sanctuary and combined by month.

Month	Inside		Outside		Combined	
	Percent <103	Percent ≥103	Percent <103	Percent ≥103	Percent <103	Percent ≥103
September	68	32	37	63	59	41
October	50	50	34	66	44	56
November	51	49	45	55	48	52
December	28	72	23	77	26	74
January	62	38	68	32	64	36
February	55	45	56	72	55	45

Table 5. The relative abundance in percent of pink shrimp found inside and outside the sanctuary based on the total population of shrimp taken at all sampling stations combined (except for stations F1 and F2). The shrimp are divided according to total length <103 mm and ≥103 mm.

Month	Inside		Outside		Combined	
	Percent <103	Percent ≥103	Percent <103	Percent ≥103	Percent <103	Percent ≥103
September	48	23	11	18	59	41
October	33	33	12	23	44	56
November	36	37	12	15	48	52
December	19	50	7	24	26	74
January	41	25	23	11	64	36
February	40	33	15	12	55	45

Table 6. Percent of the pink shrimp population <103 mm TL occurring inside the sanctuary, and percent of the population ≥103 mm TL occurring inside the sanctuary.

Month	Percent <103 mm TL	Percent ≥103 mm TL
September	82	56
October	73	59
November	75	71
December	72	67
January	63	70
February	72	73

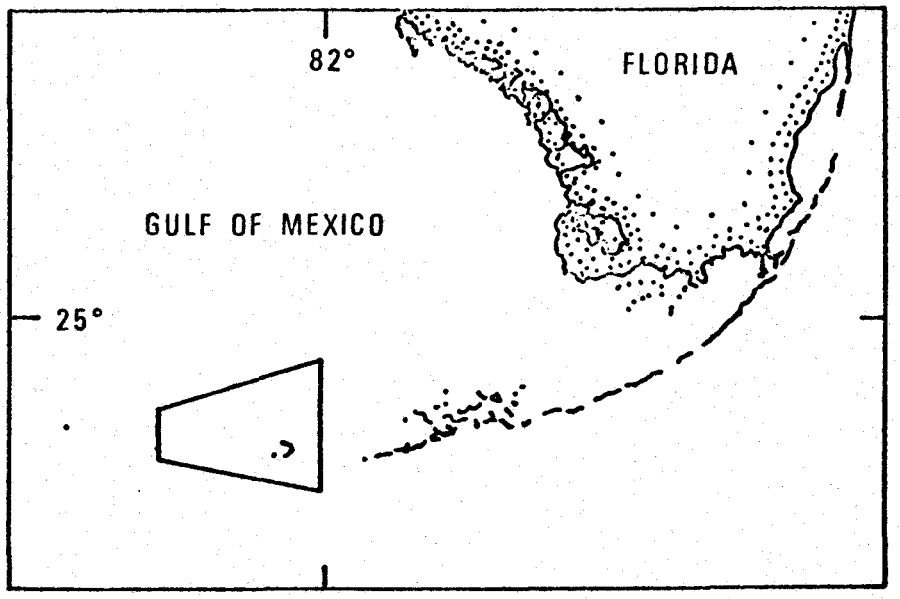


Figure 1. Location of 1957 controlled area in relationship to the southern tip of peninsular Florida and the Keys.

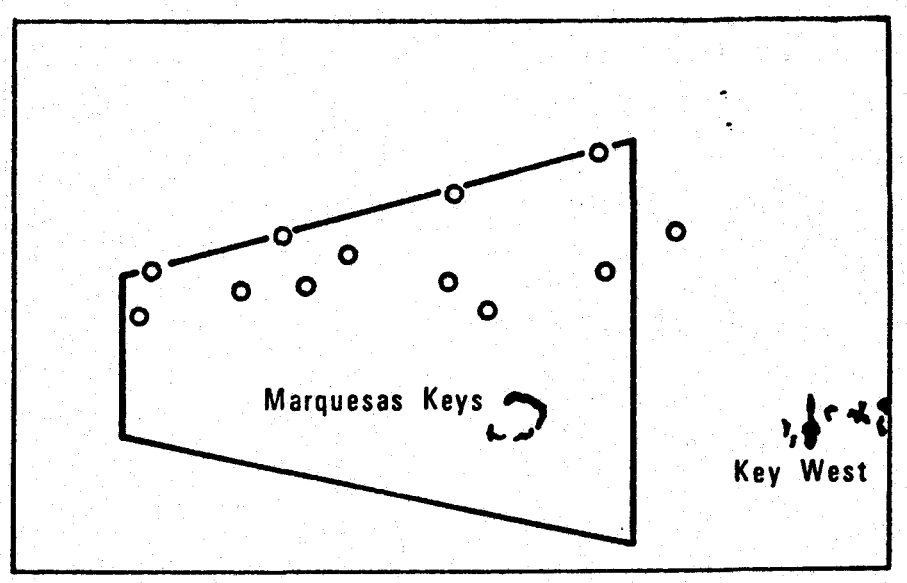


Figure 2. Controlled area showing location of sampling stations used by the State of Florida in their 1957-1958 study of shrimp sizes (Ingle et al.; 1959).

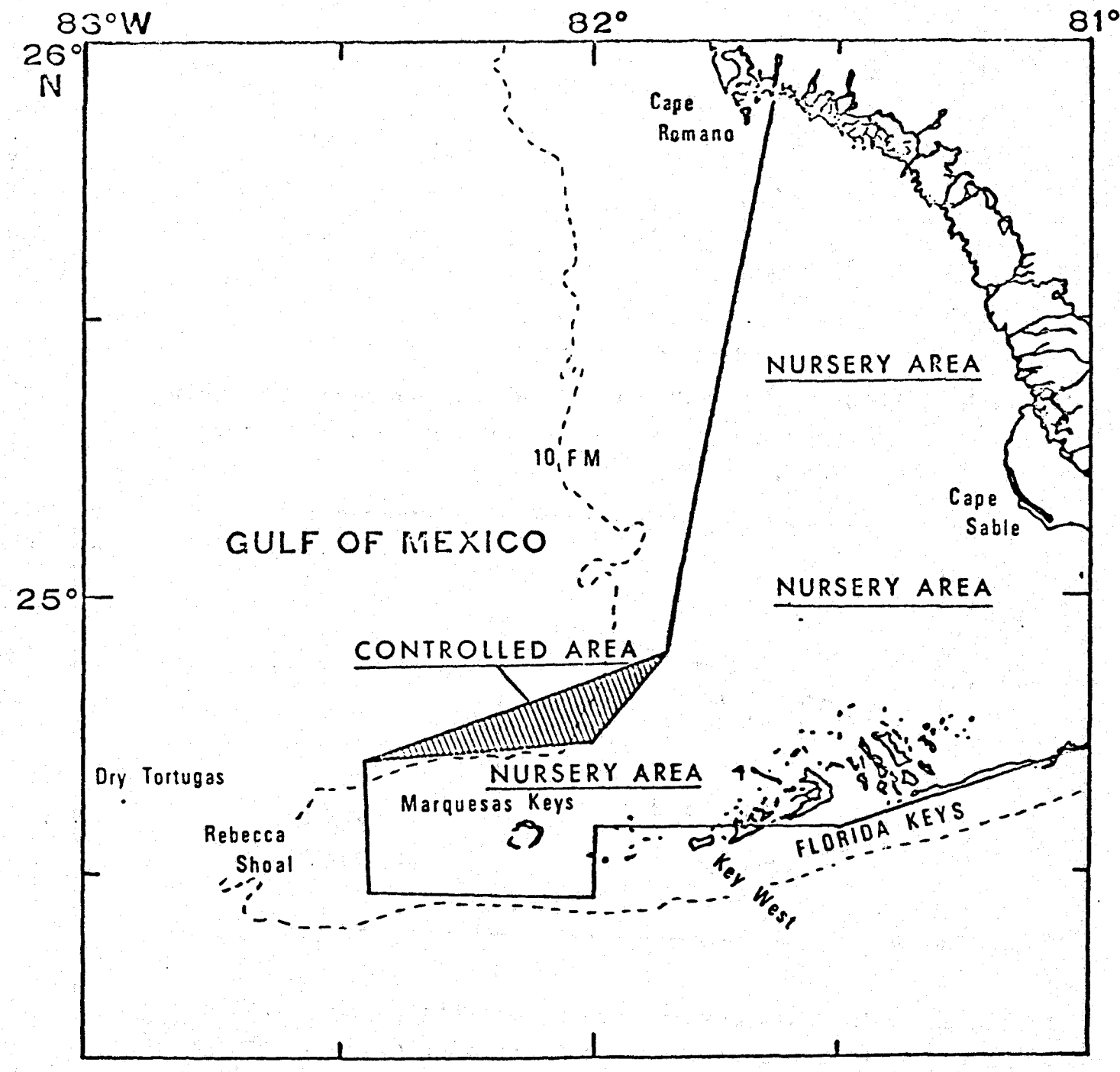
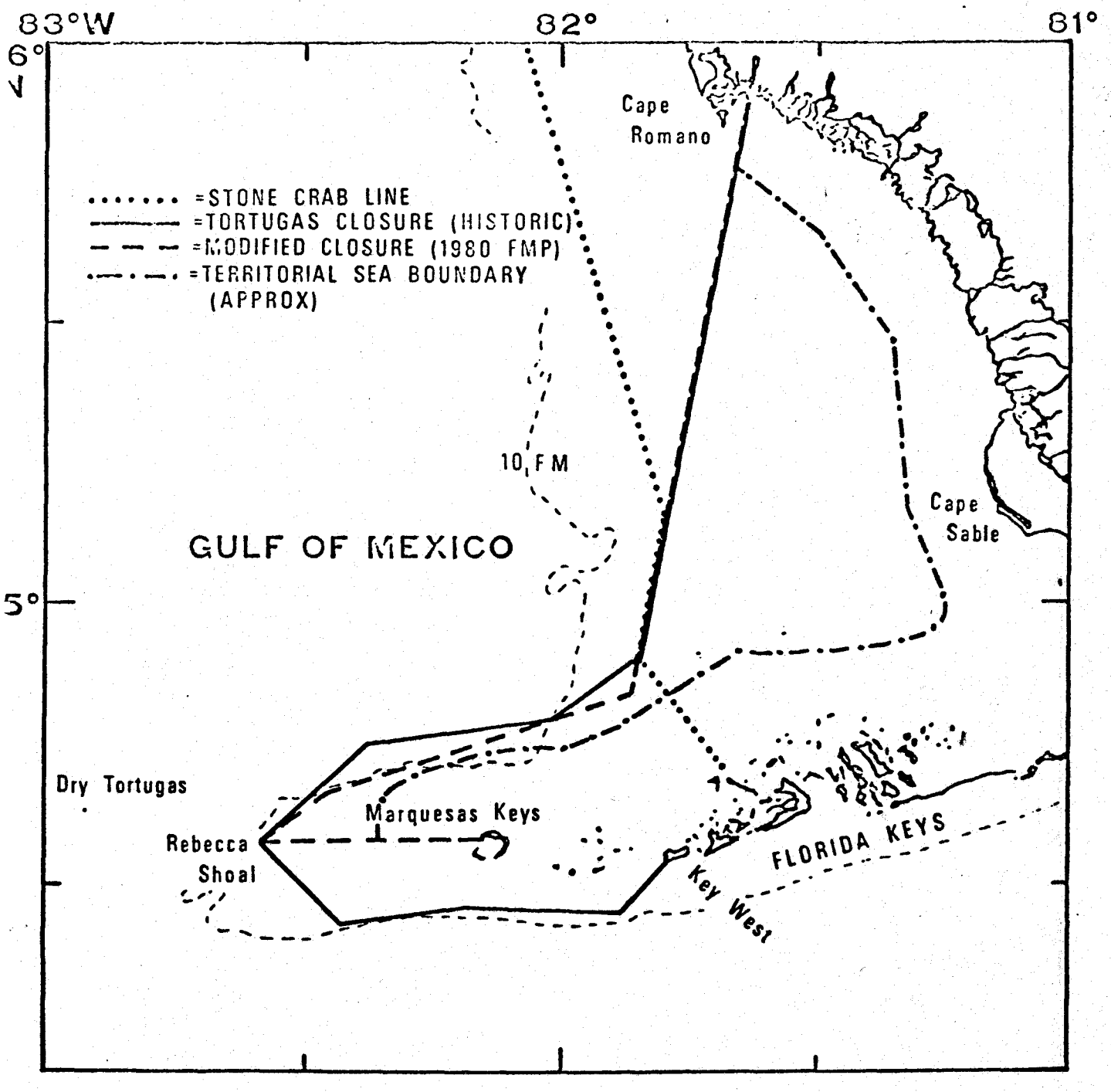


Figure 3. Pink shrimp nursery areas and controlled area of the Tortugas fishing grounds as enacted by the 1961 Florida legislature.



Figur 4. Chart of Tortugas shrimp grounds with stone crab boundary and Tortugas closed fishing area.

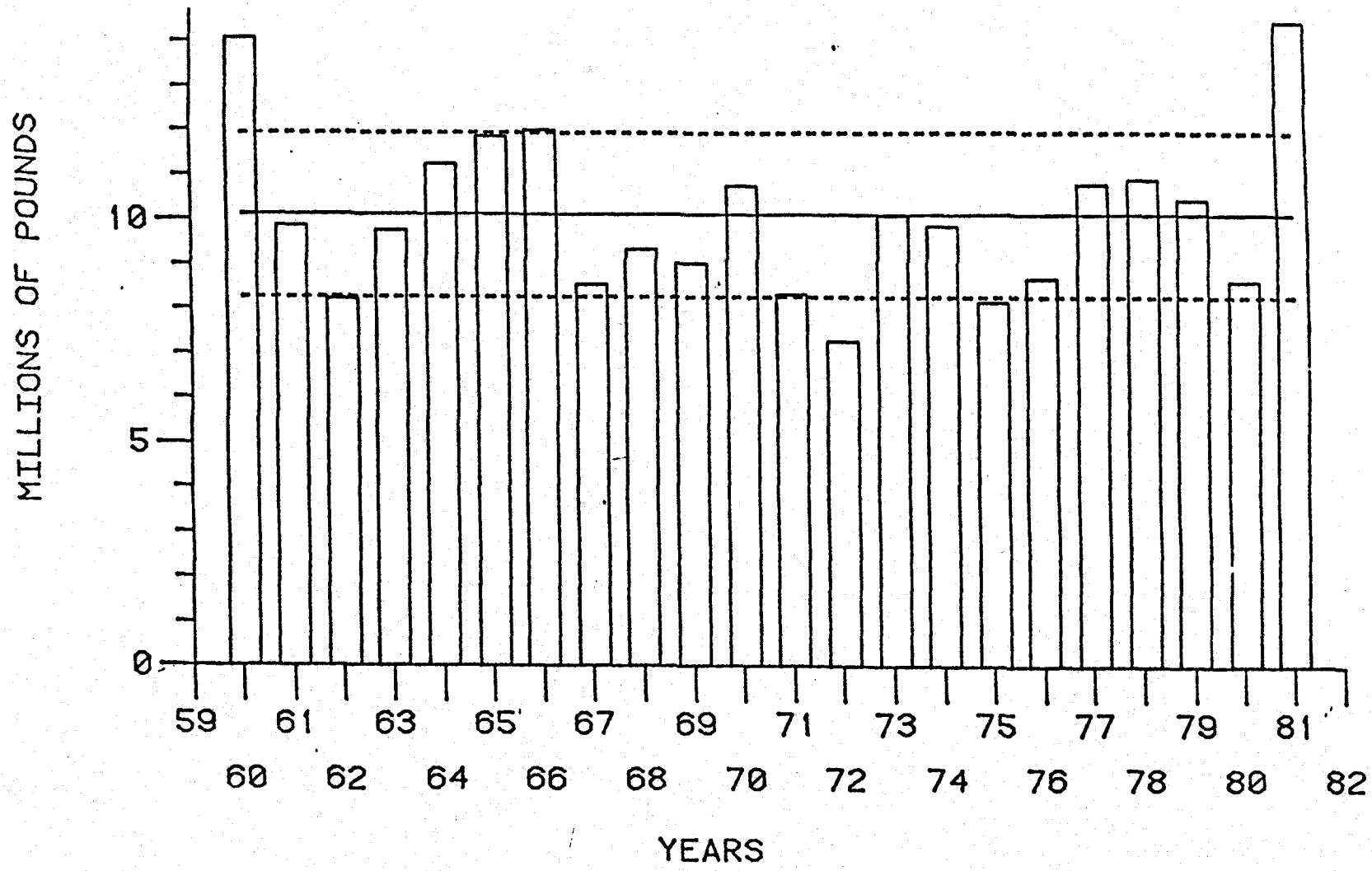


Figure 5. Annual shrimp landings in millions of pounds from statistical subareas 1, 2 and 3, 1960-1981 (solid line is average landings; broken lin is one standard deviation).

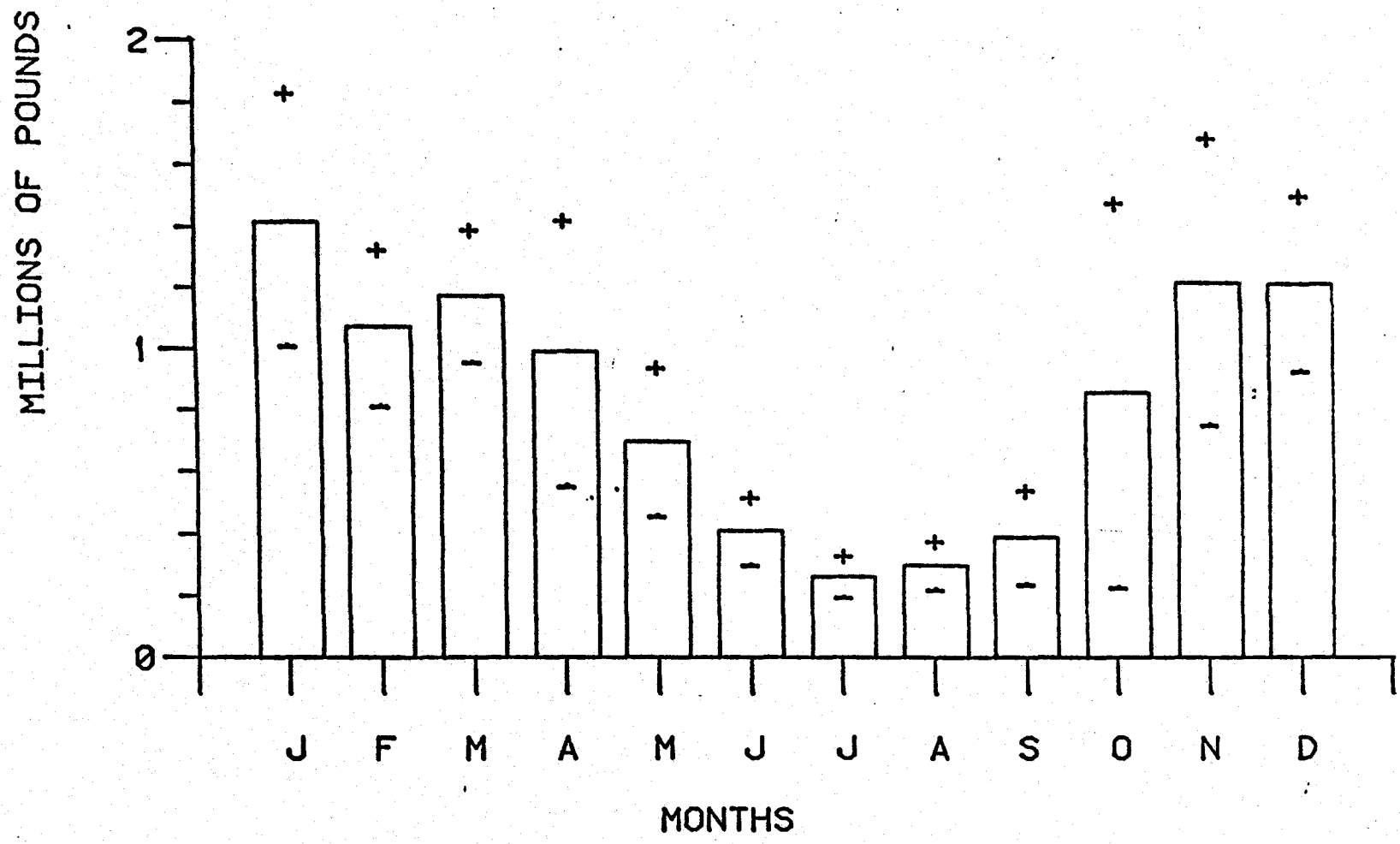


Figure 6. Average monthly pink shrimp landings in millions of pounds, 1960-1979, from statistical subareas 1, 2 and 3 ±one standard deviation.

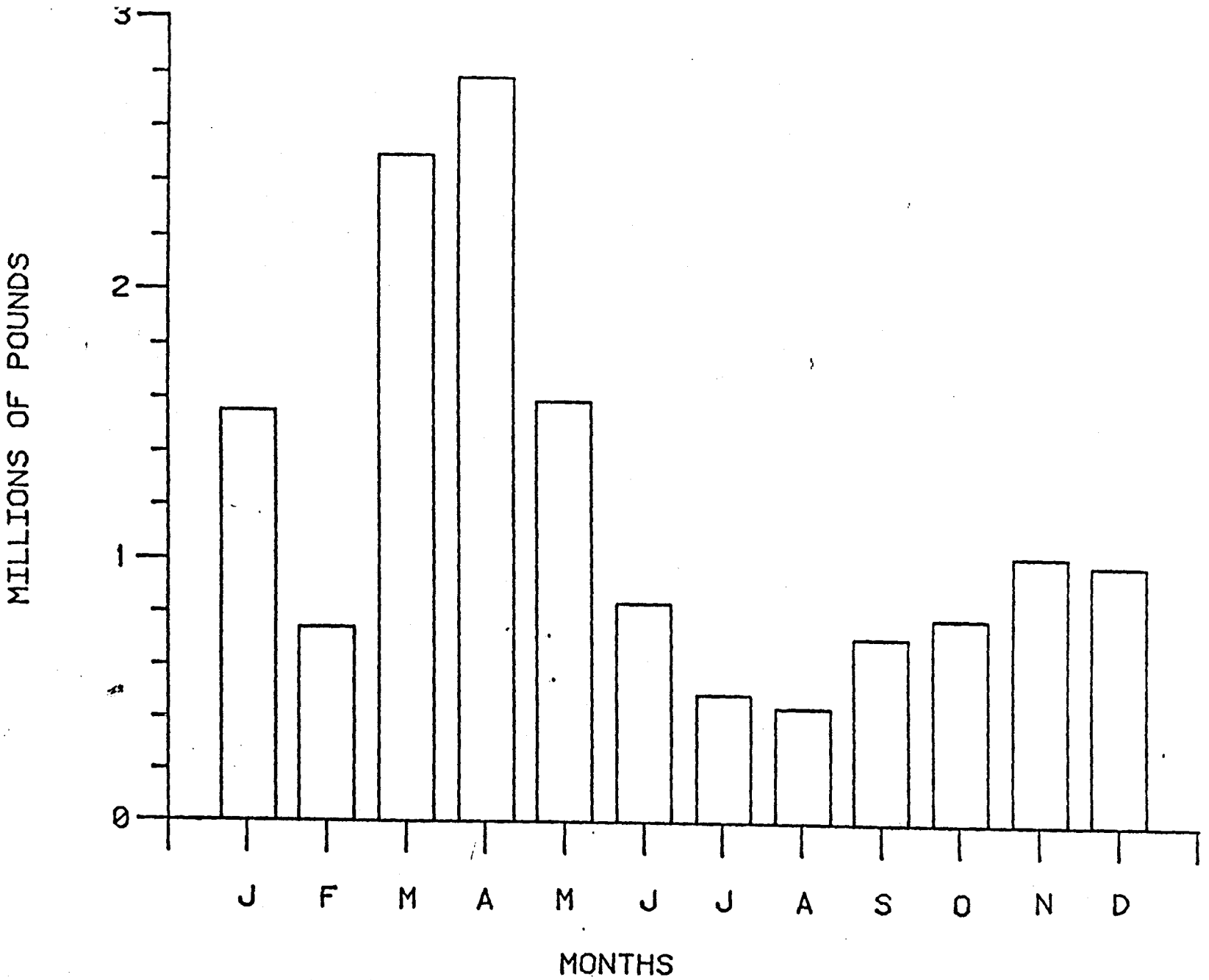


Figure 7. Monthly pink shrimp landings in millions of pounds in 1981 from statistical subareas 1, 2 and 3.

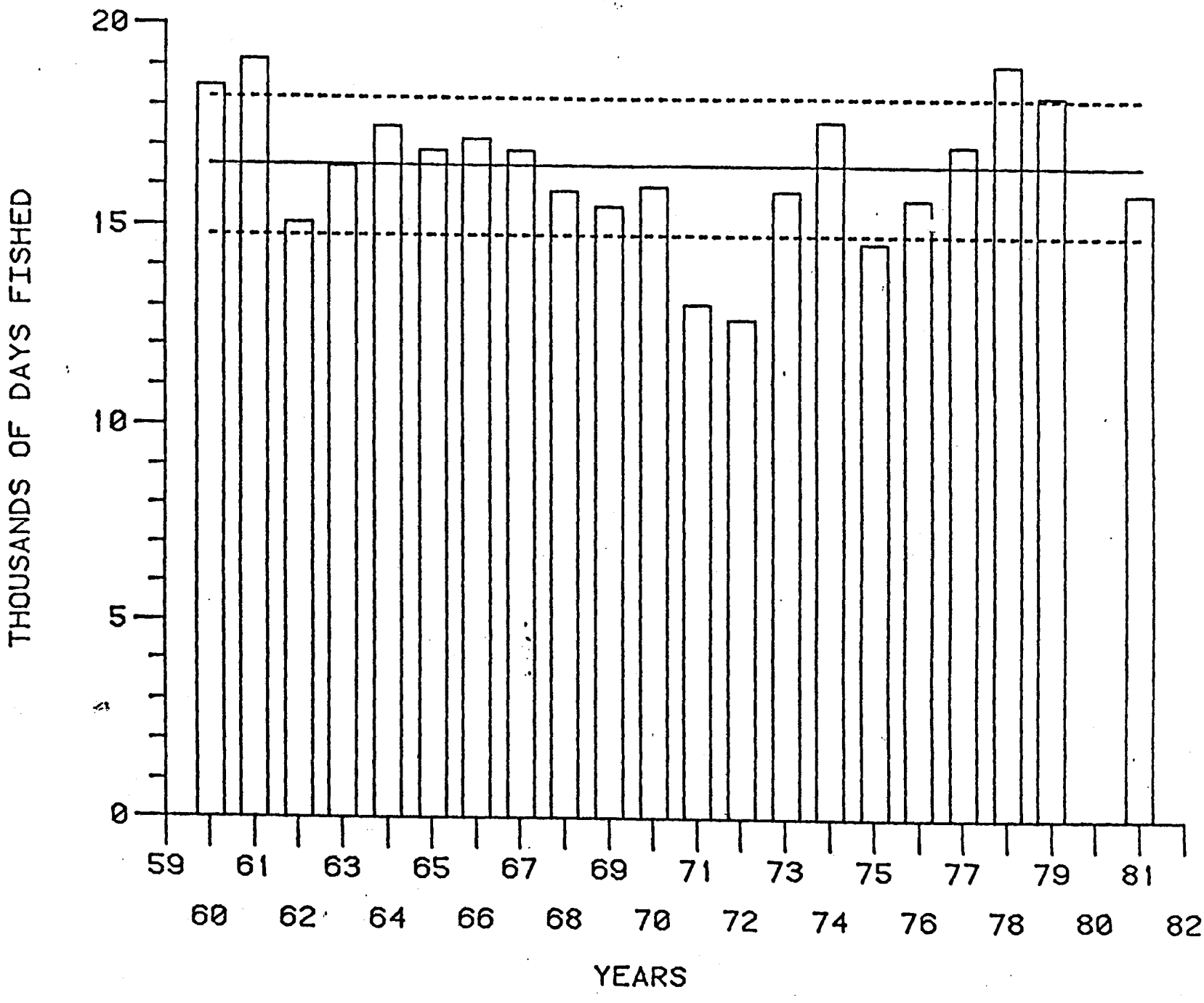


Figure 8. Fishing effort in thousands of days fished in statistical subareas 1, 2 and 3 by year from 1960-1979 and 1981 (solid line is average effort and broken line is one standard deviation).

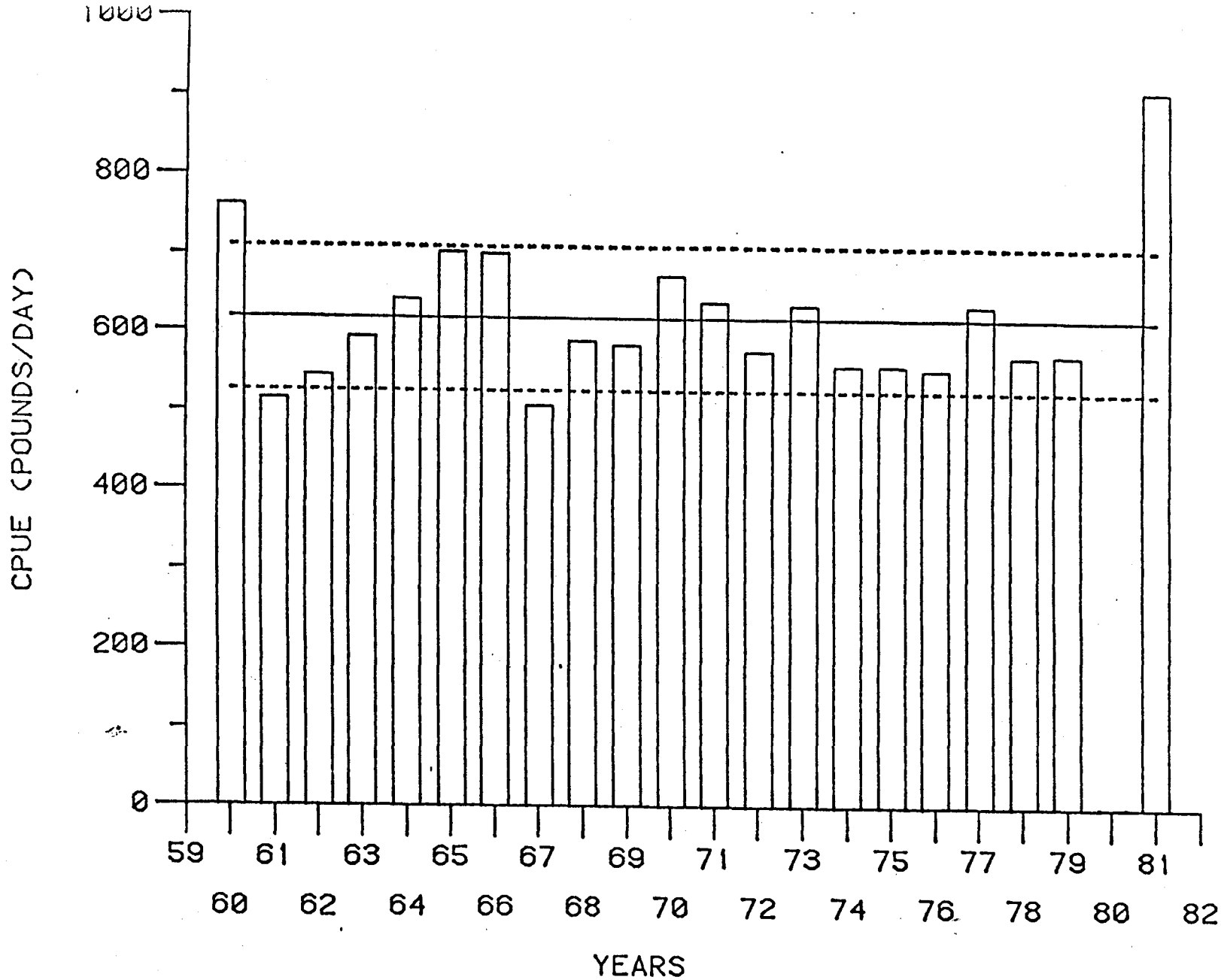
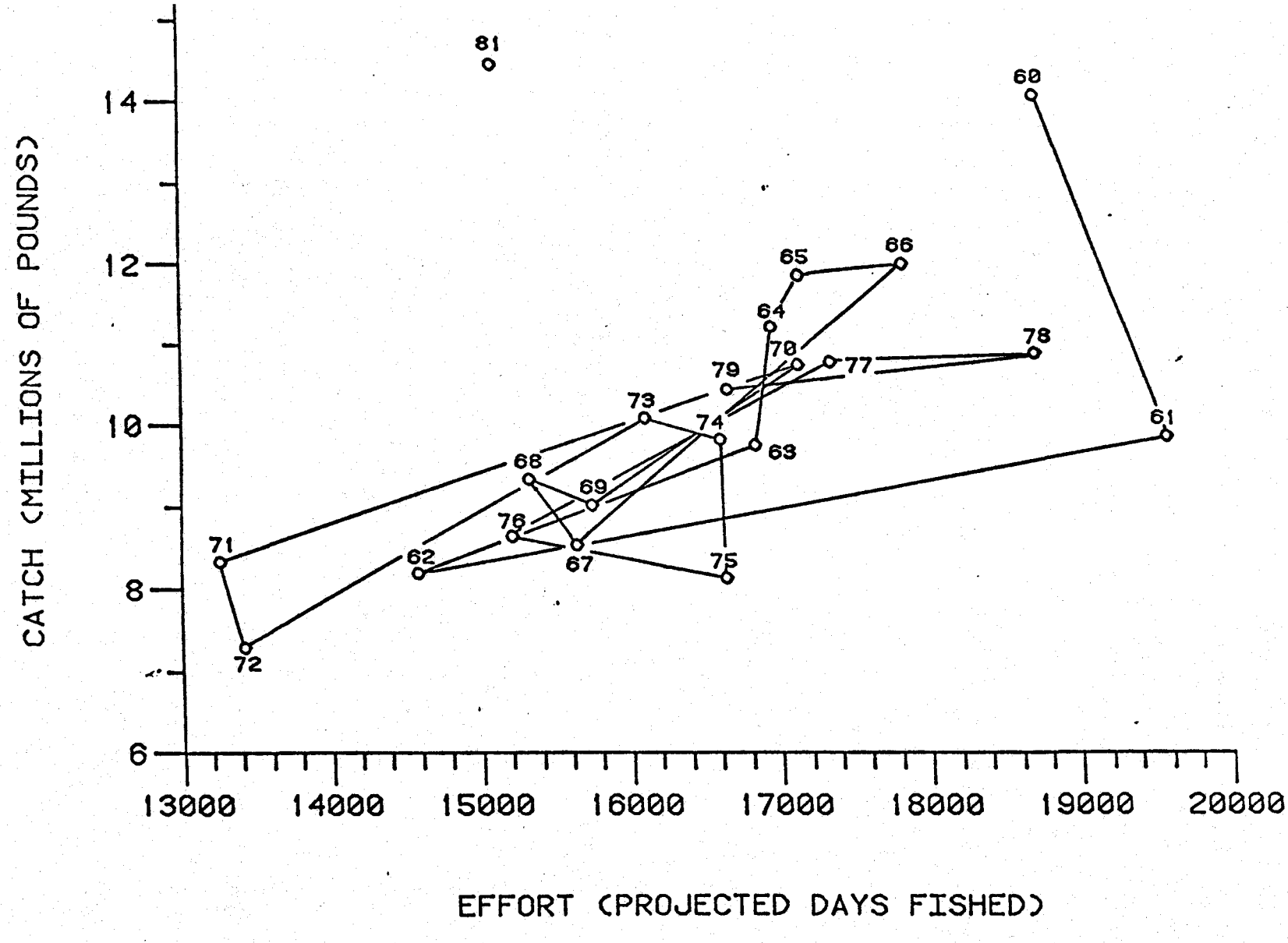


Figure 9. Catch per unit effort from 1960-1979 and 1981 in statistical subareas 1, 2 and 3 (solid line is average, broken line is one standard deviation).



Figur 10. Catch versus fishing effort in 1960-1979 and 1981 from statistical subareas 1, 2 and 3.

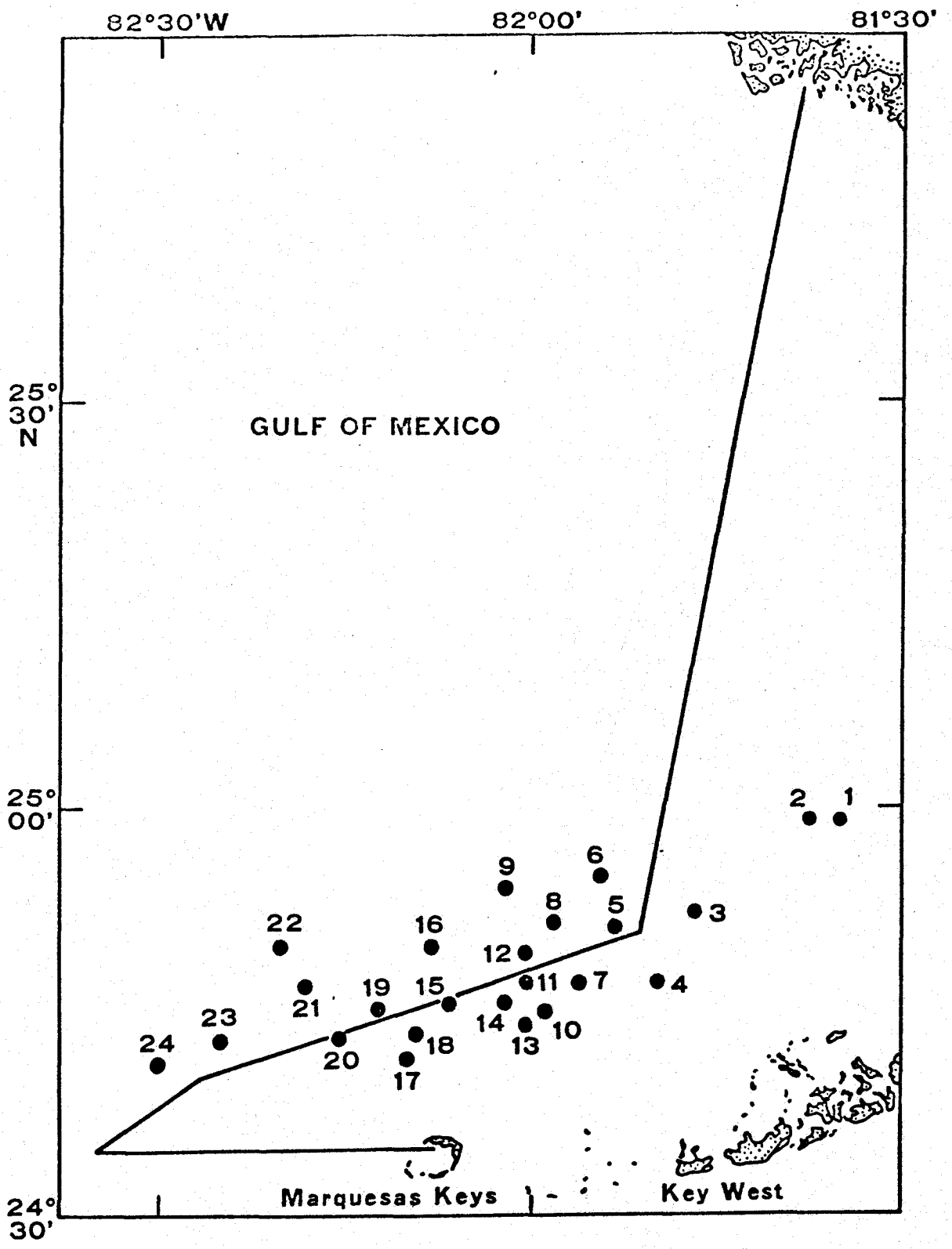


Figure 11. Map of the Tortugas Shrimp Sanctuary showing the location of 24 stations designated for monthly sampling.

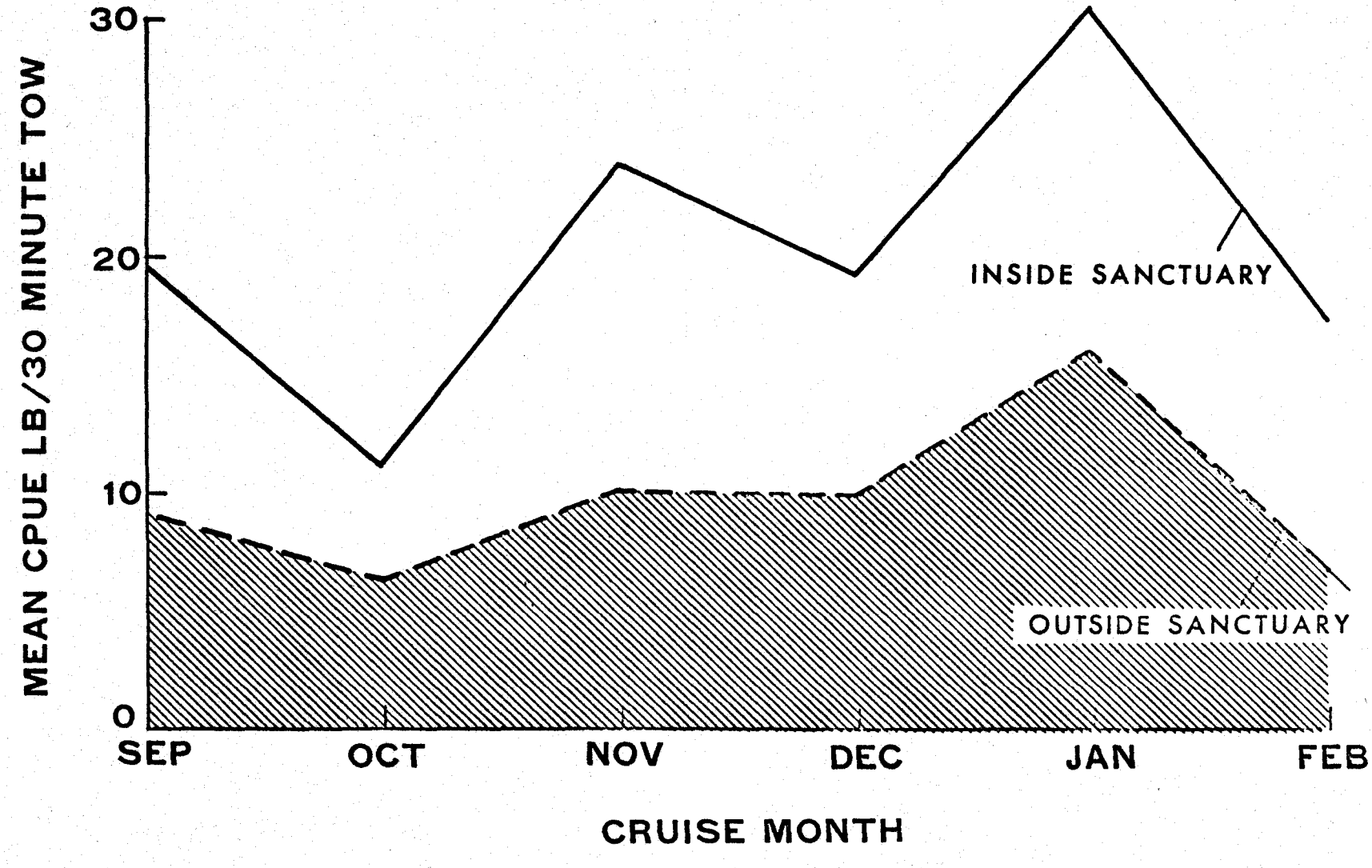


Figure 12. Average CPUE by month from sampling stations inside and outside the sanctuary.

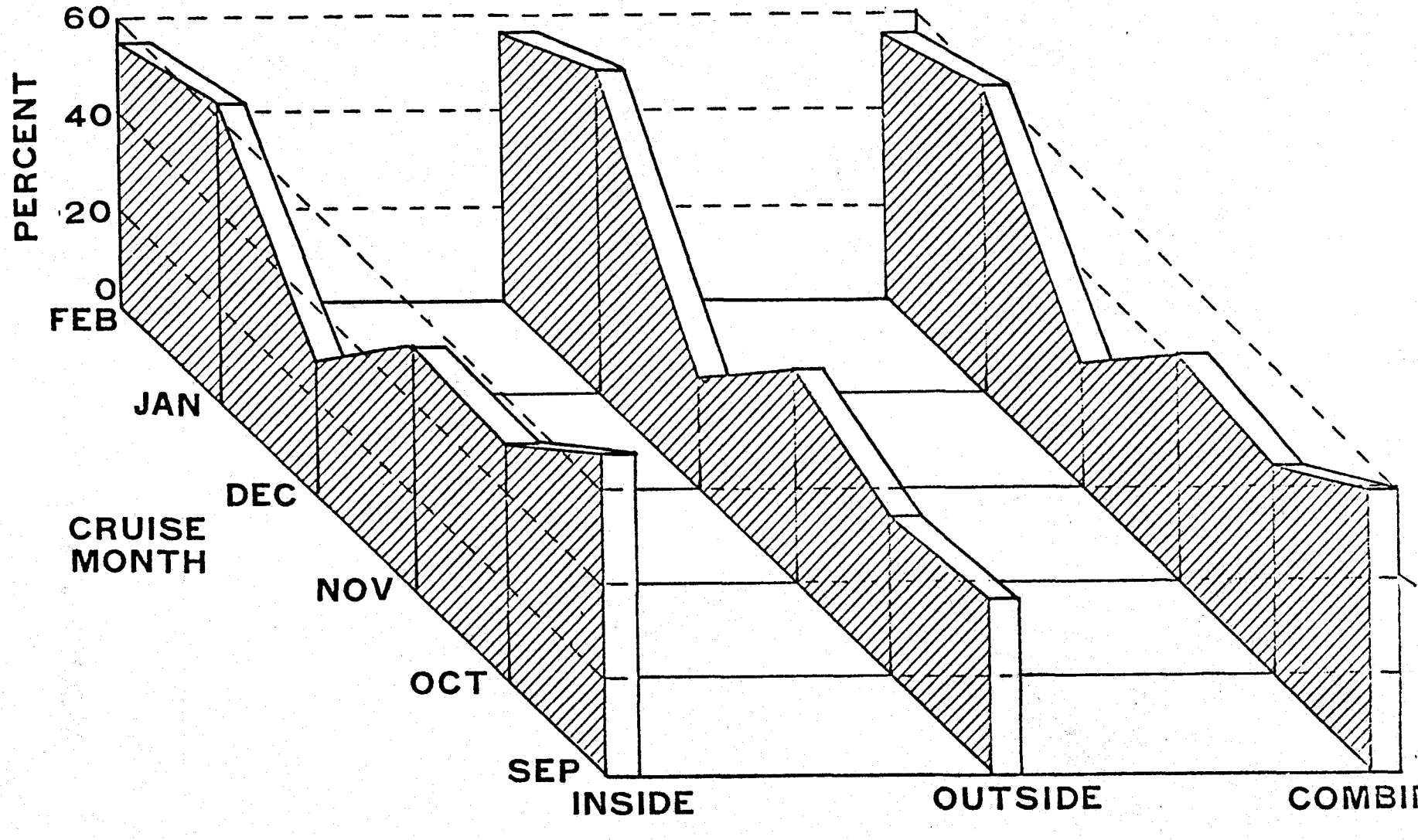


Figure 13. Relative abundance in percent of pink shrimp <103 mm TL at sampling stations inside and outside the sanctuary by month.

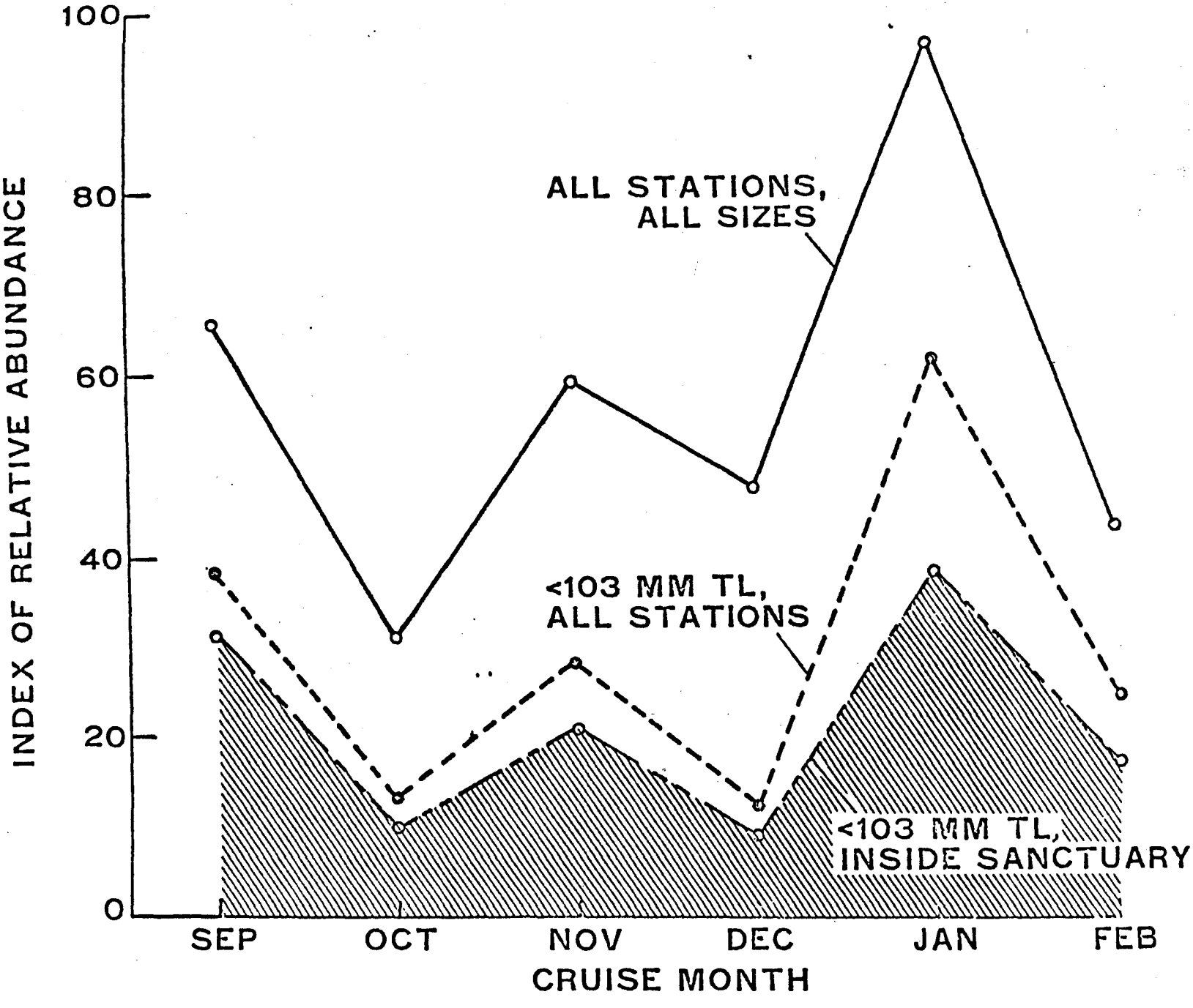


Figure 14. Relative abundance in number of pink shrimp by month.

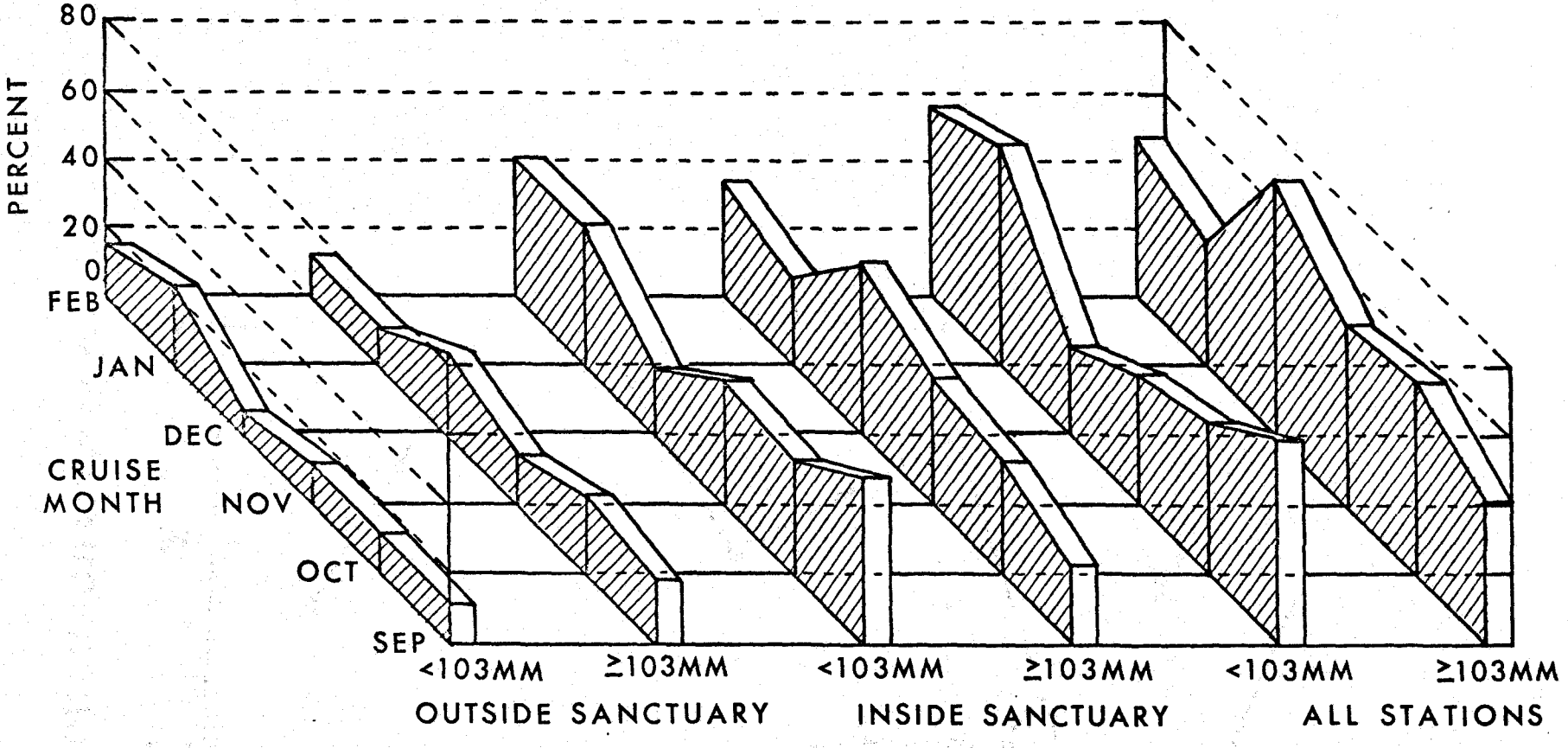


Figure 15. Percent of pink shrimp population <103 mm TL and ≥103 mm TL occurring inside and outside the sanctuary by month.

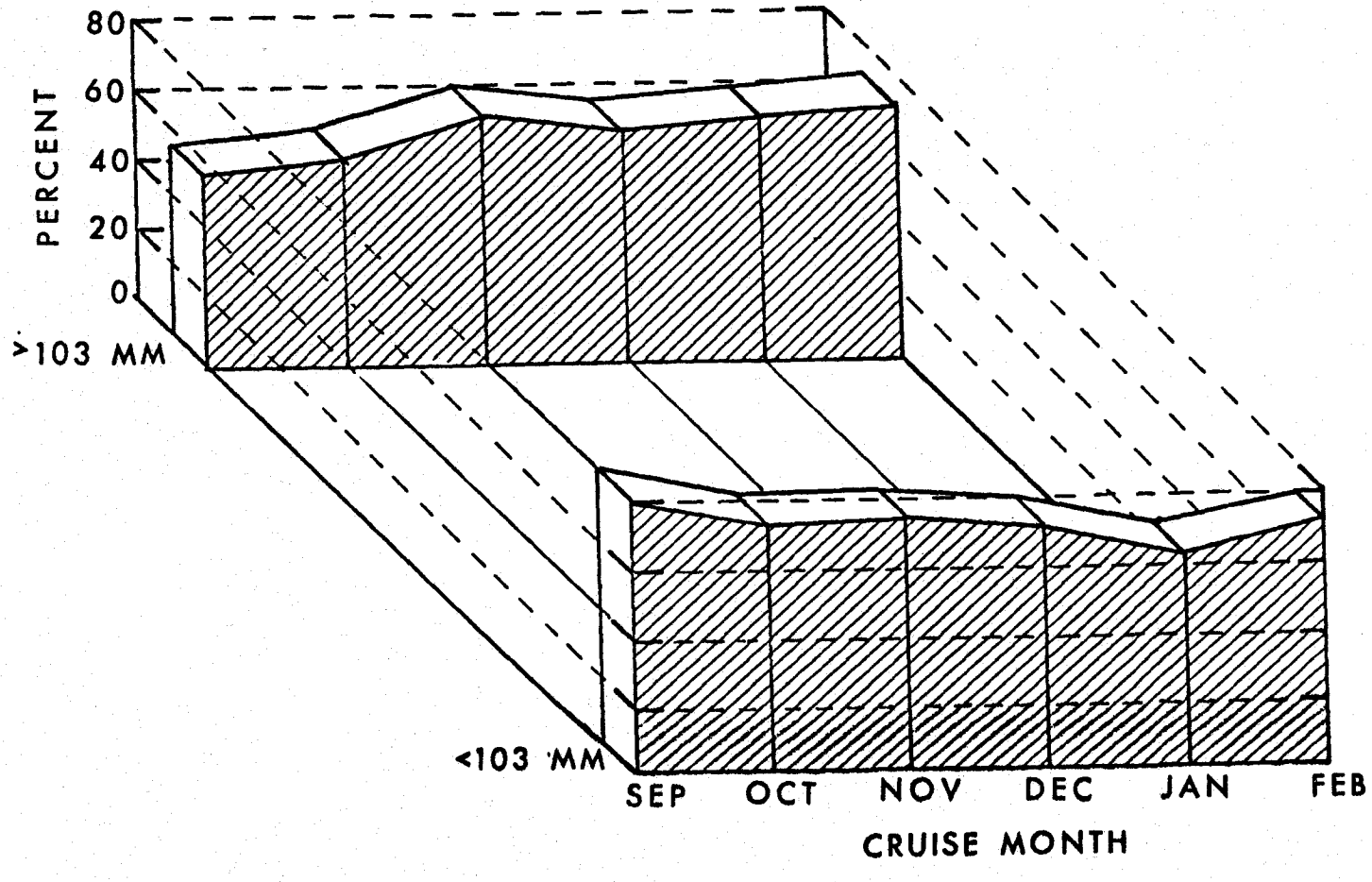


Figure 16. Percent of pink shrimp population <103 mm TL and ≥103 mm TL occurring inside the sanctuary area.

REPORT II

A PRELIMINARY ANALYSIS OF PINK SHRIMP (PENAEUS DUORARUM) SIZE AND ABUNDANCE DURING THE TORTUGAS SHRIMP SANCTUARY STUDY, SEPTEMBER 1981 - FEBRUARY 1982

BY

TERRELL W. ROBERTS

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ACKNOWLEDGEMENTS

Many people were involved in the collection and analysis of data taken in the Tortugas study. I am especially appreciative of the cooperation and effort of the Captain and crew of the MV MISS VIRGINIA who helped alleviate the drudgery and tedium of the long night hours and helped make the trips in the field enjoyable. My special thanks to Dr. Geoffrey Matthews who helped immensely with the statistics involved and prepared several computer programs to analyze the data. I also thank Mr. Frank Patella and Dennis Koi who patiently helped me with the computer and furnished the data when I needed it.

Drs. Edward Klima, Sammy Ray, and Al Jones were kind enough to review earlier drafts of the manuscript and offer many valuable suggestions for improving the text. Mr. Tom Costello also offered suggestions for the manuscript and was especially helpful in explaining the history of the fishery and the philosophy of the management methods for the Tortugas Fishery utilized in the past.

Mr. Neal Baxter was very helpful throughout this study by resolving any operational problems that came up while collecting the data and also by offering suggestions in the interpretation of some of the analyses.

Thanks are also due to Mrs. Bea Richardson for her patience in typing the many drafts of this report and to Mr. Danny Patlan for his preparation of the text figures in such a short time.

ABSTRACT

Twenty-three stations located inside and outside the Tortugas Shrimp Sanctuary were sampled once a month (September 1981 to February 1982), primarily for abundance and length/frequency data on the pink shrimp, Penaeus duorarum. The collection of data on shrimp ovarian development and temperature and salinity data were secondary objectives. Four nets were towed simultaneously for 30 minutes at each station. A complex and variable distribution of shrimp abundance and size was found in the study area.

Shrimp size tended to increase in an east to west direction during September and October. During November, this pattern changed with the largest shrimp at the middle stations and smaller shrimp at the eastern and western ends. December was an anomalous month compared to the other months since there were very few small shrimp (≤103 mm total length) in the population. The mean size of the shrimp at all stations in December was ≥106 mm. January and February show a reversal of the earlier trend with small shrimp mostly at the western stations and larger shrimp at the eastern end. Small shrimp dominated the entire population, except in December when they seemed to almost disappear from the study area. Although most of the population of small shrimp was inside the sanctuary, they were also found outside the line and even dominated the population there in January and February.

Shrimp abundance, defined as catch per unit effort (lbs-heads on/net/30 min. tow), was highly variable. The highest CPUEs occurred inside the sanctuary and a general inverse relationship existed between CPUE and mean length. The highest CPUEs generally occurred at Stations F10, F13, F14, and F17.

Commercial tows by the MV MISS VIRGINIA were permitted after regular sampling was accomplished. These tows usually clustered

around Stations F10, F13, F14, and F17. The mean size of the shrimp caught commercially usually was equivalent to the mean size of shrimp found at the closest station, but the CPUE for each commercial tow generally was less than the CPUE at the nearest sampling site. Because larger shrimp bring higher prices, the captain tried to select those locations that had a higher abundance of large shrimp. To this end, he was successful for 54 of the 70 commercial tows (77% of the time) made during the six cruises.

Salinity and temperature were measured at each station at the surface and near bottom. There was very little variation in either parameter. Except on a few occassions, salinity was mostly 34 o/oo - 36 o/oo during all six months. Anomalously low salinity and temperature readings were recorded at Station F23 in November and probably should be considered as recording errors. Temperature was also stable from surface to bottom, varying only 1.7°C during any one cruise, except September when the variability was 3°C. Temperature was highest in September (28°C average) and lowest in January (20.5°C average).

Ovarian development during the six month study period followed the trends reported in previous studies. Development indicating reproductive activity was highest during the warmest months (September and October) and lowest during December. January was slightly colder than December, but it also represents the start of the spinq peak in spawninq activity. Therefore, there was a higher proportion of advanced ovarian development during January when compared to December, and it increased again in February.

INTRODUCTION

The Gulf of Mexico Fishery Management Council (GMFMC) has the responsibility for developing a shrimp fishery management plan for the Gulf of Mexico. This plan for managing six species of shrimp was adopted in 1980, and it is reviewed annually to evaluate management measures for fairness and effectiveness in optimizing fishery yield (Gulf of Mexico Regional Fishery Management Council, 1980). One of the management measures adopted by the GMFMC was the establishment of a cooperative permanent closure with the State of Florida and the U.S. Department of Commerce in an area near the Dry Tortugas to protect small pink shrimp (Penaeus duorarum Burkenroad) until they attain a size range generally larger than 69 tails per pound. This closed area shown in Figure 1, known as the "Tortugas Shrimp Sanctuary," had coordinates established in 1974 based on previous research that showed a direct relationship between size of shrimp and depth of water (e.g., Ingle et al., 1959; Iversen et al., 1960). However, other investigators have shown that there is no simple movement of larger shrimp to deeper water outside the sanctuary nor is there segregation of pink shrimp by size (Eldred et al., 1961). Although there is a general net movement to deeper water, size frequency analysis (Ingle et al., 1959; Iversen et al., 1960) and tagging studies (Iversen and Idyll, 1960; Iversen and Jones, 1961) have found a random or back and forth movement of shrimp along a northerly or north-westerly axis. These studies indicated that, either seasonally or all year, small and large pink shrimp may occur together inside the sanctuary.

In order to allow commercial fishermen to harvest the larger shrimp in the deeper waters within the sanctuary, the boundaries of the Tortugas Shrimp Sanctuary were redefined in 1981 (Fig. 1) so that, in general, all water inside the closed area was less than

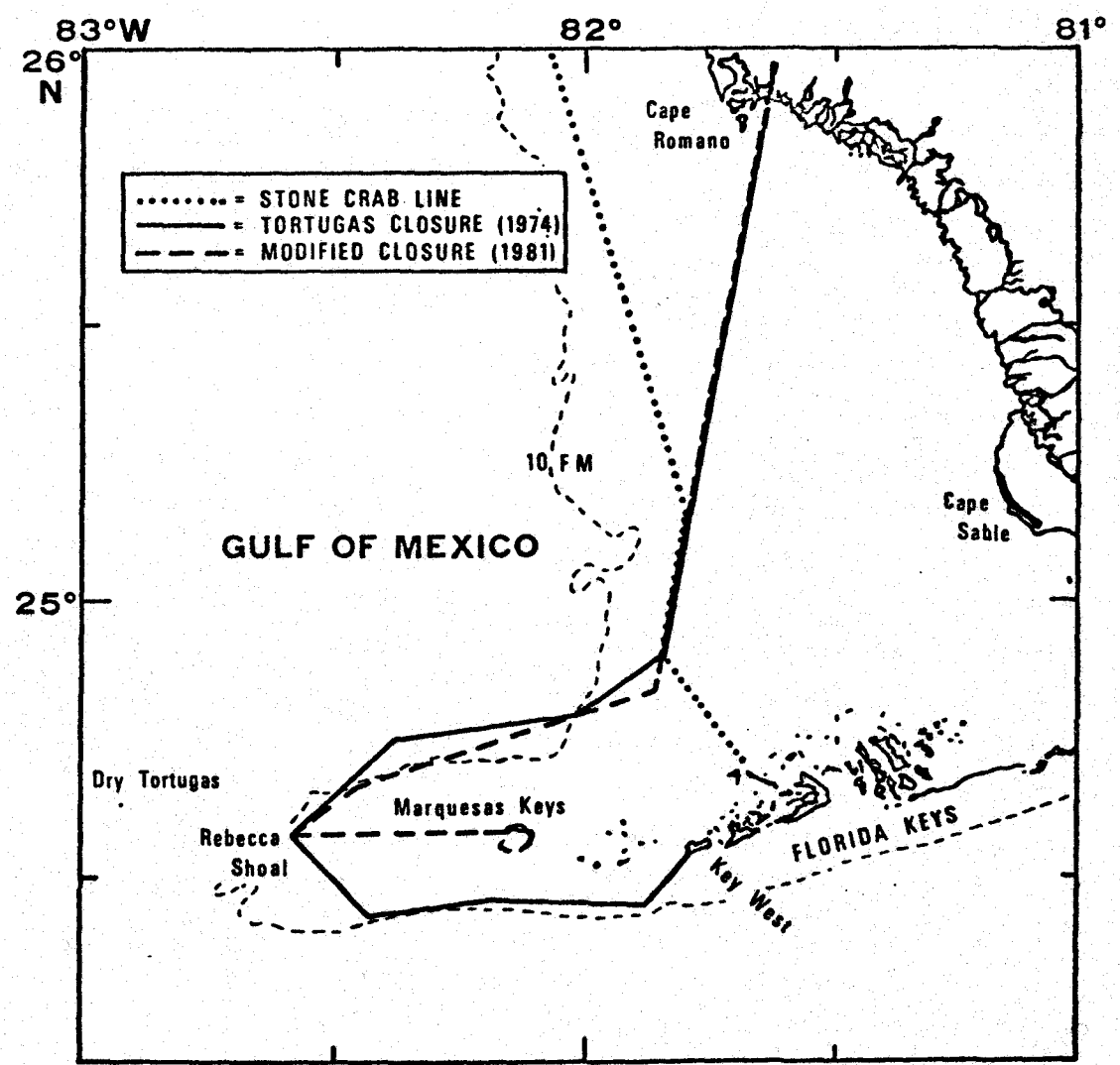

Figure 1. Map of the Tortugas area showing the stone crab line, shrimp sanctuary boundaries of 1974, and the 1981 modified sanctuary boundaries.

10-11 fathoms deep. However, the Council recognized the need for current data on which to delineate the sanctuary boundaries. Thus a sampling program was recommended to more precisely define the actual range of small shrimp in the Tortugas area.

To this end, a sampling program was initiated in September 1981 by the Galveston Laboratory of the National Marine Fisheries Service (NMFS) and funded by GMFMC to provide data on shrimp size inside the sanctuary boundary. The program was originally set for monthly sampling over a six month period (September 1981 - February 1982), but was extended for six months in March 1982 to provide a full year's data. The objectives of the study were to:

(1) Collect length/frequency data on pink shrimp within and outside the Tortugas Shrimp Sanctuary;

(2) collect ovarian development data on female pink shrimp within the study area;

(3) collect data on fish and crustacean by-catch associated with the Tortugas pink shrimp community; and

(4) characterize hydrographic parameters of the study area.

This report will be limited to the results of data analysis for the first six months of sampling and any conclusions on pink shrimp populations in the Tortugas area must necessarily be limited in scope until the full year's data have been collected and analyzed.

METHODS AND MATERIALS

The MV MISS VIRGINIA, a 23.2 m (76 ft) Florida trawler, was contracted by NMFS to conduct all sampling activities for the Tortugas Shrimp Sanctuary study. Twenty-four stations selected randomly on trawlable bottom and ranging in depth from 6 to 14 fathoms were located inside and outside the sanctuary boundary (Fig. 2). The MV MISS VIRGINIA, rigged for twin trawling with four

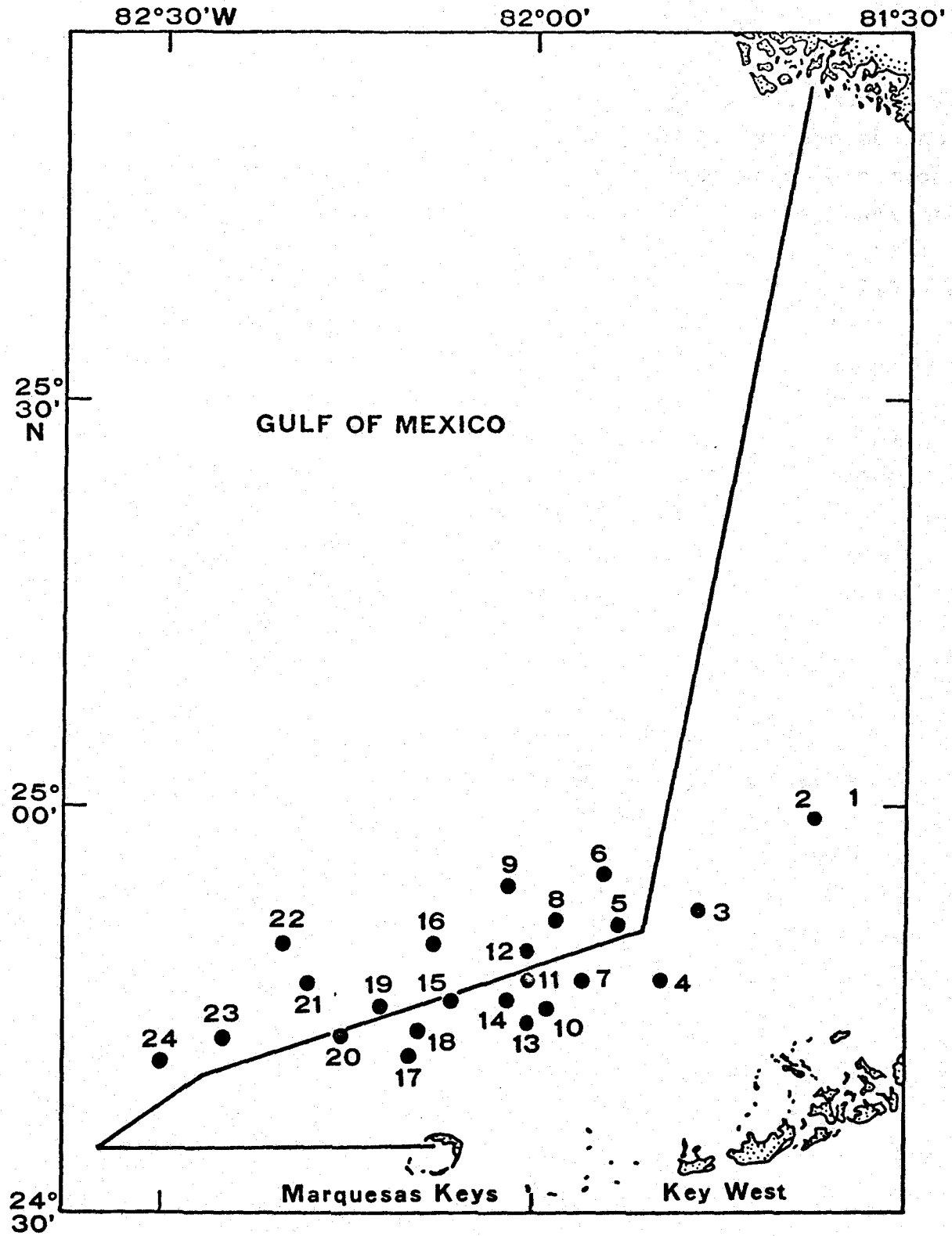

Figure 2. Map of the Tortugas Shrimp Sanctuary showing the location of 24 stations designated for monthly sampling.

12.2 m (40 ft) 4-seam flat trawls, tickler chains, and 2.4 m x 1.0 m (8 ft x 40 in) wooden doors, sampled each station at night once a month. The path of each 30 minute tow crossed at some point the station coordinates given in Table 1. Each station's towing path and location were recorded on a Loran C plotter, which has an accuracy in this region of about ± 125 ft, so that each month's sampling had a high probablity of covering the same towing path.

For the sake of convenience in handling large sample volumes brought in by four nets, it was decided to treat the data from the inboard nets differently from the outboard nets. All shrimp were sorted from the catch of all four nets separately, but only the total shrimp weight was recorded from both outboard nets. Data recorded from each inboard net included total catch weight, total fish weight, total shrimp weight, miscellaneous weight (invertebrates), and total number of shrimp (extrapolated from a three pound count of pink shrimp). In addition, a random sample of 200 pink shrimp was taken from the port inboard net for sex ratio determination and weights, total length measurements, and ovarian development determination. A five pound sample of shrimp was removed from the starboard inboard net and frozen for return to the Galveston Laboratory where total lengths and weights were determined along with a more exacting species composition. Thus, two replicate measures of shrimp weights and lengths were determined for each station.

Two hydrographic parameters, salinity and temperature, were recorded at each station at the surface and near the bottom. An optical refractometer with an accuracy of ± 0.5 o/oo and a mercury thermometer with an accuracy of ± 0.1°C were used to record the parameters.

Each monthly collecting trip was scheduled for seven nights. If any time remained after sampling each station, the captain was permitted to trawl within the sanctuary boundaries at his discre-

Table 1. Tortugas Shrimp Sanctuary station locations and depths.

Station	Latitude (° ')	Longitude (° ')	Depth (fm)
F1	24 59	81 35	6
F2	24 59	81 37	6
F3	24 52	81 46	8
F4	24 47	81 49	9
F5	24 51	81 53	9
F6	24 55	81 54	9
F7	24 47	81 56	9
F8	24 52	81 58	10
F9	24 54	82 02	12
F10	24 45	81 59	9
F11	24 47	82 00	10
F12	24 49	82 00	10
F13	24 44	82 00	9
F14	24 46	82 02	10
F15	24 45	82 07	11
F16	24 50	82 08	13
F17	24 41	82 10	8
F18	24 43	82 10	10
F19	24 45	82 12	11
F20	24 43	82 15	11
F21	24 43	82 19	11
F22	24 50	82 20	14
F23	24 43	82 25	11
F24	24 41	82 30	12

tion. Each commercial tow was timed, position coordinates recorded, and total shrimp weight estimated from the packaged catch. In addition, a randomly selected sample of 200 pink shrimp was sexed, measured, and weighed. A five pound box was collected at random from a maximum of six commercial tows during the cruise. These samples were frozen and returned to the Galveston Laboratory for processing.

All data derived from the Tortugas Shrimp Sanctuary collections were stored on magnetic tape files at the U.S. Office of Personnel Management Computer Service Center in Macon, Georgia. A Honeywell 66/80 computer in Macon and NMFS computer programs were used for some analysis of the data. A Tektronix 4051 mini-computer and 4662 plotter at the Galveston Laboratory were used for all analysis of variance, graphical analyses, and plotting.

RESULTS AND DISCUSSION

The analyses of data on length/frequency distribution of pink shrimp, catch effort, ovarian development, and hydrographic parameters for the six month period under consideration will be presented in this section of the report. The primary focus of this study is to examine the size distribution of pink shrimp so that the boundaries of the Tortugas Shrimp Sanctuary can be determined more precisely to protect immature shrimp without hindering the commercial harvest of larger shrimp. Therefore, the length/frequency distribution of these shrimp will be considered first.

LENGTH/FREQUENCY

Because these data consist of shrimp measurements taken at 24 stations over a six month period, data analysis must first determine if there are significant differences in shrimp lengths, not

only between stations (spatial distribution), but also between cruises (temporal distribution) as well as any interaction (spatial vs. temporal) between stations and cruises. Since the stations and cruises represent fixed treatment effects, a Model I two-way anova was used to test for any significance between these treatments and interaction as well (Sokal and Rohlf, 1969).

Two-Way Anlaysis of Variance

Table 2 shows the two-way anova for 23 stations x 6 cruises. Station F1 has been eliminated from all analyses because it could not be sampled on three of the six cruises due to the large number of crab traps spread randomly throughout the area. Samples from Stations F21 and F22 of Cruise IV (December 1981) could not be obtained due to the large amount of jellyfish (Aurelia sp.) brought up in the nets, and only one length/frequency sample was recovered at Stations F3 and F20 of Cruise I (September 1981). These missing values were replaced for computation of the two-way anova by estimates calculated using Yates' method (Steel and Torrie, 1960). These estimated values do not add information to the anova, therefore one degree of freedom should be subtracted from the error d.f and total d.f. for each estimated value. However, because only six d.f. are involved out of 138 error d.f. and 275 total d.f. and the computer program available on the Tektronix mini-computer does not allow for internal correction, this small adjustment was not made and, in this case, would not change the final results of the anlaysis.

Only the mean lengths from the two measured samples from each station were used in this analysis because of the prohibitive cost of computer time and memory had the complete data matrix of up to 400 or more shrimp lengths per station been used. Transformation of the mean values was not necessary since most of the values were

Table 2. Results of a two-way analysis of variance of shrimp mean lengths at 23 stations on six cruises. Station F1 has been deleted and missing values calculated for F3 and F20 of Cruise I and F21 and F22 of Cruise IV.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Cruises	5	2531.78	506.36	67.97	0.000***
Stations	22	2830.75	128.67	17.27	0.000***
Interaction	110	10637.38	96.70	12.98	0.000***
Error	138	1028.00	7.45		
Total	275	17027.91			

based on large numbers (>100) of measurements, which according to the Central Limit Theorem implies that the mean lengths should approach a normal distribution (a primary prerequisite for analysis of variance).

The shrimp length/frequencies from the two inboard nets have been pooled for each station except F1 of each cruise. Because there are 136 such histograms (there are no data for F21 and F22 of Cruise IV), they have not been included in this report, but will be furnished to interested parties upon request.

The two-way anova (Table 2) shows that not only are there significant differences between cruises ($P<.001$) and between stations ($P<.001$), but also in the interaction between cruises and stations ($P<.001$). This significant interaction means that when cruises and stations are considered together, the effect of either treatment (cruise or station) on size of shrimp cannot be predicted from the average response of the separate factors. Therefore, all further analyses will consist of one-way anova of the stations of each cruise considered separately. This method of analysis will exclude any added interaction effects and will allow a more meaningful interpretation of differences between stations of mean pink shrimp lengths.

Before leaving the two-way anova, it would be helpful to see the effects of interaction by examining Figure 3, a two-way plot of the mean lengths of 23 stations x 6 cruises. Each rectangle represents the relative size of the shrimp, i.e. the larger the rectangle, the greater the mean length of shrimp for that station and cruise. Cruises I and II show a general trend with the largest shrimp occurring at the western-most stations and the smallest near the eastern end. Cruises III and IV, however, show no clear segregation of size by station. Cruise III has very few large shrimp and they appear to be scattered in the middle and western stations.

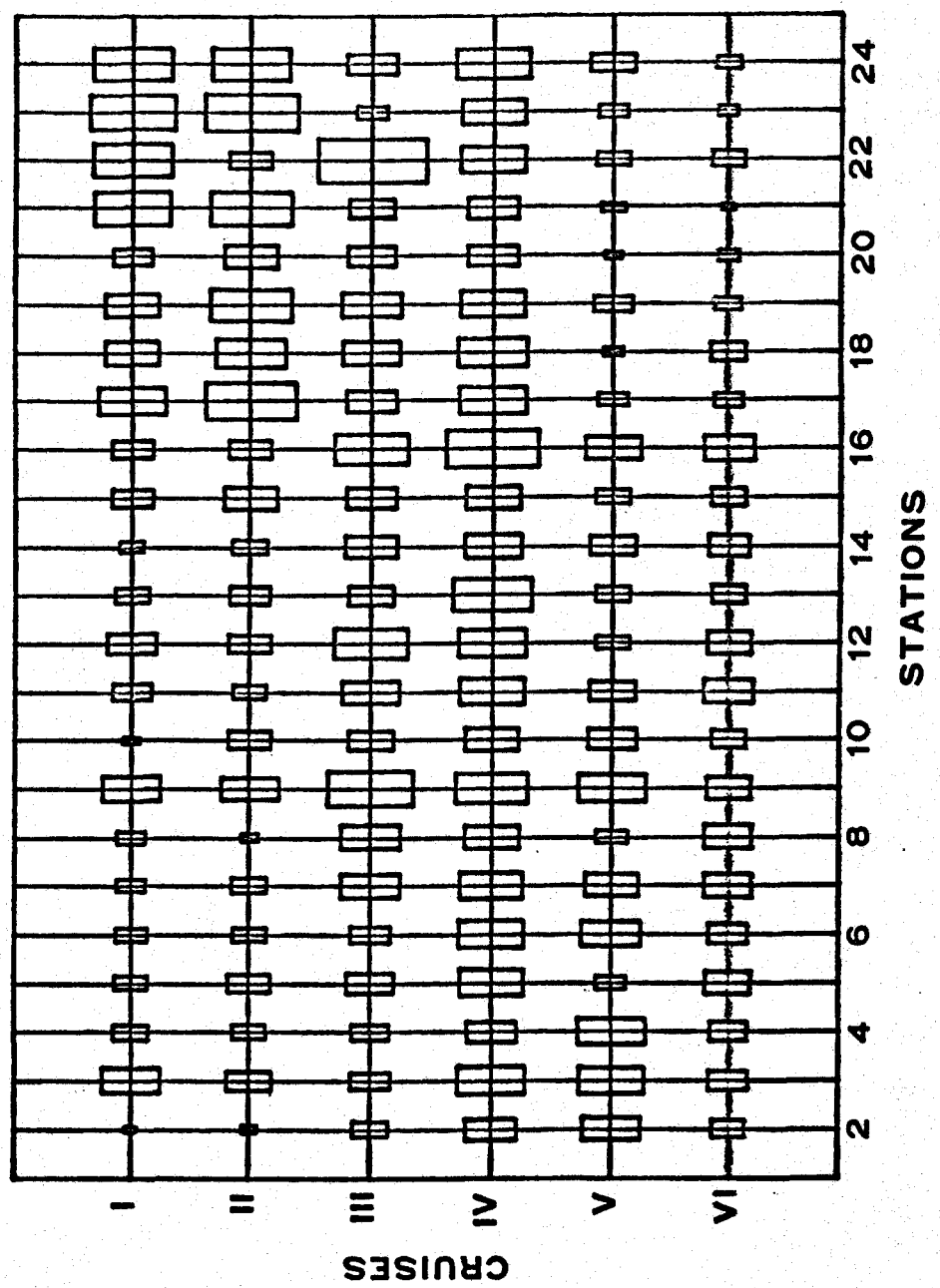

Figure 3. Two-way plot of shrimp mean lengths for 23 stations and six cruises. Each rectangle represents the relative mean length of pink shrimp at a station. Station F1 has been deleted.

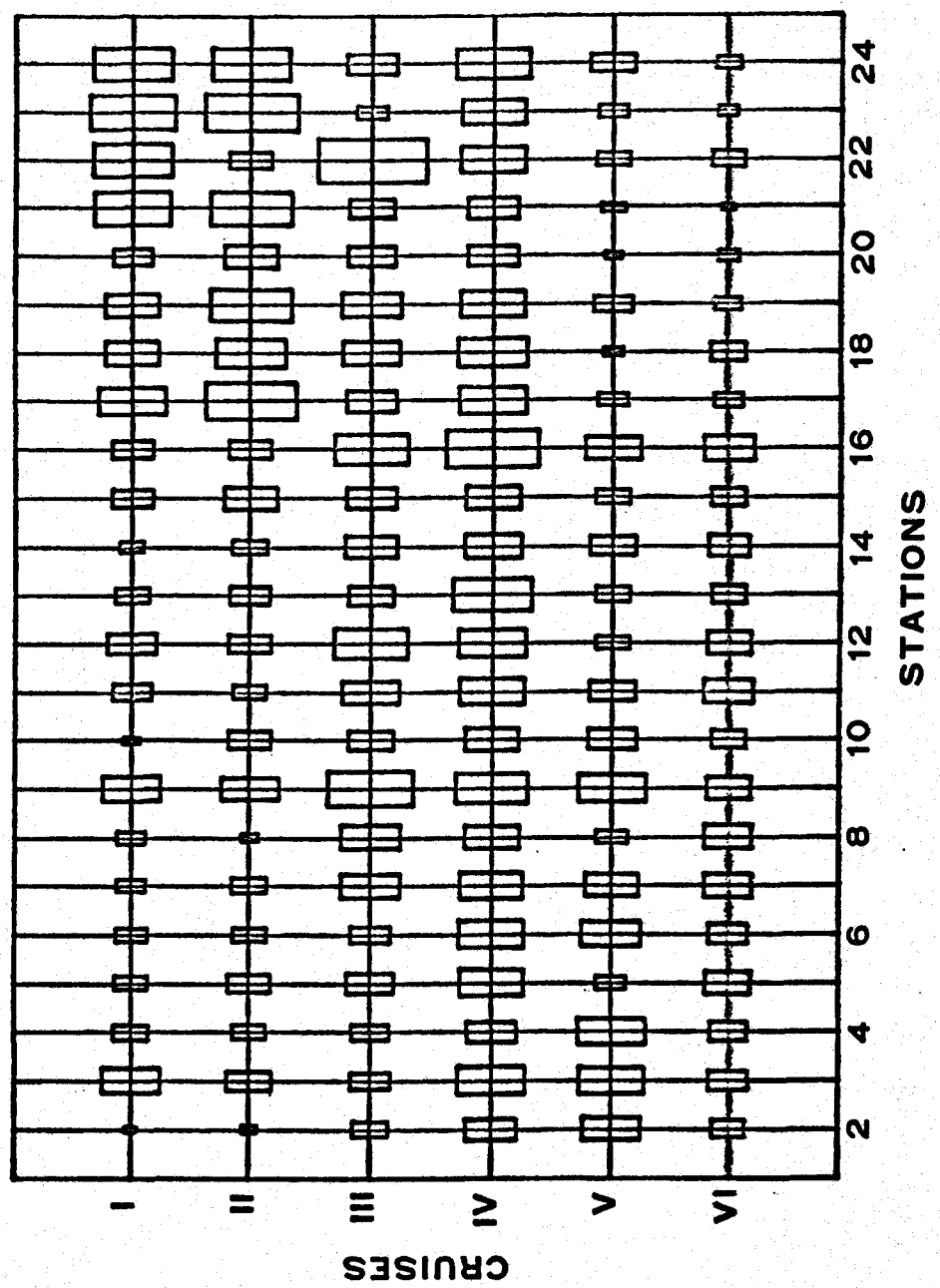

Figure 3. Two-way plot of shrimp mean lengths for 23 stations and six cruises. Each rectangle represents the relative mean length of pink shrimp at a station. Station F1 has been deleted.

Cruise IV shows an almost uniform distribution of large shrimp throughout the study area. Cruises V and VI, however, show a reversal of the size trends of Cruises I and II. Not only are the shrimp apparently smaller, overall, than on previous cruises, but the larger ones are located mostly at the shallower eastern end of the study area. These six cruises show a rather complex pattern of length/frequency distributions that is not easily interpreted. Because of this, the establishment of a pattern of movement or migration of pink shrimp cannot be described with any confidence at this early stage of the analysis.

One-Way Analysis of Variance

Table 3 shows the results of a one-way anova of each of the six cruises. In every case, there is a significant difference ($P<.001$) in the mean lengths of shrimp between the stations. In order to determine which stations caused the rejection of the null hypothesis of no difference in mean lengths, Student-Neuman-Keuls (S-N-K) stepwise multiple range test was employed (Sokal and Rohlf, 1969). This method arranges the means by ascending or descending order and then tests the range between largest and smallest means, then largest and next smallest mean, and continues in a step-wise fashion until a set of means is found that is not significantly different. One difficulty with this method is that when a large set of values are compared, several ranges may occur that will have several values in common. In such an event, one must then determine which arrangement gives the most meaningful biological interpretation of the results. In the final arrangement, it is sometimes necessary to reallocate one or more stations to a non-overlapping range which has similar mean values, but different variances. This is done to reduce the complexity of the data to a more comprehensible level. Examples of this action follow in the

Table 3. Results of a one-way analysis of variance of shrimp mean lengths between 23 stations of a cruise. Station F1 has been eliminated from all cruises. Stations F3 and F20 have been deleted from Cruise I and F21 and F22 from Cruise IV.

Cruise I

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Stations	20	3446.00	172.30	30.66	0.000***
Error	21	118.00	5.62		
Total	41	3564.00			

Cruise II

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Stations	22	3787.83	172.17	37.36	0.000***
Error	23	106.00	4.61		
Total	45	3893.83			

Cruise III

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Stations	22	2410.43	109.57	24.71	0.000***
Error	23	102.00	4.43		
Total	45	2512.43			

Table 3 (Continued)

Cruise IV

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Stations	20	789.29	39.46	9.69	0.000***
Error	21	85.50	4.07		
Total	41	874.79			

Cruise V

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Stations	22	1760.43	80.02	12.44	0.000***
Error	23	148.00	6.43		
Total	45	1908.43			

Cruise VI

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Stations	22	1139.74	51.81	7.66	0.000***
Error	23	155.50	6.76		
Total	45	1295.24			

cruise analysis.

Table 4 is provided to allow quick translation of total length given in the following discussions to count size if needed.

Cruise I (September 17-23, 1981). Table 5 shows the results of the S-N-K test for 21 stations sampled during Cruise I (Station F1 has been excluded from all analyses as explained earlier and Stations F3 and F20 were excluded because they have only one sample mean each). Although there are several stations located in more than one range, careful examination suggests the existence of four major groups which are shown topographically in Figure 4. Only Station F17 had to be moved from one overlapping group to one of the four major groups. These groups show a general trend of increasing mean length of pink shrimp from eastern to western stations and agree fairly w ll with the two-way plot of mean lengths for Cruise I in Figure 3. In this case, the sanctuary boundaries do protect some of the small shrimp, but these same immature shrimp can also be found outside the line. Only Stations F17 and F18 inside the sanctuary have shrimp whose mean length exceeds the Florida legal minimum size of 103 mm.

Cruise II (October 21-28, 1981). The results of the S-N-K test for 23 stations sampled in October 1981 are shown in Table 6. Seven ranges or groups were identified in this data set, but they were reduced again to only four major groups. Stations F18 and F23 were reallocated from separate groups and placed in Group D (see Table 6 and Fig. 5). Stations F3, F5, F10, F12, F13, F16, and F22 occurred in both Groups B and C. Inspection of the station mean lengths revealed they had a greater similarity to the other mean lengths in Group B and were therefore removed from Group C. The results of this analysis are portrayed topographically in Figure 5. The same

Table 4. Conversion values for translating total shrimp length (mm) into shrimp counts (heads-on/lb and heads-off/lb) for pink shrimp. The values given are for combined counts (average of male-female counts).

Total Length (mm)	Number Per Pound Heads-on	Heads-off	Total Lengths (mm)	Number Per Pound Heads-on	Heads-off
90	70.9	112.0	112	36.5	58.6
91	68.3	108.1	113	35.5	57.1
92	66.0	105.6	114	34.6	55.4
93	64.4	100.9	115	33.7	54.1
94	61.8	97.6	116	32.8	52.5
95	60.1	95.5	117	32.0	51.4
96	58.2	92.6	118	31.1	49.9
97	56.4	89.0	119	30.4	48.8
98	54.7	87.3	120	29.6	47.6
99	52.8	84.1	121	28.8	46.3
100	51.3	81.8	122	28.2	45.4
101	49.9	79.6	123	27.5	44.1
102	48.5	77.6	124	26.8	43.3
103	47.0	75.0	125	26.2	42.1
104	45.7	72.7	126	25.5	41.1
105	44.3	70.4	127	24.9	40.0
106	43.3	68.8	128	24.4	39.4
107	41.9	66.8	129	23.8	38.4
108	40.7	64.9	130	23.2	37.4
109	39.7	63.5	131	22.7	36.5
110	38.5	61.8	132	22.2	35.7
111	37.6	60.2	133	21.7	34.9

Table 5. Results of a Student-Neuman-Keuls range test on shrimp mean lengths at 21 stations of Cruise I. Stations F1, F3, and F20 have been deleted. Letters below nonsignificant ranges used refer to station groups shown on topographic maps.

Nonsignificant Station Groups	Station Number	Station Mean Lengths (mm)	Nonsignificant Ranges Used
	2	90.0	
	10	92.0	A
	14	95.5	
	7	97.5	
	8	97.5	
	6	99.0	
	5	99.5	
	13	100.0	B
	4	100.5	
	11	102.0	
	15	103.0	
	16	103.0	
	12	106.0	
	19	108.0	C
	18	108.5	
	9	110.5	
	17	114.0	
	21	118.0	
	24	119.0	D
	22	119.5	
	23	122.0	

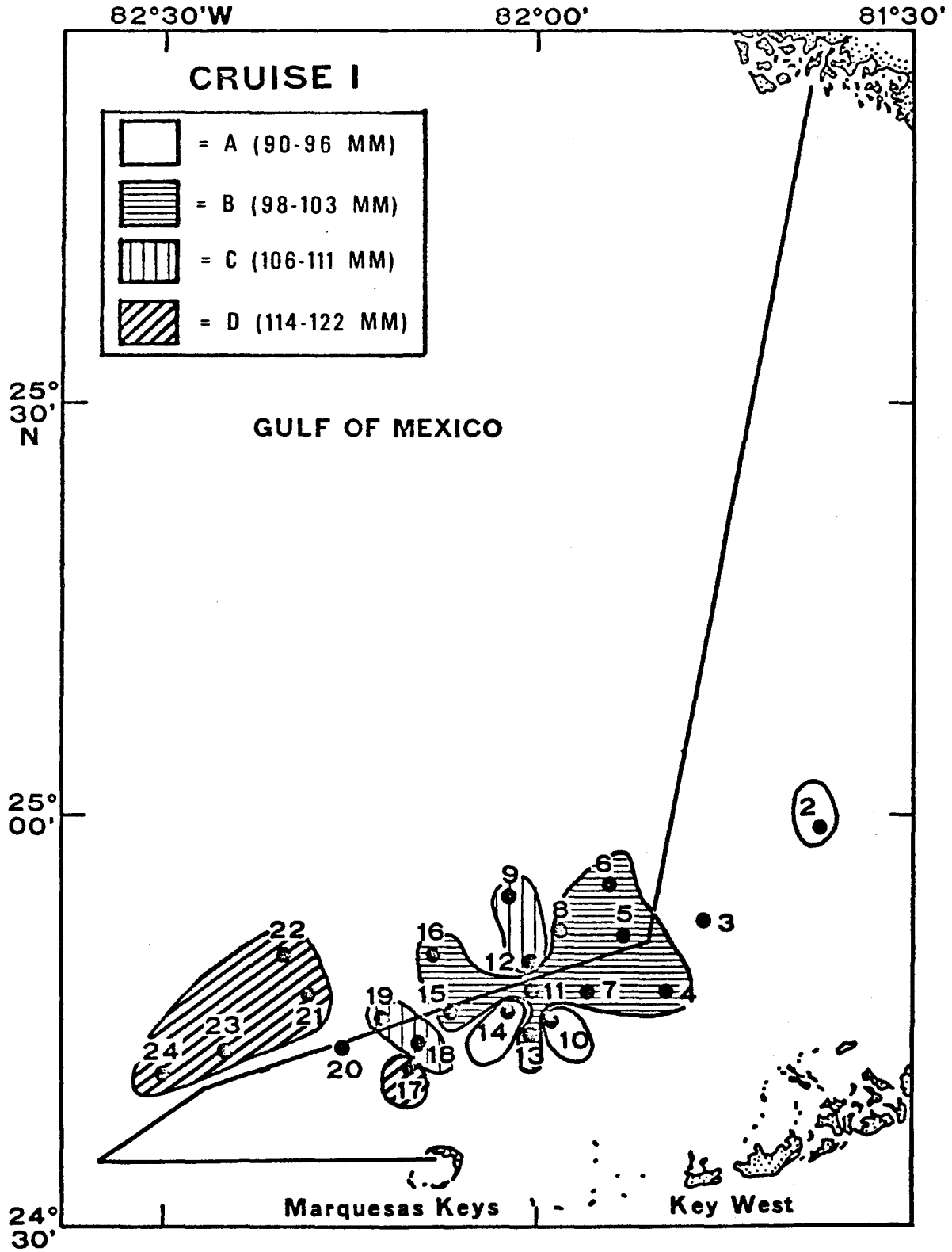

Figure 4. Sample stations grouped by the Student-Neuman-Keuls test according to the mean lenghts of pink shrimp occurring at each site of Cruise I (September 1981). Stations F1, F3 and F20 have been deleted.

Table 6. Results of a Student-Neuman-Keuls range test on shrimp mean lengths at 23 stations of Cruise II. Station F1 has been deleted. Letters below nonsignificant ranges used refer to station groups shown on topographic maps.

Nonsignificant Station Groups	Station Number	Station Mean Lengths (mm)	Nonsignificant Ranges Used
	2	91.5	A
	8	92.5	
	4	99.0	B
	11	99.0	
	6	99.5	
	7	100.0	
	14	100.0	
	13	102.0	
	5	102.5	
	10	102.5	
	12	102.5	
	22	102.5	
	16	103.0	
	3	104.0	
	15	107.5	C
	20	107.5	
	9	109.0	
	18	114.5	D
	24	118.0	
	19	119.0	
	21	119.5	
	17	123.0	
	23	124.5	

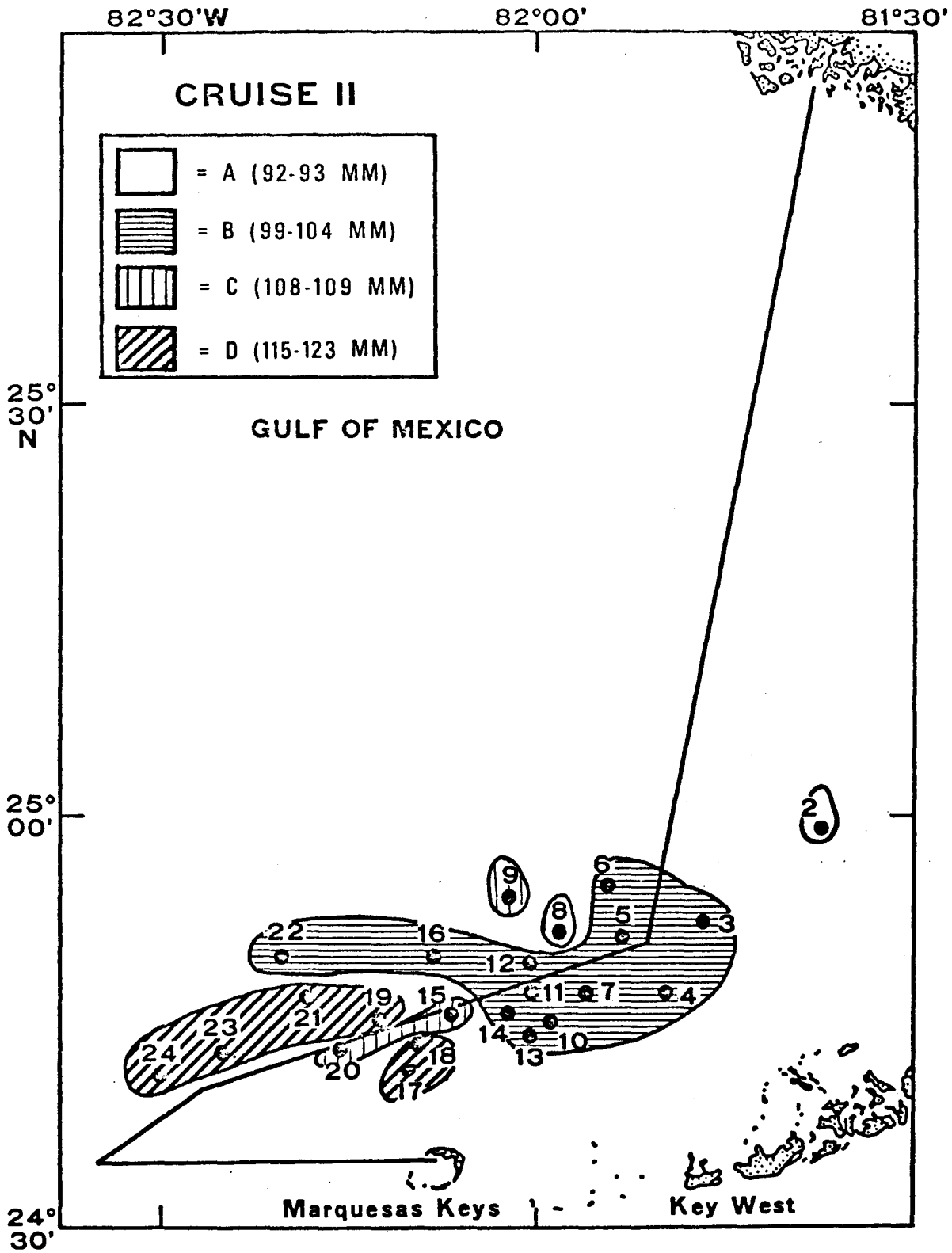

Figure 5. Sample stations grouped by the Student-Neuman-Keuls test according to the mean lengths of pink shrimp occurring at each site of Cruise II (October 1981). Station F1 has been deleted.

general trends that occurred during September can be found in the Octob r data. There is a general increase in mean length toward the western stations. However, since both sizes can be found on either side of the line, the sanctuary boundary does not reflect the overall distribution of small or large pink shrimp.

Cruise III (November 16-23, 1981). The size distribution of shrimp in November 1981 represents a change from the trend developed in the first two crusies. Once again there are four major groups of stations delineated by the S-N-K test (Table 7), but three stations (F6, F11, F23) must be reallocated from separate overlapping groups and placed in the major groups. In addition, one station (F22) was significantly different from all the groups and remains by itself. The results are shown topographically in Figure 6. Size distributions are more complicated in November, but with the exception of Station F23, the smallest shrimp (<103 mm) are found at the east rn stations (F2, F3, F4, F6). The largest shrimp are found at Stations F9, F12, F16, and F22 in the middle of the east-west line of sampling sites and outside the sanctuary boundary. Except for Stations F6 and F23, the sanctuary provides protection for shrimp under 103 mm total length. However, mid-sized shrimp (104-110 mm) are also found inside the sanctuary boundary.

Cruise IV (December 9-16, 1981). With all stations and months considered during this study, the largest shrimp overall were caught in December 1981. No station had a mean size less than 106 mm total length, indicating a general decrease in numbers of undersized shrimp in the study area. Table 8 shows that only two major groups are needed to cluster the stations in the S-N-K test, and that Station F16 is significantly different and does not cluster with th other stations. Stations F21 and F22 could not be sampled

Table 7. Results of a Student-Neuman-Keuls range test on shrimp mean lengths at 23 stations of Cruise III. Station F1 has been deleted. Letters below nonsignificant ranges used refer to station groups shown on topographic maps.

Nonsignificant Station Groups	Station Number	Station Mean Lengths (mm)	Nonsignificant Ranges Used
	23	97.5	
	2	100.0	
	4	100.5	A
	3	101.5	
	6	102.0	
	10	103.5	
	13	103.5	
	21	103.5	
	5	105.0	
	20	105.0	B
	15	106.0	
	17	106.0	
	24	106.0	
	14	107.0	
	11	108.5	
	18	109.0	
	8	109.5	C
	19	109.5	
	7	110.0	
	12	115.5	
	16	115.5	D
	9	120.5	
	22	131.0	E

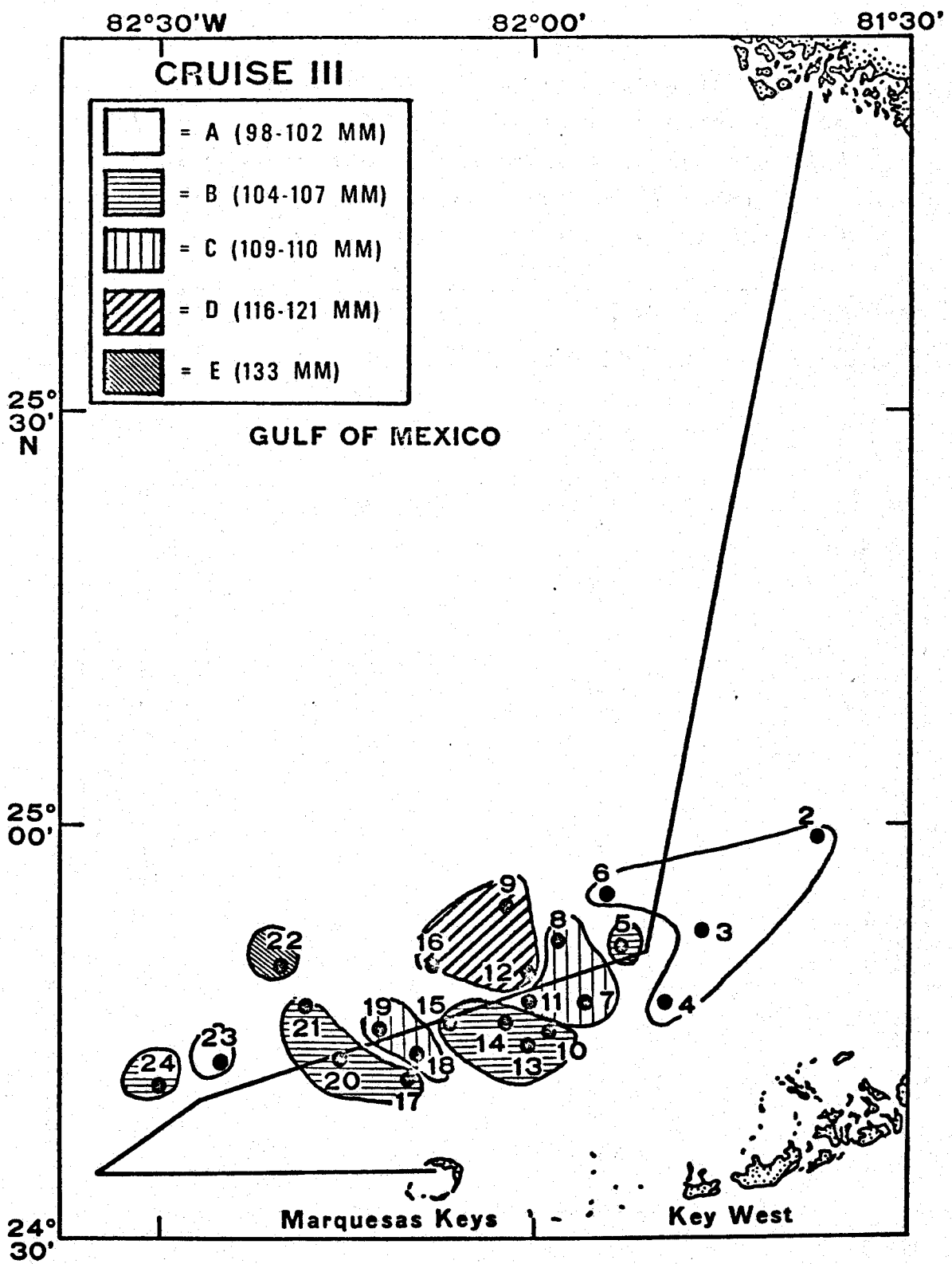

Figure 6. Sample stations grouped by the Student-Neuman-Keuls test according to the mean lengths of pink shrimp occurring at each site of Course III (November 1981). Station F been deleted.

Table 8. Results of a Student-Neuman-Keuls range test on shrimp mean lengths at 21 stations of Cruise IV. Stations F1, F21, and F22 have been deleted. Letters below non-significant ranges used refer to station groups shown on topographic maps.

Nonsignificant Station Groups	Station Number	Station Mean Lengths (mm)	Nonsignificant Ranges Used
	4	106.0	
	2	106.5	
	20	106.5	
	10	107.5	A
	8	108.0	
	15	108.0	
	14	109.0	
	7	111.0	
	5	111.5	
	23	111.5	
	11	112.0	
	19	112.0	
	6	112.5	B
	3	113.0	
	17	113.0	
	12	113.5	
	18	114.5	
	9	115.5	
	24	116.5	
	13	118.0	
	16	124.5	C

at this time. The topographic distribution shown in Figure 7 is complicated, but in general, the smallest shrimp, although larger than the Florida count law, are found inside the sanctuary. Based on December's data, the need for a sanctuary during December does not appear to be as great as in the three previous months.

Cruise V (January 19-26, 1982). The size trends in January 1982 are somewhat easier to interpret than in the previous two months. Table 9 shows three major groups in the size data, and Figure 8 again reveals a general east-west trend in size. However, this trend is the reverse of that found in September and October 1981. The largest mean sizes are found at the eastern stations, both inside and outside the sanctuary, and the smallest sizes are generally at the western end. Most of the stations where small shrimp were found are outside the limits of the sanctuary; therefore, small shrimp are afforded no protection.

Cruise VI (February 18-24, 1982). The size distribution of shrimp in samples obtained during this cruise is more complex than Cruise V, but there is some overall similarity between the two. Table 10 shows three major groups of mean lengths with the smallest shrimp occurring once again at the western-most stations and mostly outside the sanctuary (Fig. 9). However, the largest shrimp (108-111 mm) are now located in a group of stations in the middle of the study ar a and only Stations F7 and F11 of this group are inside the sanctuary. The mid-sized shrimp (102-106 mm) are primarily inside the sanctuary and located at the middle and eastern stations.

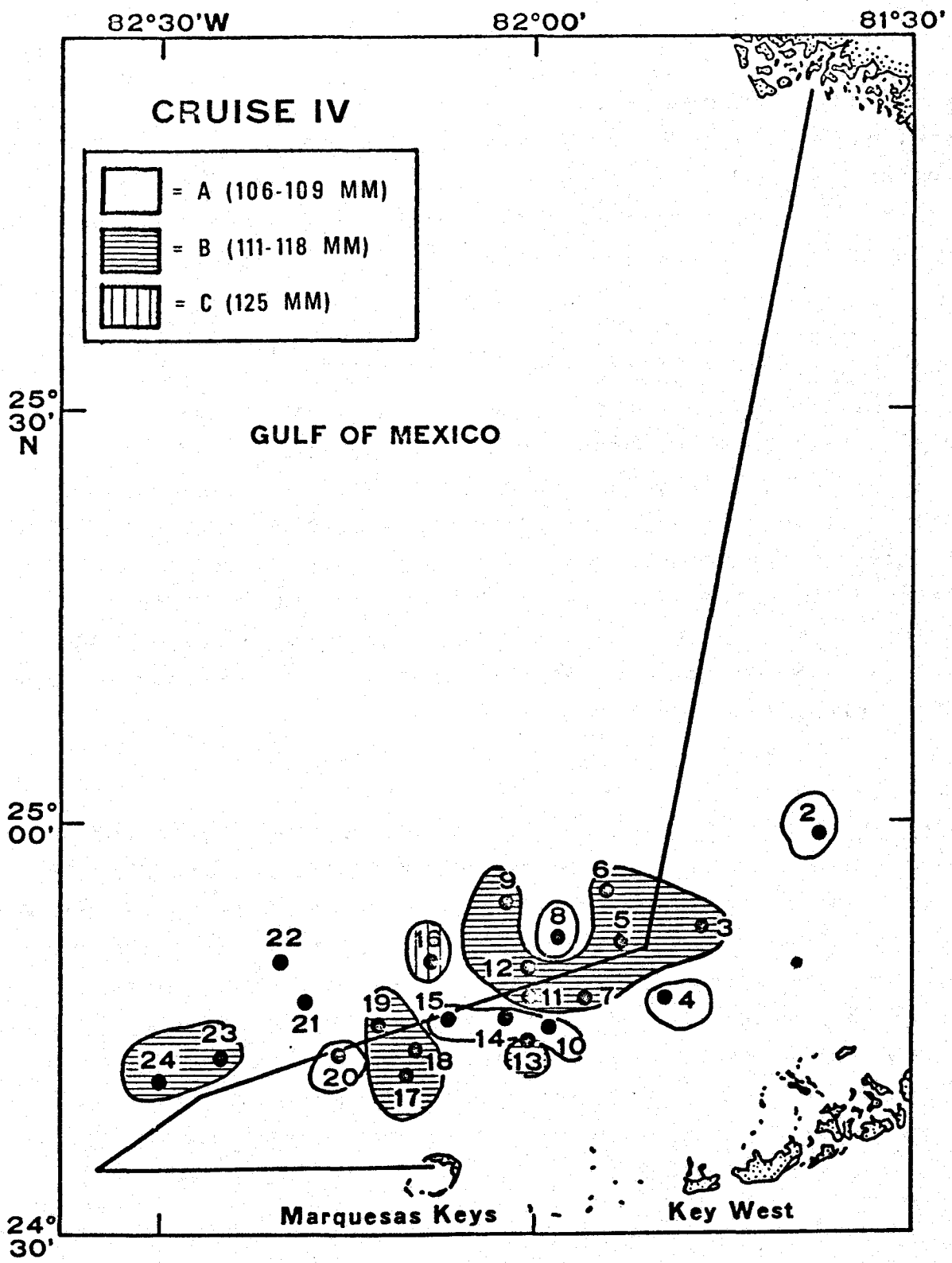

Figure 7. Sample stations grouped by the Student-Neuman-Keuls test according to the mean lengths of pink shrimp occurring at each site of Cruise IV (December 1981). Stations F1, F21 and F22 have been deleted.

Table 9. Results of a Student-Neuman-Keuls range test on shrimp mean lengths at 23 stations of Cruise V. Station F1 has been deleted. Letters below nonsignificant ranges used refer to station groups shown on topographic maps.

Nonsignificant Station Groups	Station Number	Station Mean Lengths (mm)	Nonsignificant Ranges Used
	20	92.5	
	18	93.5	
	21	95.0	
	23	97.0	
	5	97.5	
	17	97.5	A
	8	98.0	
	12	99.0	
	15	99.0	
	22	99.0	
	13	99.5	
	19	101.5	
	24	104.0	
	11	104.5	B
	14	104.5	
	10	105.5	
	7	107.5	
	16	108.5	
	2	109.0	
	6	110.0	
	3	112.0	C
	4	113.0	
	9	113.0	

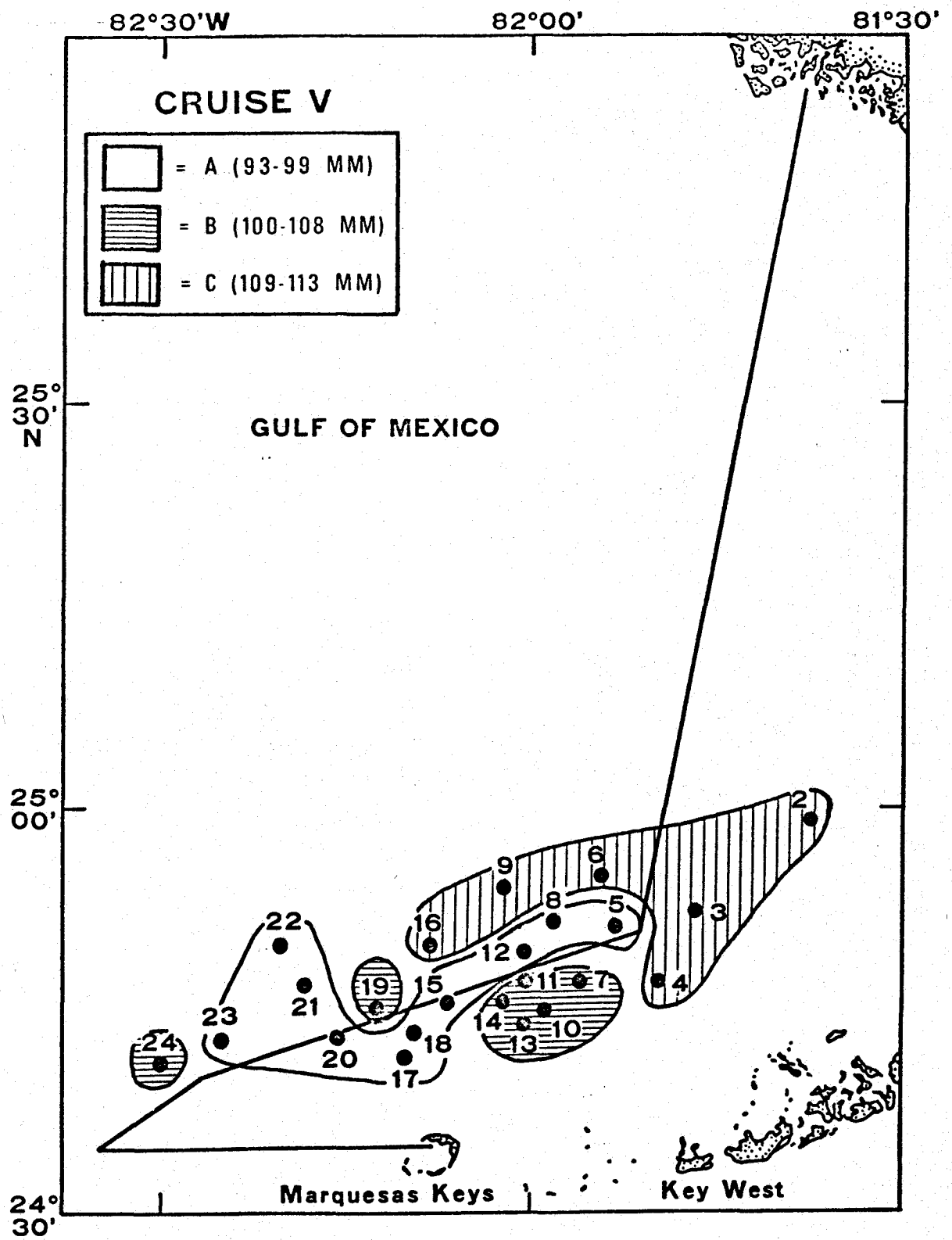

Figure 8. Sample stations grouped by the Student-Neuman-Keuls test according to the mean lengths of pink shrimp occurring at each site of Cruise V (January 1982). Station F1 has been deleted.

Table 10. Results of a Student-Neuman-K uls range test on shrimp mean lengths at 23 stations of Cruise VI. Station F1 has been deleted. Letters below nonsignificant ranges used refer to station groups shown on topographic maps.

Nonsignificant Station Groups	Station Number	Station Mean Lengths (mm)	Nonsignificant Ranges Used
	21	91.5	
	23	95.0	
	20	96.0	A
	24	97.5	
	19	98.5	
	17	99.5	
	22	101.5	
	2	102.0	
	10	102.5	
	13	102.5	
	15	103.0	
	18	103.0	B
	4	104.0	
	3	104.5	
	6	105.0	
	14	106.0	
	9	107.5	
	12	107.5	
	5	108.0	
	7	109.0	C
	8	109.0	
	11	110.0	
	16	110.5	

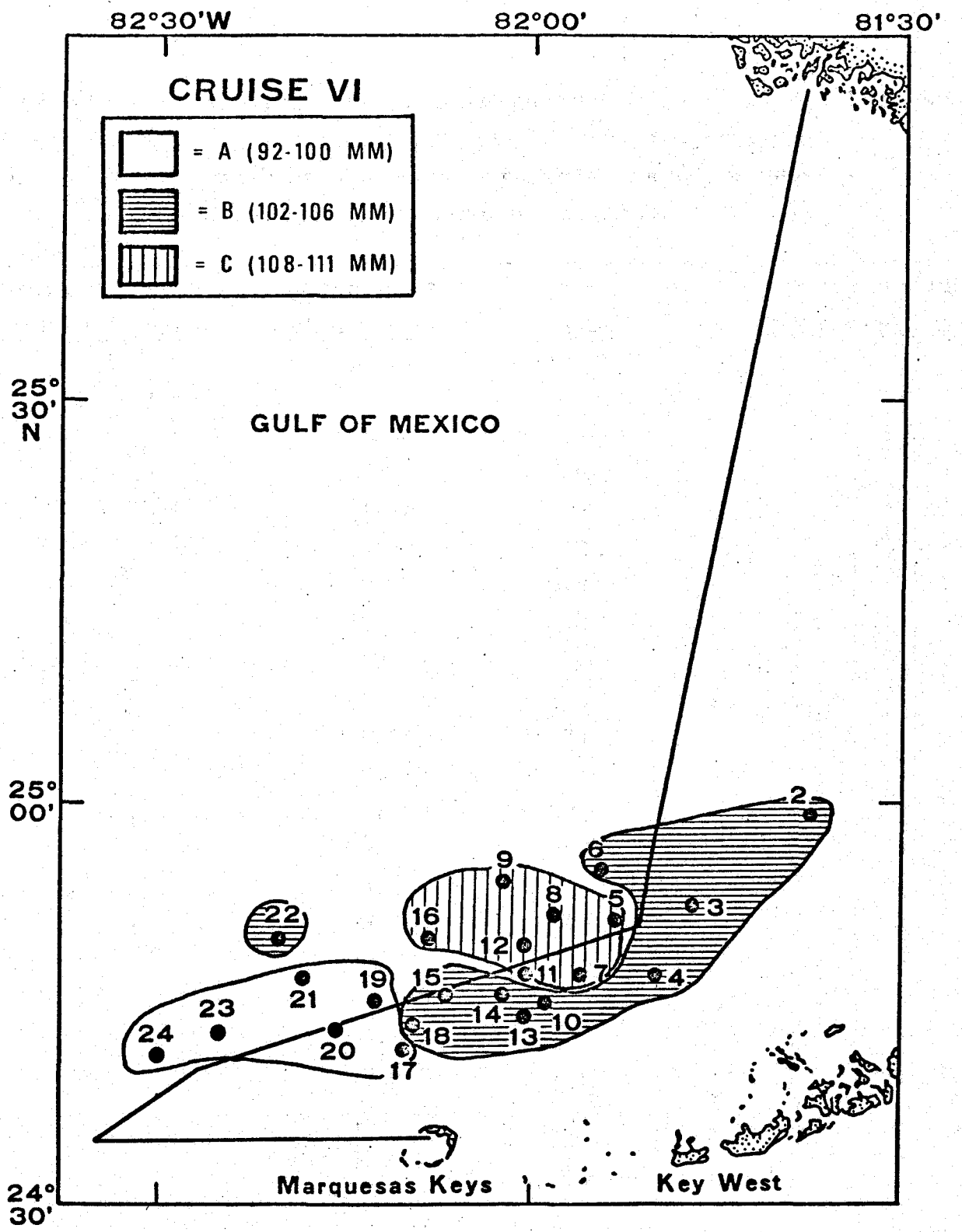

Figure 9. Sample stations grouped by the Student-Neuman-Keuls according to the mean lengths of pink shrimp occurri at each site of Cruise VI (February 1982). Station has been deleted.

Discussion

In a discussion of size distribution of shrimp, the terms "small" and "large" are relative and carry different meanings to different readers. In an effort to define and divide these two size categories, an arbitrary size of 103 mm total length (equivalent to a count of 47 heads-on/lb) was chosen based on the Florida count law as previously described. Thus, small shrimp refer to those pink shrimp less than 103 mm total length and large shrimp are those greater than 103 mm total length.

Although no simple pattern in the mean size distribution of pink shrimp has emerged in the first six month's data, the data indicate that the largest shrimp are found at the western end of the study area during September and October 1981 and the smallest shrimp are at the eastern end. This pattern shifts in November 1981 with the largest shrimp now being found in the middle of the study area, but the smallest shrimp are still at the shallower eastern end. Therefore, for the first three months (September through November), the sanctuary provides protection for most of the small shrimp at the eastern end, but also includes large shrimp inside the exclusion zone in the middle and western regions.

December 1981 data are unique in this study in that small shrimp, although present, appear to represent a smaller fraction of the biomass of the population since the mean lengths of shrimp at all stations are 106 mm or greater. Based on the mean lengths of shrimp taken during this month, it appears that the need for protection of small shrimp is not as great as in the three previous months. In fact, the sanctuary line may only prevent the harv st of larger shrimp.

January and February 1982 data represent another shift in the size distribution pattern. The January pattern is more complex

than February's, but in general, the smallest shrimp are now located in the deeper western stations of the study area, both inside and outside the sactuary, and the largest shrimp are found near the middle and eastern end. Thus, both small and large shrimp can be found inside and outside the sanctuary in each month of this study. This points out the fact that the line is not always protecting all of the small shrimp and during certain months, may only prevent the commercial harvest of large shrimp at certain sites (e.g. December). This distribution pattern makes it difficult to envision a sanctuary that would protect the small shrimp, yet allow the harvest of large shrimp at the same time.

Since it is difficult to describe a detailed distribution pattern for pink shrimp in these data based on station or monthly differences, Tables 11, 12 and 13 were prepared to simplify the analysis by consolidating stations inside or outside the sanctuary. This approach will present a broad overview of shrimp distribution in and around the sanctuary, but it will also mask small scale spatial differences (station to station) that also appear in the data as presented in the above discussion.

Table 11 shows the relative abundance of pink shrimp inside and outside the sanctuary based on the total population of shrimp taken at all stations for each month. The percentages of shrimp $<$103 mm or $\geq$103 mm were calculated from the total number caught at each station (extrapolated from the 3 lb. count). Then, by using the length/frequency determinations for each station, the number of shrimp in each size category was determined. These numbers were summed for the stations inside the line and again for the stations outside the line and then divided by the overall total number of shrimp in order to derive the percentages in Table 11. Stations F1 and F2 were deleted: F2 was deleted in order to get an even number

Table 11. The monthly relative abundance of pink shrimp found inside and outside the sanctuary based on the total popu-laton taken at all sampling stations combined (except for Stations F1 and F2). The shrimp are divided according to total length <103 mm and ≥103 mm.

	Inside Sanctuary		Outside Sanctuary	
	% <103 mm	% ≥103 mm	% <103 mm	% ≥103 mm
September	48	23	11	18
October	32	33	12	23
November	36	37	12	15
December	19	50	7	24
January	41	25	23	11
February	40	33	15	12

of stations on both sides of the sanctuary and F1 was deleted for reasons previously explained. Data were not taken for Stations F21 and F22 in December and had to be created by using an average value from all stations outside the sanctuary in December in order to minimize the bias in these calculations.

The total number of shrimp <103 mm and ≥103 mm for all stations by month used in Tables 11-13 are presented in the appendix.

When considering the distribution of the total population of shrimp, two trends become apparent in Table 11. First, most of the small shrimp (19%-48%) are found inside the sanctuary (a fact which is emphasized in Table 13) when compared to the percentage outside the line (7%-23%). Second, most of the large shrimp (23%-50%) occur inside the sanctuary with December having the highest percentage (50%). However, most of the shrimp outside the line are ≥103 mm (15%-24%), except for the months of January and February (11% and 12%, respectively). These last two months are unusual in that small shrimp (55%-64% <103 mm vs. 36%-45% ≥103 mm) dominate the population as a whole. December data are opposite to January and February data, however, in that large shrimp (74% ≥103 mm vs. 26% <103 mm) are dominant in the population. Thus, the sanctuary may not be needed in December (at least where the sampling stations are located).

Another way of looking at these data is to directly compare and contrast the populations inside and outside the sanctuary. Thus, Table 12 compares the percentages of small and large shrimp caught at stations inside the sanctuary to those caught outside the sanctuary. These percentages were calculated as explained for Table 11, except the total populations are derived from the combined stations inside the sanctuary or from the combined stations outside the sanctuary. As a result, for shrimp caught only inside the line, over half (50%-68%) of these shrimp are <103 mm for all

Table 12. The monthly r lative abundance of pink shrimp ‹103 mm and ›103 mm total length occurring at stations located inside the sanctuary and at stations outside the sanctuary, as well as all stations combined. Stations F1 and F2 have been excluded.

	Inside		Outside		Combined	
	‹103 mm	›103 mm	‹103 mm	›103 mm	‹103 mm	›103 mm
September	68	32	37	63	59	41
October	50	50	34	66	44	56
November	51	49	45	55	48	52
December	28	72	23	77	26	74
January	62	38	68	32	64	36
February	55	45	56	44	55	45

months except December (28%). Again, as shown in Table 11, the stations outside the line are dominated by large shrimp (55%-77%), except for January and February (32% and 41%, respectively).

In order to emphasize the distribution of small shrimp (i.e., whether they are mostly inside or outside the sanctuary), Table 13 was prepared by subdividing the total shrimp population into two populations according to total length <103 mm or ≥103 mm. The percentages of all shrimp <103 mm or ≥103 mm occurring inside the sanctuary for each month are shown in Table 13. This best illustrates the abundance and distribution of small shrimp, but, at the same time, may be misleading. As an example, Table 13 does show a large majority of the small shrimp population (63%-82%) is inside the sanctuary. However, it should be remembered that for December (72% in Table 13), small shrimp make up only 26% (Table 11) of the total population.

Thus, even though the sanctuary does appear to be protecting the majority of the small shrimp population (Table 13), this observation is based on a consolidation of all station data by month. As pointed out in the S-N-K analyses of mean lengths at the sampling sites, certain stations inside the sanctuary contain predominantly larger shrimp and their distribution is variable by month. Therefore, the generalized picture given in Tables 11, 12, and 13 does not show the complex nature of shrimp size distribution, but on the other hand, the overall view is more easily understood.

CATCH PER UNIT EFFORT

The catch per unit effort (CPUE) data consists of two parts: total shrimp weight per net at the 23 sampling stations and estimated total shrimp weight from all nets combined during the commercial tows. In order to standardize the catch effort, CPUE will be

Table 13. The monthly relative abundance of pink shrimp occurring inside the sanctuary. Percentages are based on the total population of shrimp <103 mm and the total population ≥103 mm at all sampling stations, except Stations F1 and F2.

	Inside Sanctuary	
	% of Total Population <103 mm	% of Total Population ≥103mm
September	82	56
October	73	59
November	75	71
December	72	67
January	63	70
F bruary	72	73

defined as the weight of all shrimp (heads-on) in pounds per 40 foot net per 30 minute tow.

Since four nets were towed simultaneously, a one-way anova was used to check for any significant difference in the catch between any of the nets. A preliminary check on the data using Taylor's power law equation (Taylor, 1961) indicated the need for a square root transformation of the data before testing with analysis of variance. Table 14 shows the results of the anova of the transformed data. There was no statistical difference ($P = .827$) in shrimp weight between the nets and Bartlett's test indicated that all variances were homogeneous. Therefore, the mean weight of all nets was used for each station in the following analysis.

Table 15 shows the results of a one-way anova of CPUE for all stations of each cruise. The station CPUEs for each cruise are significantly different ($P<.001$), indicating a patchy distribution in shrimp abundance in the study area. The Student-Neuman-Keuls stepwise test was also applied to the transformed CPUE data of each cruise in order to identify which stations were significantly different. A complex pattern emerged as a result of this treatment of the data. In general, however, the highest CPUEs for all six cruises occurred inside the sanctuary. Data for each cruise are presented separately.

Cruise I (September 17-23, 1981)

Table 16 shows the results of the S-N-K test on the September 1981 data. There were seven groups identified by the test, but only four groups were necessary to cluster the stations (Fig. 10). Stations F10, F14, F2 (55.5, 40.5, and 0.2 lbs, respectively) were sufficiently different that thay did not cluster with any other group and remain separate. As stated above, the highest CPUEs (at Stations F10, F14, F4, F13, F17, and F18) occurred inside the sanctuary, but F21, also in the same group, is located outside the

Table 14. Results of a one-way analysis of variance of shrimp weight between four nets on five cruises. A square root transformation was used on the weights data. Cruise I was deleted because only two nets were sampled at each station. Station F1 was deleted from all cruises and Stations F2, F3, F12, F15, F17 of Cruise II; F2, F3 of Cruise III; F2, F21, F22 of Cruise IV; F2, F11 of Cruis V; and F2, F9 of Cruise VI were also deleted because samples were not collected from all four nets.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Nets	3	1.91	0.64	0.298	0.827
Error	400	854.95	2.14		
Total	403	856.86			

Table 15. Results of one-way analyses of variance of shrimp weight between stations for six cruises. A square root transformation was used on the weights data. Stations F1, F2, F3 have been eliminated from all cruises and Stations F21 and F22 from Cruise IV.

Cruise I

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Stations	20	81.36	4.07	29.39	0.000***
Error	21	2.91	0.14		
Total	41	84.27			

Cruise II

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Stations	20	121.96	6.10	48.11	0.000***
Error	59	7.48	0.13		
Total	79	129.44			

Cruise III

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Stations	20	167.95	8.40	202.29	0.000***
Error	63	2.62	0.04		
Total	83	170.57			

Table 15 (Continued)

Cruise IV

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Stations	18	98.22	5.46	63.04	0.000***
Error	57	4.93	0.09		
Total	75	103.16			

Cruise V

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significanc Level (P=)
Stations	20	187.31	9.37	75.31	0.000***
Error	62	7.71	0.12		
Total	82	195.02			

Cruise VI

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance Level (P=)
Stations	20	110.24	5.51	62.77	0.000***
Error	62	5.44	0.09		
Total	82	115.68			

Table 16. Results of a Student-Neuman-Keuls range test on shrimp weights at 21 stations of Cruise I. A square root transformation was used on weights data. Stations F1, F3, and F20 have been deleted. Letters below nonsignificant ranges used refer to station groups shown on topographic maps.

Nonsignificant Station Groups	Station Number	Station Mean Lengths ($\sqrt{lbs}$)	Nonsignificant Ranges Used
	2	0.38	A
	9	1.66	
	23	1.80	B
	22	2.34	
	12	2.64	
	8	2.65	C
	5	2.72	
	11	2.83	
	6	3.30	
	19	3.30	
	16	3.67	D
	7	3.74	
	24	3.74	
	15	4.06	
	21	4.36	
	18	4.42	
	13	4.60	E
	4	4.65	
	17	5.43	
	14	6.34	F
	10	7.45	

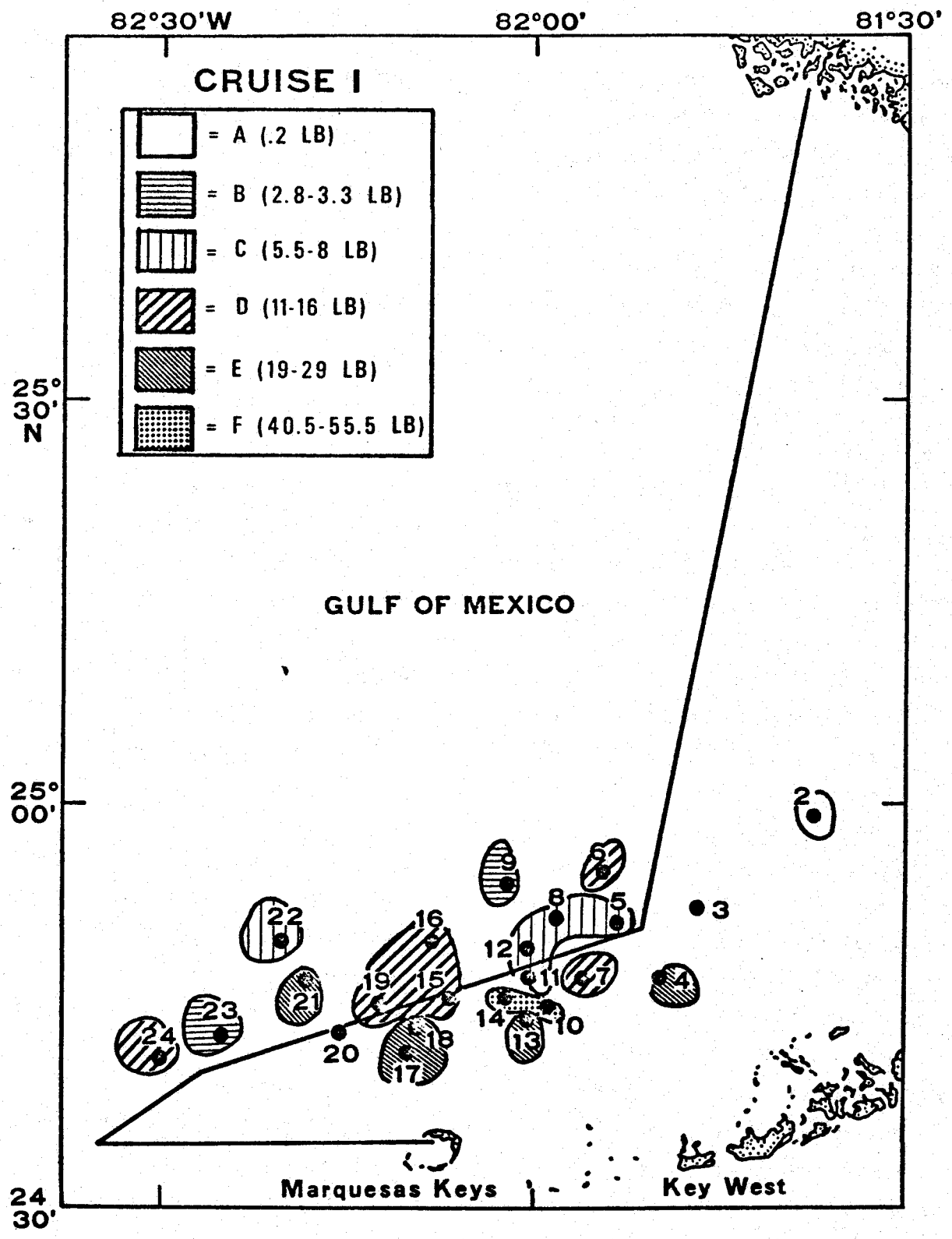

Figure 10. Sample stations grouped by the Student-Neuman-Keuls test according to mean shrimp weights occurring at each site of Cruise I (September 1981). Stations F1, F3 and F20 have been deleted.

line. The lowest CPUE (0.2 lbs) is found at Station F2 inside the sanctuary and Station F9 and F23 (2.8-3.3 lbs) outside the line. Although the highest CPUE occurred at Stations F10 and F14, these stations had the smallest (90-96 mm) shrimp (see Fig. 4). The largest shrimp at Stations F17 and F21 (114-122 mm) occurred in the next highest CPUE group (Group E in Fig. 10), otherwise, the larger shrimp did not always occur in large numbers during this cruise.

Cruise II (October 21-28, 1981)

Table 17 shows a complex arrangement of ten station groups for the October 1981 data, but they can be reduced to six major groups. With the exception of Station F16 which is outside the sanctuary, the results of this cruise were similar to that of Cruise I. The highest CPUE (17-25 lbs) (F13, F17, F10, F18, and F20) occurred inside the sanctuary (Fig. 11). However, other than the highest CPUEs occurring inside the line, there is no general recognizable trend in the data. Only Stations F17 and F18 have both a high CPUE and a large mean length (115-123 mm). Stations F19, F21, and F23 have a mean length of 115-123 mm, but a CPUE of only 10-13 lbs.

Cruise III (November 16-23, 1981)

The November data (Table 18) show nine groups plus three stations which did not join any other groups. Only four major groups and three stations (F4, F9, F10) are shown in Figure 12. Stations F4 and F10 are separate and have the highest CPUE (40.9-45.3 lbs), but the smallest (100.5-103.5 mm) shrimp (see Fig. 6). Station F9 was also separated and had the lowest CPUE (1.1 lbs) of all stations, but one of the largest mean lengths (120.5 mm).

In general,this pattern of inverse relationship between shrimp size and CPUE follows for the other groups in Figure 12. Clusters in this cruise differ from September and October in that the CPUE groups are generally arranged in bands with decreasing CPUE with

Table 17. Results of a Student-Neuman-Keuls range test on shrimp weights at 23 stations of Cruise II. A square root transformation was used on weights data. Station F1 has been deleted. Letters below nonsignificant ranges used refer to station groups shown on topographic maps.

Nonsignificant Station Groups	Station Number	Station Mean Weigths ($\sqrt{lbs}$)	Nonsignificant Ranges Used
	8	0.62	
	2	0.77	A
	12	1.00	
	5	1.26	
	6	1.59	
	3	1.69	B
	24	1.71	
	4	1.80	
	22	2.09	
	14	2.10	
	9	2.22	C
	15	2.50	
	11	2.64	
	7	3.24	
	23	3.32	D
	21	3.56	
	19	3.60	
	20	4.10	
	10	4.16	E
	18	4.21	
	16	4.36	
	17	4.65	F
	13	4.94	

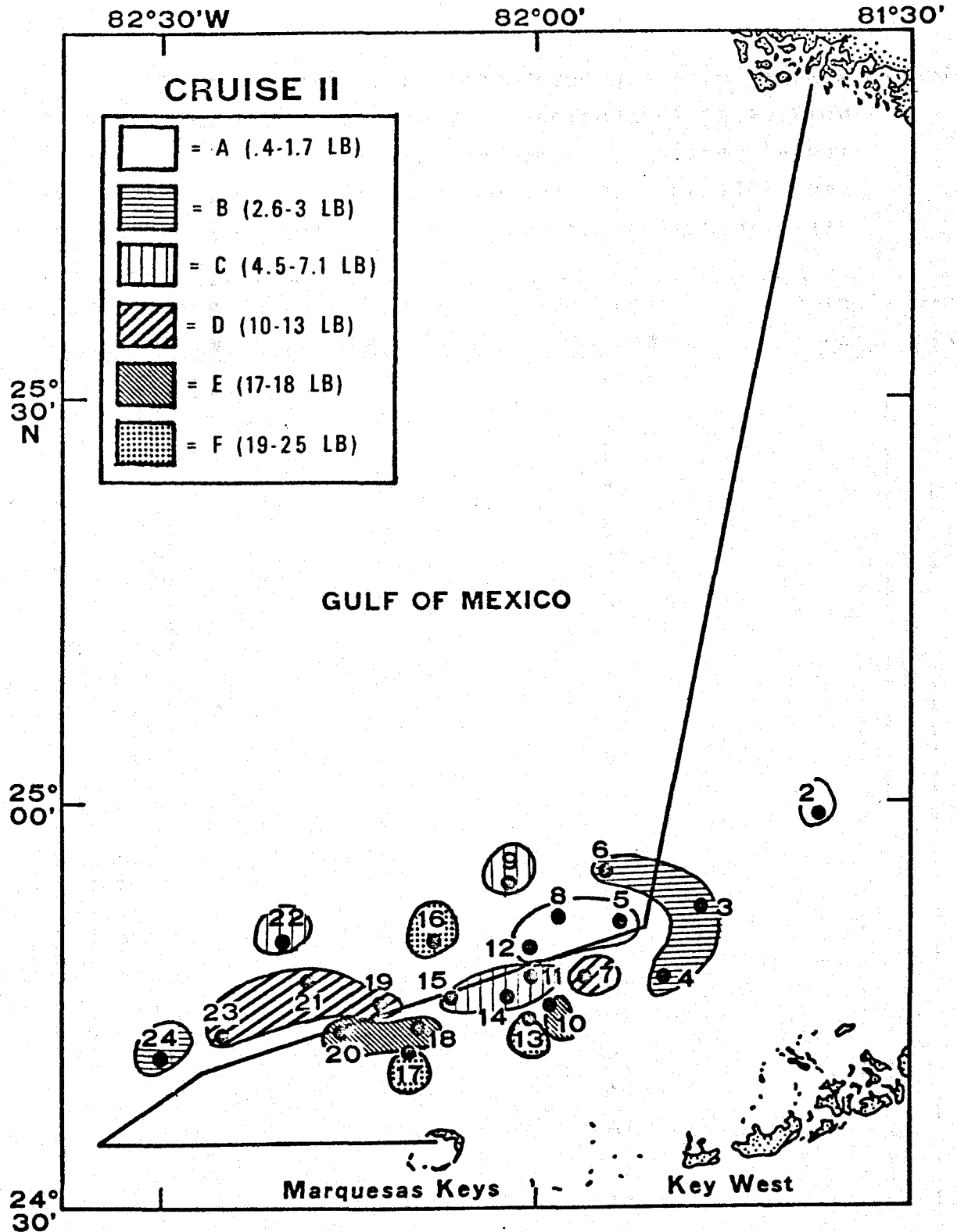

Figure 11. Sample stations grouped by the Student-Neuman-Keuls test according to mean shrimp weights occurring at each site of Cruise II (October 1981). Station F1 has been deleted.

Table 18. Results of a Student-Neuman-Keuls range test on shrimp weights at 23 stations of Cruise III. A square root transformation was used on weights data. Station F1 has been deleted. Letters below nonsignificant ranges used refer to station groups shown on topographic maps.

Nonsignificant Station Groups	Station Number	Station Mean Weigths ($\sqrt{lbs}$)	Nonsignificant Ranges Used
	9	1.01	A
	22	2.09	
	6	2.13	
	8	2.32	B
	20	2.61	
	16	2.90	
	12	3.19	
	23	3.21	
	21	3.49	C
	18	3.51	
	15	3.65	
	19	3.73	
	17	4.14	D
	24	4.16	
	3	4.70	
	11	4.89	
	5	4.92	
	13	4.97	E
	14	5.02	
	2	5.07	
	7	5.31	
	4	6.39	F
	10	6.73	

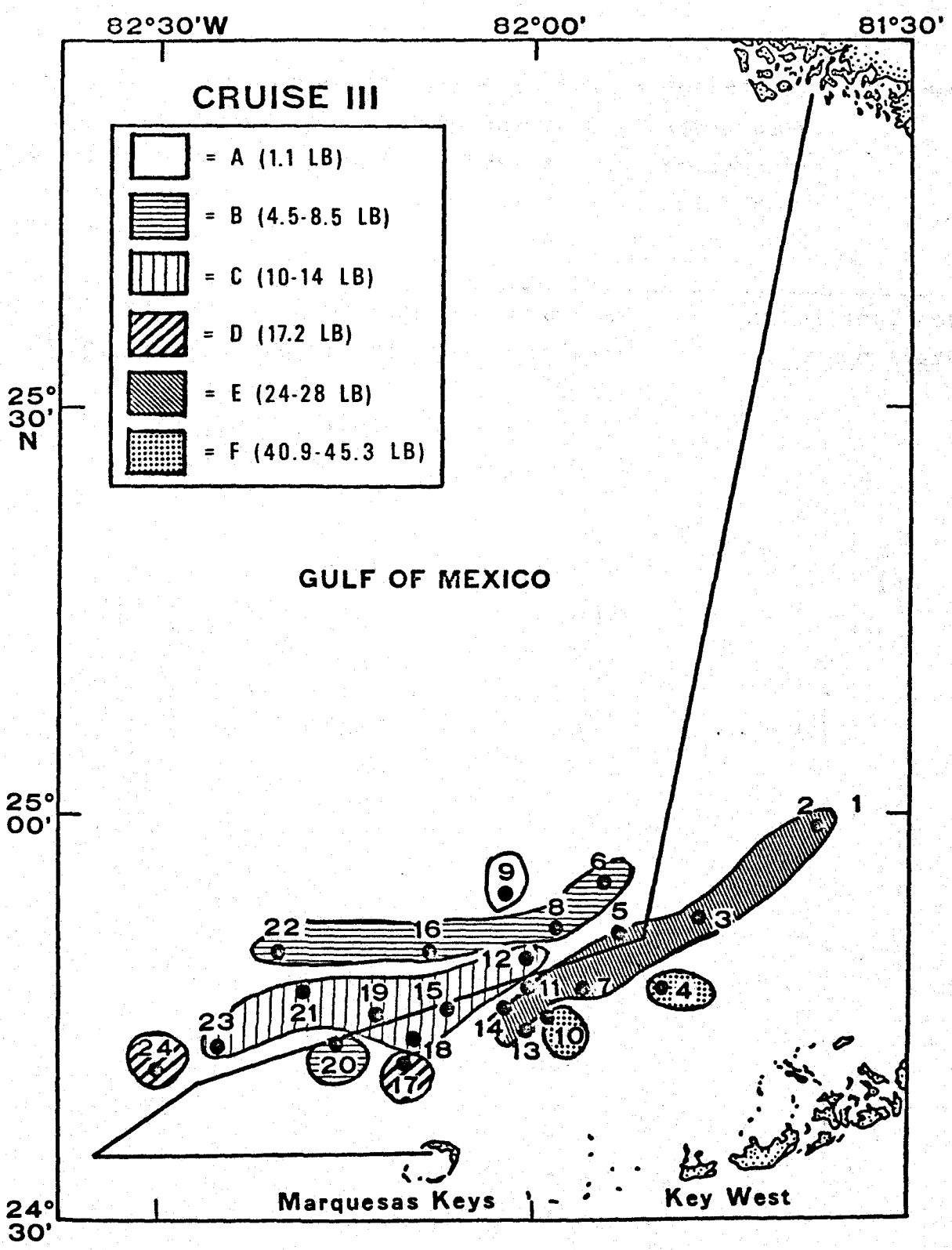

Figure 12. Sample stations grouped by the Student-Neuman-Keuls test according to mean shrimp weights occurring at each site of Cruise III (November 1981). Station F1 has been deleted.

increasing distance from the sanctuary. The only exceptions to this trend are Stations F17, F20, and F24.

Cruise IV (December 9-16, 1981)

Nine groups were initially identified for the December 1981 data (Table 19), but only five were used in Figure 13. The same overall trend occurs in these data, i.e. the highest CPUE (27-32 lbs) is found inside the sanctuary and the groups consist, for the most part, of stations scattered across the study area. Again, the stations with the highest CPUE (F3, F10, F13, F17) also had small to medium mean lengths (107.5-118 mm; see Fig. 7) in the December data. However, it should be noted that all stations during this cruise had shrimp with mean lengths of 106 mm or greater.

Cruise V (January 19-26, 1982)

The same general trends in CPUE distribution found in the four previous months are also found in January 1982. Six groups of the 11 identified in Table 20 are shown in Figure 14. The highest CPUEs (40-50 lbs) occur inside the sanctuary, but these high abundance stations (F7, F10, F11, F13, F18) also have small (93.5-107.5 mm) shrimp (see Fig. 8). The largest shrimp are found at stations with a CPUE of 15 lbs or much lower (Groups A, B, and C).

Cruise VI (February 18-24, 1982)

Only six groups are separated in the February 1982 data set (Table 21), five of which are shown in Figure 15. Stations F3, F7, and F11 inside the sanctuary have the highest CPUE (30-31 lbs), but F7 also belongs to a group in Figure 9 with a large mean length (108-111 mm). Otherwise, the same general pattern of an inverse relationship between CPUE and mean length is followed on this cruise.

Table 19. Results of a Student-Neuman-Keuls range test on shrimp weights at 21 stations of Cruise IV. A square root transformation was used on weights data. Stations F1, F21, F22 have been deleted. Letters below nonsignificant ranges used refer to station groups shown on topographic maps.

Nonsignificant Station Groups	Station Number	Station Mean Weigths ($\sqrt{lbs}$)	Nonsignificant Ranges Used
	2	1.47	
	9	1.84	
	12	2.09	A
	24	2.16	
	19	2.28	
	23	2.88	
	4	3.01	B
	16	3.30	
	7	3.51	C
	6	3.58	
	18	3.98	
	14	4.01	
	15	4.10	
	5	4.52	D
	20	4.52	
	11	4.56	
	8	4.67	
	13	5.20	
	3	5.33	
	10	5.56	E
	17	5.63	

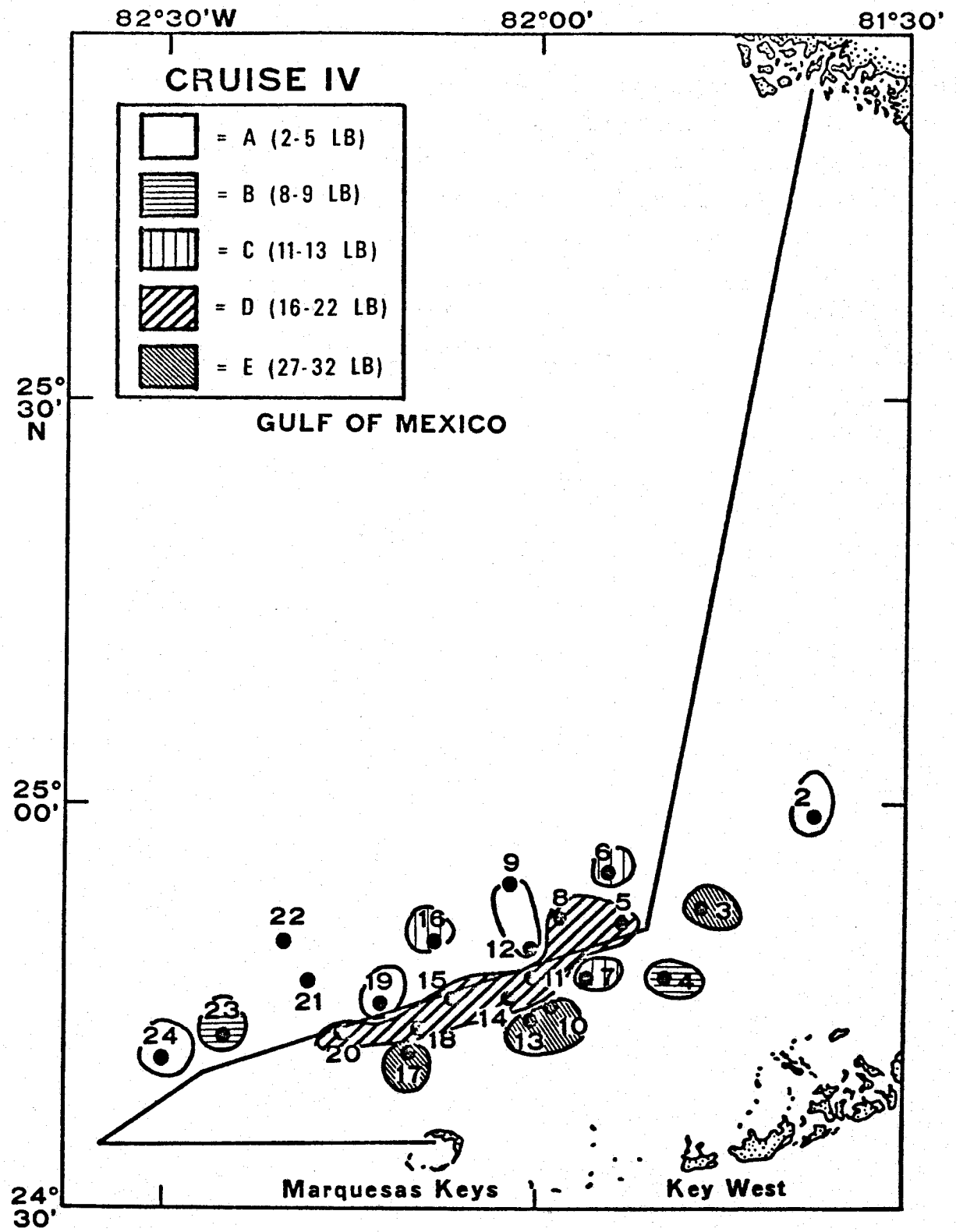

Figure 13. Sample stations grouped by the Student-Neuman-Keuls test according to mean shrimp weights occurring at each site of Cruise IV (December 1981). Stations F1, F21 and F22 have been deleted.

Table 20. Results of a Student-Neuman-Keuls range test on shrimp weights at 23 stations of Cruise V. A square root transformation was used on weights data. Station F1 has been deleted. Letters below nonsignificant ranges used refer to station groups shown on topographic maps.

Nonsignificant Station Groups	Station Number	Station Mean Weigths ($\sqrt{lbs}$)	Nonsignificant Ranges Used
	2	1.77	
	12	2.10	A
	9	2.14	
	16	2.64	
	3	3.08	B
	6	3.12	
	24	3.35	
	19	3.36	C
	8	3.75	
	4	3.90	
	20	4.58	
	23	4.65	D
	21	5.02	
	15	5.05	
	22	5.21	
	5	5.40	
	14	5.70	E
	17	5.98	
	11	6.32	
	18	6.40	
	13	6.55	F
	7	6.75	
	10	7.05	

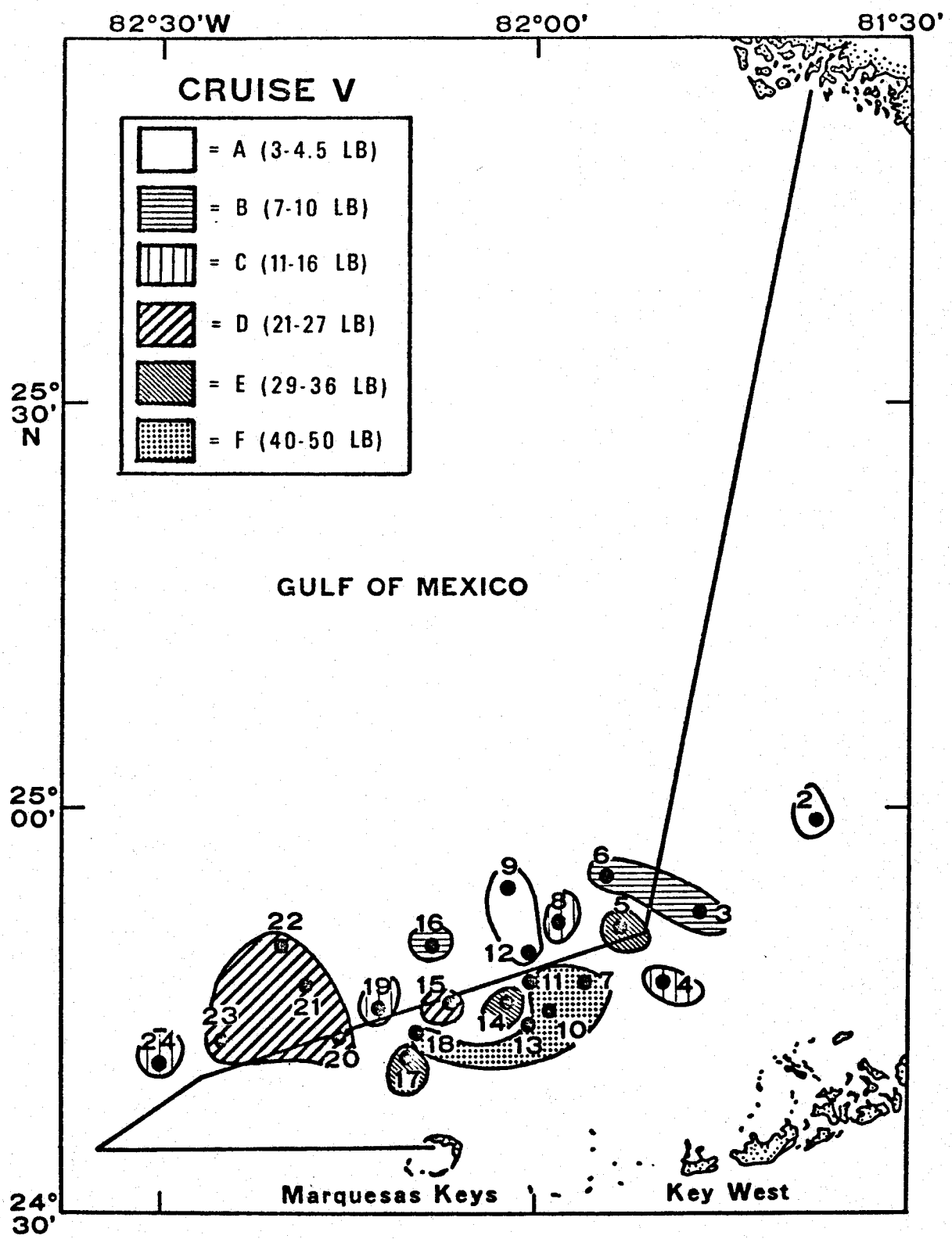

Figure 14. Sample stations grouped by the Student-Neuman-Keuls test according to mean shrimp weights occurring at each site of Cruise V (January 1982). Station F1 has been deleted.

Table 21. Results of a Student-Neuman-Keuls range test on shrimp weights at 23 stations of Cruise VI. A square root transformation was used on weights data. Station F1 has been deleted. Letters below nonsignificant ranges used refer to station groups shown on topographic maps.

Nonsignificant Station Groups	Station Number	Station Mean Weigths ($\sqrt{lbs}$)	Nonsignificant Ranges Used
	21	1.65	
	19	1.72	
	2	1.76	
	6	1.90	
	12	1.95	A
	11	2.10	
	8	2.12	
	9	2.17	
	22	2.44	
	24	2.47	
	16	2.53	
	18	3.03	
	20	3.10	B
	15	3.30	
	23	3.57	
	14	3.80	
	4	3.89	C
	17	3.96	
	5	4.03	
	13	4.52	D
	3	5.50	
	7	5.54	E
	10	5.56	

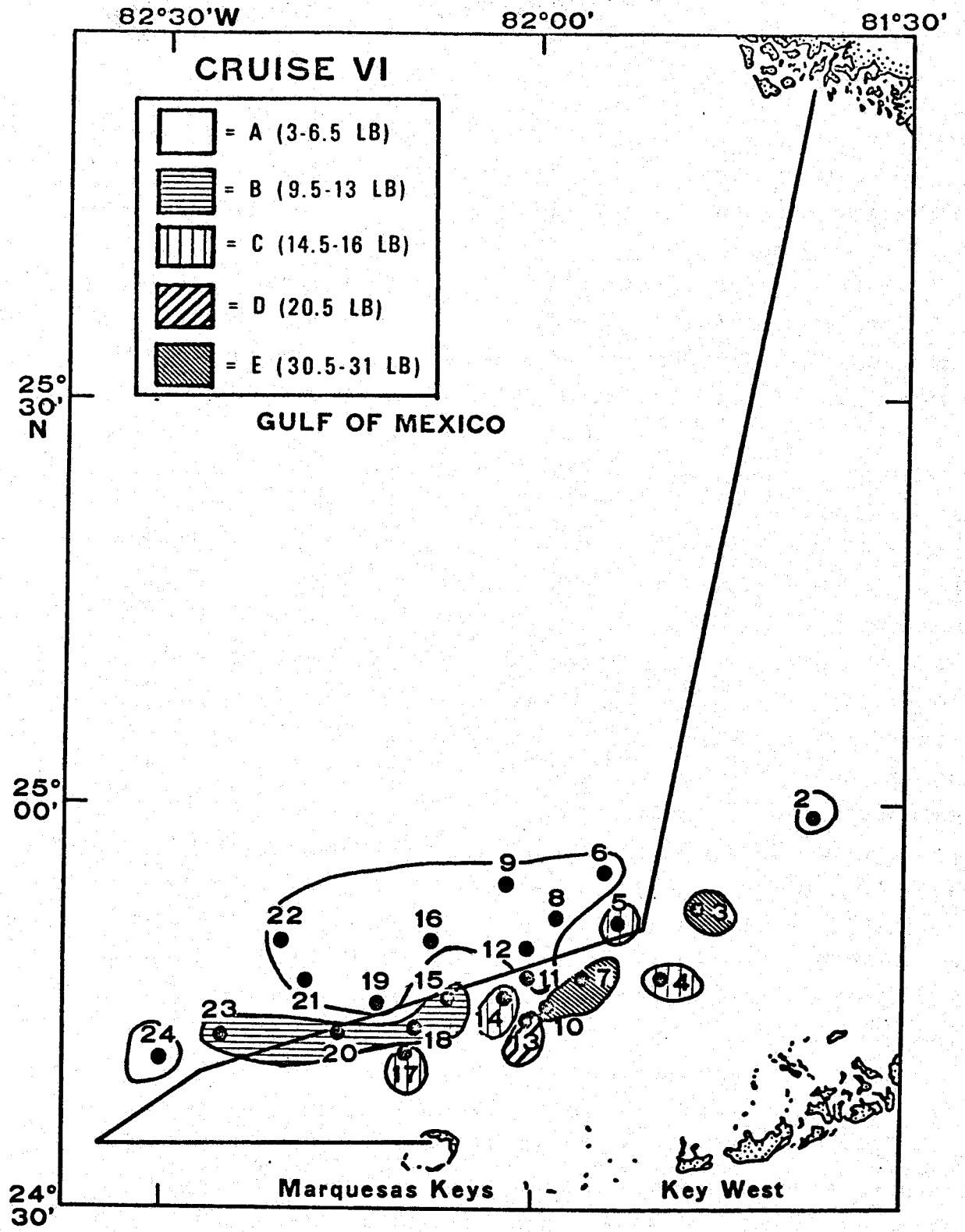

Figure 15. Sample stations grouped by the Student-Neuman-Keuls test according to mean shrimp weights occurring at each site of Cruise VI (February 1982). Station F1 has been deleted.

Discussion

Data for all six months of this study show the same general trends in CPUE distribution -- the highest CPUEs occur at stations inside the sanctuary (Table 22) and there is a general inverse relationship between CPUE and mean length.

Table 22 shows a range of average CPUEs inside the sanctuary of 11.03 lbs in October to 30.43 lbs in January. Outside the sanctuary the average CPUE varied from 6.4 lbs in October to 15.86 lbs in January, the low and high months for CPUE on both sides of the line.

Table 23 shows a more detailed break-down of CPUE at the sampling sites. In this table, stations were grouped according to three different ranges of CPUE. These ranges were arbitrarily chosen, but the lower limit of Group B was selected in an effort to show the minimum CPUE needed by most trawlers to just break even on expenses. This value, of course, is quite variable, but it does provide a base for this discussion. As shown in Table 23, most stations in the more profitable CPUEs (Groups B and C) are found inside the sanctuary in all months of the study. But, it should be remembered that most of these high CPUE stations inside the line are also populated by shrimp whose mean length is <103 mm (see Table 12 and Fig. 10-14). However, these small shrimp are less profitable to the shrimping industry and, as will be shown in the next section, commercial trawling would probably concentrate on those areas with larger shrimp which are also present inside the sanctuary.

The problem of explaining the high CPUE inside the sanctuary still remains. One possible explanation for the high CPUE inside the sanctuary is that the phenomenon may be related to fishing pressure. Heavy commercial pressure outside the sanctuary may reduce the shrimp population there. This fact could also partially

Table 22. Mean CPUEs (lbs/net/30 min. tow) and standard deviations of pink shrimp from both inboard nets of all stations inside and outside the sanctuary and all stations combined by month. Stations F3 and F20 (inside the line) in September have data from only one net and Stations F21 and F22 (outside the line) in December have no data.

	Inside Sanctuary		Outside Sanctuary		Combined Stations	
	CPUE	STD	CPUE	STD	CPUE	STD
September	19.96	15.52	9.25	4.95	14.84	12.88
October	11.03	8.56	6.40	5.65	8.82	7.67
November	23.92	10.96	10.16	6.26	17.34	11.36
December	19.25	8.60	9.92	6.69	14.68	9.26
January	30.43	15.51	15.86	9.17	23.46	14.79
February	17.25	9.75	6.81	4.52	13.58	8.90

Table 23. Summary of sample CPUE inside and outside the sanctuary line by month. The number in each weight class is the number of sampling stations in that weight range. The lower limit of Group B was chosen as an average lower limit for the break-even point for most trawlers in their CPUE. This was arbitrarily calculated as five to six boxes of shrimp (heads-on) per 10 hour night.

	Catch Per Unit Effort (lbs (heads-on)/net/30 min. tow)					
	Inside Sanctuary			Outside Sanctuary		
	A (<8 lbs)	B (8-20 lbs)	C (>20 lbs)	A (<8 lbs)	B (8-20 lbs)	C (>20 lbs)
September	3	4	5	6	5	0
October	6	4	2	7	4	0
November	1	3	8	4	6	1
December	1	5	6	4	3	2
January	1	2	9	3	4	4
February	2	6	4	9	2	0

explain the inverse relationship between CPUE and mean length since the shrimp fleet will concentrate where the larger and more profitable shrimp are located. Another possible explanation for lower numbers of large shrimp is that natural mortality and emigration will reduce the population in the study area over a period of time. Therefore, as the shrimp grow, fewer survive or remain in the area and their abundance decreases (immigration of shrimp back into the area will complicate this pattern, however). Thus, it is difficult to explain the distribution of shrimp abundance vs. size in the study area when the cause and effects of natural movement and mortality and fishing pressure are so difficult to separate and identify in these data.

Commercial Tows

The general position of the commercial tows for all six cruises in relation to the sampling stations are shown in Figure 16. The coordinates of the tows as well as the mean size of the shrimp, catch effort, count size, and percentage $\geq$103 mm are included in Table 24. It is evident from Figure 16 that there are three major concentrations of trawling activity located inside the sanctuary; around Station F10 between F7 and F13, between F13 and F18, and between F18 and F17. Since these are likely areas where commercial activity would concentrate if the sanctuary did not exist, the following discussion will focus on these areas.

The captain did not trawl in the primary areas under consideration during Cruise I, but concentrated his efforts around Stations F14 and F20. Station F20 was excluded from any analysis of mean length or CPUE during September because only one measured sample was available. However, commercial CPUE around F20 varied from 12.5-21.7 lbs and mean length was 103-116 mm. The shrimp in commercial tows were smaller at F14 (95-98 mm), but the CPUE was

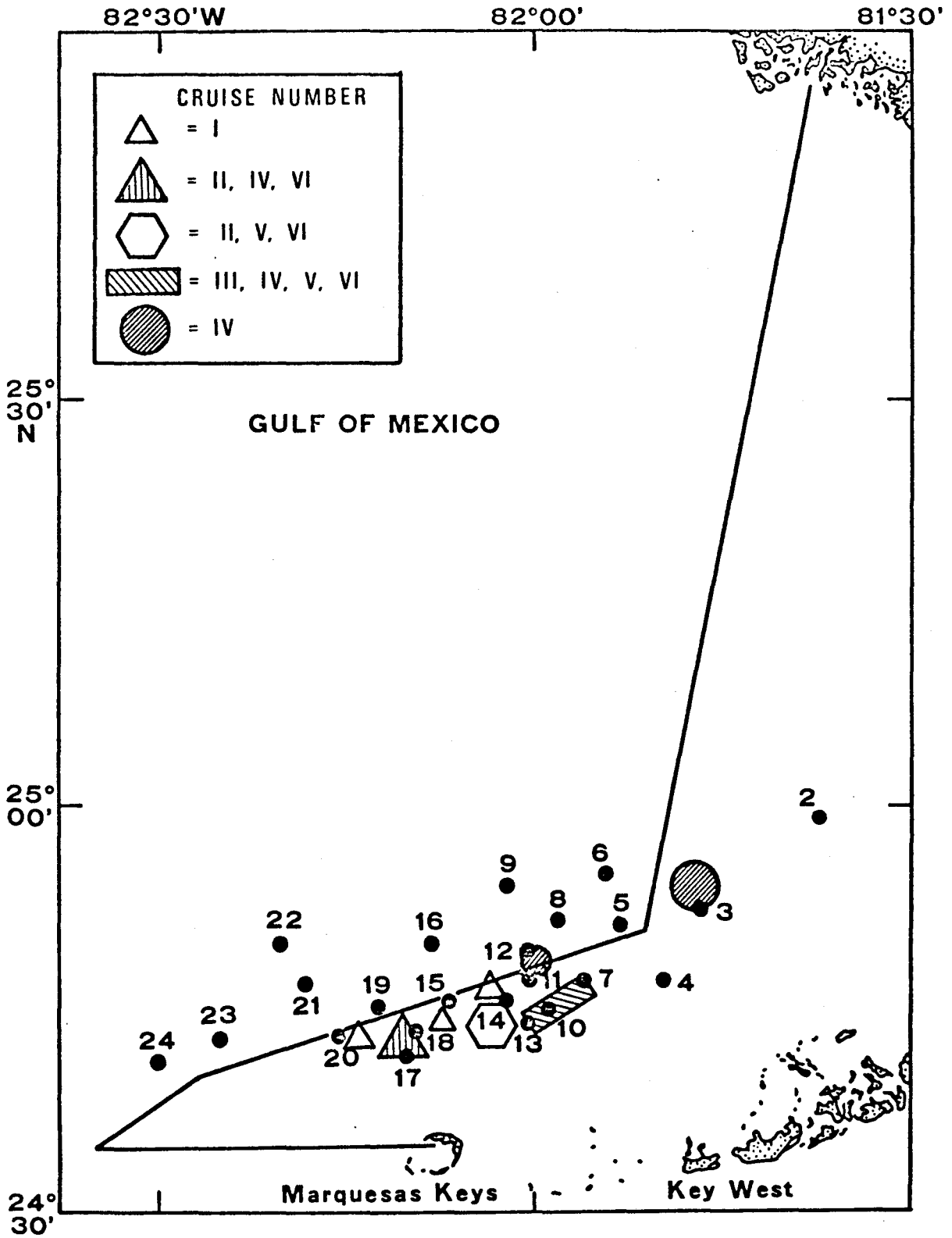

Figure 16. Locations of primary trawling sites of the commercial tows made during all six cruises in relation to the sampling stations.

Table 24. Station number and coordinates, CPUE, shrimp mean length, percentage of shrimp ≥103 mm total length, and count size for all commercial tows of all cruises.

*Data for Station 107 of Cruise VI taken from only three nets.

Station	Total Shrimp Weight (lbs)	Towing Time (hrs)	CPUE (lbs/net/30 min)	Latitude (° ' N)	Longitude (° ' W)	Mean Length (mm)	Shrimp ≥103 mm (%)	Count Size (Heads-on/lb)
				Cruise I				
101	520	3.0	21.7	24 42	82 15	116	83	33
102	200	2.0	12.5	24 42	82 13	107	53	42
103	250	1.5	20.8	24 41	82 14	103	46	47
104	600	3.0	25.0	24 46	82 02	98	25	55
105	450	2.0	28.1	24 46	82 02	96	18	58
106	400	2.0	25.0	24 46	82 03	95	18	60
107	250	3.0	10.4	24 44	82 07	112	74	37
108	400	3.0	25.0	24 44	82 07	103	43	47
				Cruise II				
101	420	2.5	21.0	24 43	82 06	120	78	30
102	200	1.75	14.3	24 43	82 06	112	69	37
103	100	1.5	8.3	24 43	82 06	115	72	34
104	200	3.0	8.3	24 42	82 09	112	60	37
105	350	3.5	12.5	24 42	82 10	116	69	33
106	310	3.75	10.3	24 43	82 10	117	73	32
107	440	3.0	18.3	24 43	82 04	103	46	47
108	360	3.75	12.0	24 44	82 09	116	72	33
109	210	3.0	8.8	24 44	82 11	112	66	37
110	390	3.5	13.9	24 44	82 09	111	61	38

Table 24 (Continued)

Station	Total Shrimp Weight (lbs)	Towing Time (hrs)	CPUE (lbs/net/30 min)	Latitude (° ' N)	Longitude (° ' W)	Mean Length (mm)	Shrimp >103 mm (%)	Count Size (Heads-on/lb)
				Cruise III				
101	600	3.0	25.0	24 45	81 59	101	43	50
102	420	2.5	21.0	24 47	81 58	110	67	39
103	600	3.0	25.0	24 44	81 59	105	49	44
104	600	3.0	25.0	24 45	81 56	107	52	42
105	660	4.0	20.1	24 44	81 59	103	41	47
106	750	3.75	25.0	24 44	82 01	102	41	49
107	660	3.5	23.6	24 45	81 56	108	55	41
108	540	3.25	20.8	24 45	81 56	105	48	44
109	380	2.0	23.8	24 45	81 56	102	44	49
110	560	3.0	23.3	24 46	81 57	105	52	44
111	600	4.0	18.8	24 46	81 57	108	58	41
				Cruise IV				
101	300	3.5	10.7	24 54	81 47	112	75	37
102	360	3.5	12.9	24 54	81 46	110	72	39
103	480	3.5	17.1	24 53	81 47	107	56	42
104	600	3.5	21.4	24 53	81 47	108	55	41
105	300	3.5	10.7	24 53	81 47	104	52	46
106	570	3.5	20.4	24 42	82 11	114	76	35
107	435	3.0	18.1	24 42	82 11	108	63	41
108	540	3.5	19.3	24 42	82 11	116	82	33
109	330	3.0	13.8	24 43	82 10	110	67	39
110	780	4.5	21.7	24 44	81 56	110	68	39
111	840	4.0	26.3	24 48	82 00	108	62	41
112	540	4.5	15.0	24 45	81 58	109	61	40

Table 24 (Continued)

Cruise V

Station	Total Shrimp Weight (lbs)	Towing Time (hrs)	CPUE (lbs/net/30 min)	Latitude (° ' N)	Longitude (° ' W)	Mean Length (mm)	Shrimp ≥103 mm (%)	Count Size (Heads-on/lb)
101	680	2.5	34.0	24 45	81 57	105	46	44
102	260	1.5	21.7	24 46	81 57	107	50	42
103	540	2.0	33.8	24 45	81 57	106	55	43
104	720	3.0	30.0	24 45	81 57	112	61	37
105	660	3.0	27.5	24 45	81 57	104	45	46
106	540	3.0	22.5	24 45	81 58	108	57	41
107	660	3.0	27.5	24 45	81 58	111	62	38
108	600	3.0	25.0	24 45	81 58	106	52	43
109	600	3.0	25.0	24 44	82 00	103	47	47
110	480	3.0	20.0	24 44	82 04	110	62	39
111	600	3.0	25.0	24 44	82 05	112	67	37
112	600	3.5	21.4	24 44	82 05	106	53	43
113	680	3.5	24.3	24 44	82 05	107	55	42
114	480	3.0	20.0	24 44	82 05	115	70	34

Table 24 (Continued)

Cruise VI

Station	Total Shrimp Weight (lbs)	Towing Time (hrs)	CPUE (lbs/net/30 min)	Latitude (° ' N)	Longitude (° ' W)	Mean Length (mm)	Shrimp ≥103 mm (%)	Count Size (Heads-on/lb)
101	400	2.0	25.0	24 45	81 59	103	47	47
102	300	2.5	15.0	24 45	81 55	100	41	51
103	420	3.5	15.0	24 45	81 55	112	58	37
104	500	3.5	17.9	24 45	81 55	104	48	46
105	400	3.5	14.3	24 45	81 55	102	43	49
106	420	3.5	15.0	24 45	81 55	113	62	36
*107	200	3.5	9.5	24 45	81 55	97	34	56
108	76	1.5	6.3	24 44	81 58	100	35	51
109	250	3.0	10.4	24 42	82 10	101	41	50
110	150	1.5	12.5	24 43	82 04	105	49	44
111	300	3.0	12.5	24 44	81 59	99	36	53
112	250	2.0	15.6	24 44	81 56	95	29	60
113	550	3.5	19.6	24 44	81 56	95	29	60
114	450	3.5	16.1	24 45	81 58	99	35	53
115	420	3.5	15.0	24 44	81 56	93	26	64

higher (25-28.1 lbs) than at F20. The mean size of commercially caught shrimp is equivalent to the study samples at F14 (96 mm), but commercial CPUE (25-28.1 lbs) is less than the sample CPUE (40.5 lbs).

The same general trends established during Cruise I hold true for the other five cruises in the three areas of activity: the mean length of the commercial catch was equivalent to the mean length of the samples at the nearest stations, but commercial CPUE, for the most part, was less than the sample CPUE. The relationship between commercial CPUE and sample CPUE was variable, but in general, the commercial catch was less than the sample catch. There is no satisfactory explanation in the data for this phenomenon, but one possibility is the fact that few of the commercial tows coincided with the actual station location and sometimes one or more nights may separate the trawling times between the commercial visits and the sampling visits. Therefore, there could be a spatial as well as a temporal factor involved in the differences between the CPUEs. Another possibility is the fact that commercial tows usually had a towing time of 2.5-3.5 hours and the entire tow may not have been over the most productive bottom.

Although the mean lengths of most of the commercially caught shrimp for the six cruises were greater than 103 mm, shrimp under 103 mm were sometimes taken in great abundance (16 of 70 commercial tows had catches with mean lengths <103 mm). In the past, these smaller shrimp would be discarded by the practice of culling. However, with the appearance of freezer boats in the shrimp fleet, these smaller shrimp are no longer discarded since they can be frozen whole on board and then processed at the large land-based processing plants using modern technology which wastes very little of the shrimp. The MV MISS VIRGINIA is a freezer boat and, although smaller shrimp bring a lower price, these shrimp were retained rather than being lost through the practice of culling (see Costello (MS) for a discussion of culling).

The important thing to note in Table 24 is that when given a choice of trawling area, the captain was able to catch shrimp over the Florida legal limit 77% of the time inside the sanctuary. Of course this figure will be variable with respect to time and probably would also change if there were unrestricted commercial activity in the sanctuary. But it is evident in these data that there is a concentration of legal-sized shrimp inside portions of the sanctuary during the study period. Also, it is evident that the captain concentrated on those areas with larger shrimp based on his prior knowledge and on the sample data collected during the cruise.

HYDROGRAPHY

The measured hydrographic parameters of surface and bottom temperature and salinity are presented in Figure 17 to characterize the environment of the study area for the period September 1981 to February 1982. Except for the months of October and November (Cruises II and III), salinity at the surface and near bottom never fluctuated beyond 34 o/oo-36 o/oo, indicating a nearly uniform salinity regimen in the study area. In October, Station F4 surface salinity reached 37 o/oo and Stations F9 and F14 bottom salinities reached 38 o/oo and 37 o/oo, respectively. No cause for this variation was apparent in the data or in the location of the stations. Nevertheless, these slightly higher salinity values are of little environmental consequence since pink shrimp are normally exposed to larger fluctuations in the shallow bays, where they mature before moving to deeper water.

During November 1981, a bottom salinity of 38 o/oo was recorded at Station F8. Again, no cause for this higher value could be determined, and it may have been a recording error. Station F23 on this cruise is especially suspect as having incorrect readings. Both temperature and salinity readings at the surface and near bottom were anomalously lower than usual and probably should be

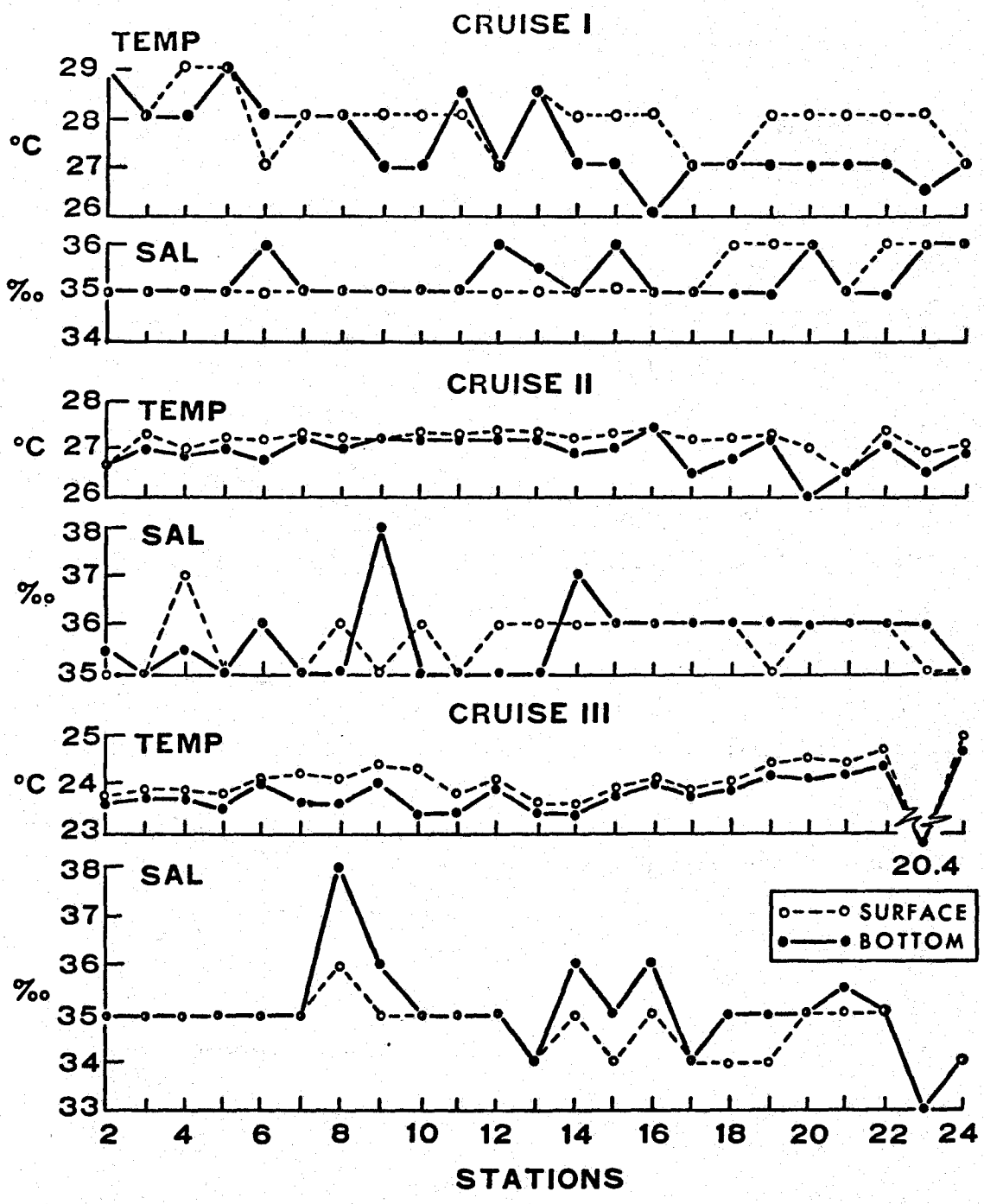

Figure 17. Salinity and temperature measurements of the surface and near bottom at each station (excluding F1) at all cruises. See text for an explanation of anomalous readings at F23 of Cruise III.

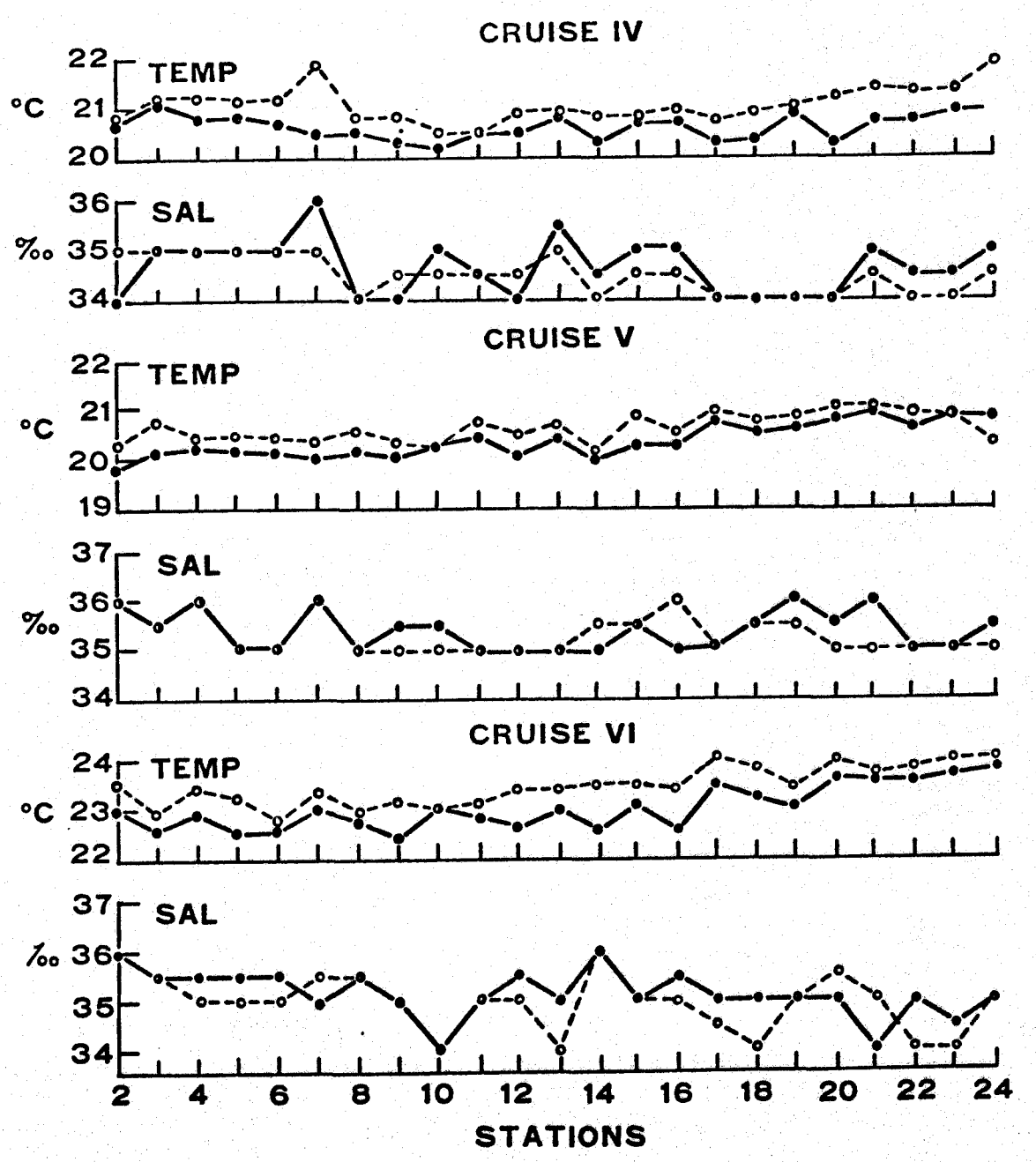

Figure 17 (Continued)

disregarded. A cold front or an upwelling event could explain the temperature drop, but no cold front came through at that time. Also, to our knowledge there are no past records of upwelling events in this locality.

Temperature was also very uniform at all stations during any one cruise, with a nearly uniform temperature from surface to bottom at all depths (6-14 fathoms) in the study area. Only one anomalous temperature was recorded and that was at Station F23 of Cruise III that has been described previously.

The greatest fluctuations in temperature occurred during September 1981 and that was only 3°C between lowest and highest readings of surface and bottom values. Otherwise, temperature never fluctuated more than 1.7°C during a cruise. However, temperatures between cruises did vary according to season. The average water temperature was highest in September (28°C) and dropped each month until January (20.5°C). February water temperatures had risen to about 23°C during Cruise VI.

It appears from the above data that neither temperature nor salinity vary enough to be responsible for any size or density discontinuities in shrimp distributions in the study area. However, temperature may have a seasonal rather than a direct effect on shrimp movements, in general, as described by Ingle et al. (1959) and Eldred et al. (1961).

OVARIAN DEVELOPMENT

Gross maturity stages of female pink shrimp were checked in the field during routine length measurements by macroscopic examination of the ovaries. The following stages of development were used and represent a modification of the stages used by Joyce (1965).

Stage 1 - Undeveloped to beginning development. Ovaries clear and small to opaque and slightly enlarged.

Stage 2 - Developing to developed. Ovaries turning yellowish and enlarged to bright yellow and near maximum size.

Stage 3 - Ripe. Ovaries slightly greenish to olive green and at maximum size.

Stage 4 - Spent. Ovaries sometimes yellowish and small in size.

We found no positive evidence of Stage-4 individuals in our samples, probably due to inexperience in detecting differences between Stage-2 and Stage-4. Joyce (1965) also encountered difficulties in determining Stage-4 individuals, at least during the early part of his sampling.

Figure 18 shows ovarian maturity stages for samples from 23 stations of each cruise. An overall comparison of the cruises indicates there is a greater proportion of developing and developed females in September and October. This timing coincides with the highest water temperatures (28°C and 27°C, respectively). The greatest numbers of shrimp in advanced stages during these months also occur at the deeper stations (F17, F18, F20, F21, F22, F23, and F24) near the western end of the study area (8-14 fathoms). This finding agrees with previous research by Munro et al. (1968) who found spawning throughout the year in the Tortugas area at temperatures of 19°C to 30°C, but mostly when temperatures exceeded 25°C. They also found that the center of spawning activity moved to deeper waters from spring to fall.

The lowest occurrences of advanced maturity stages were in November (24°C) and December (21°C) 1981. This reduced reproductive activity due to lower water temperature also follows Munro et al.'s (1968) hypothesis. Although the month of January had a slightly lower water temperature (20.5°C), an increasing proportion of developing females were noted. This pattern of increasing female maturity continued in February 1982 which had increasing

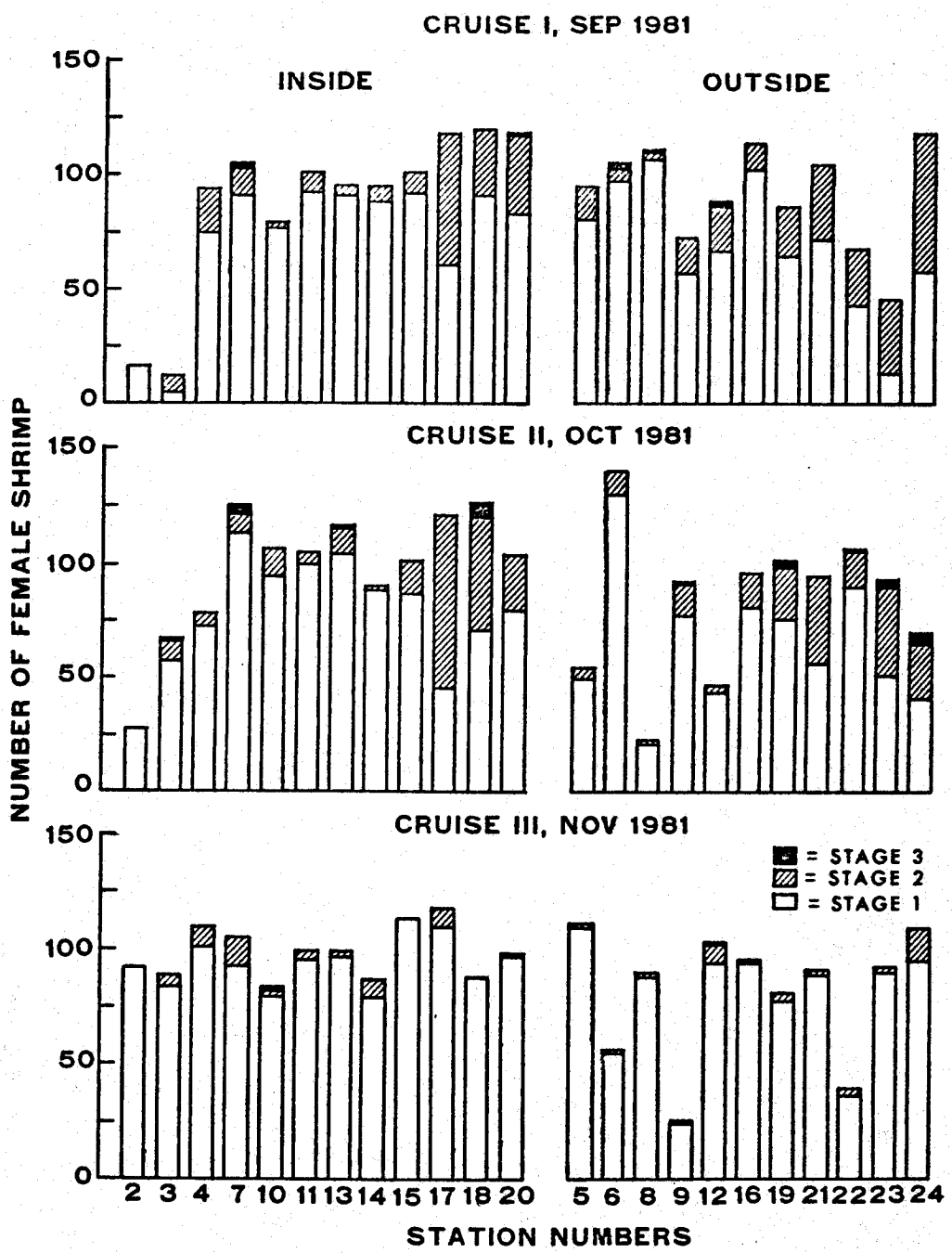

Figure 18. Graphs of pink shrimp ovarian development stages at each station (excluding F1) of all cruises.

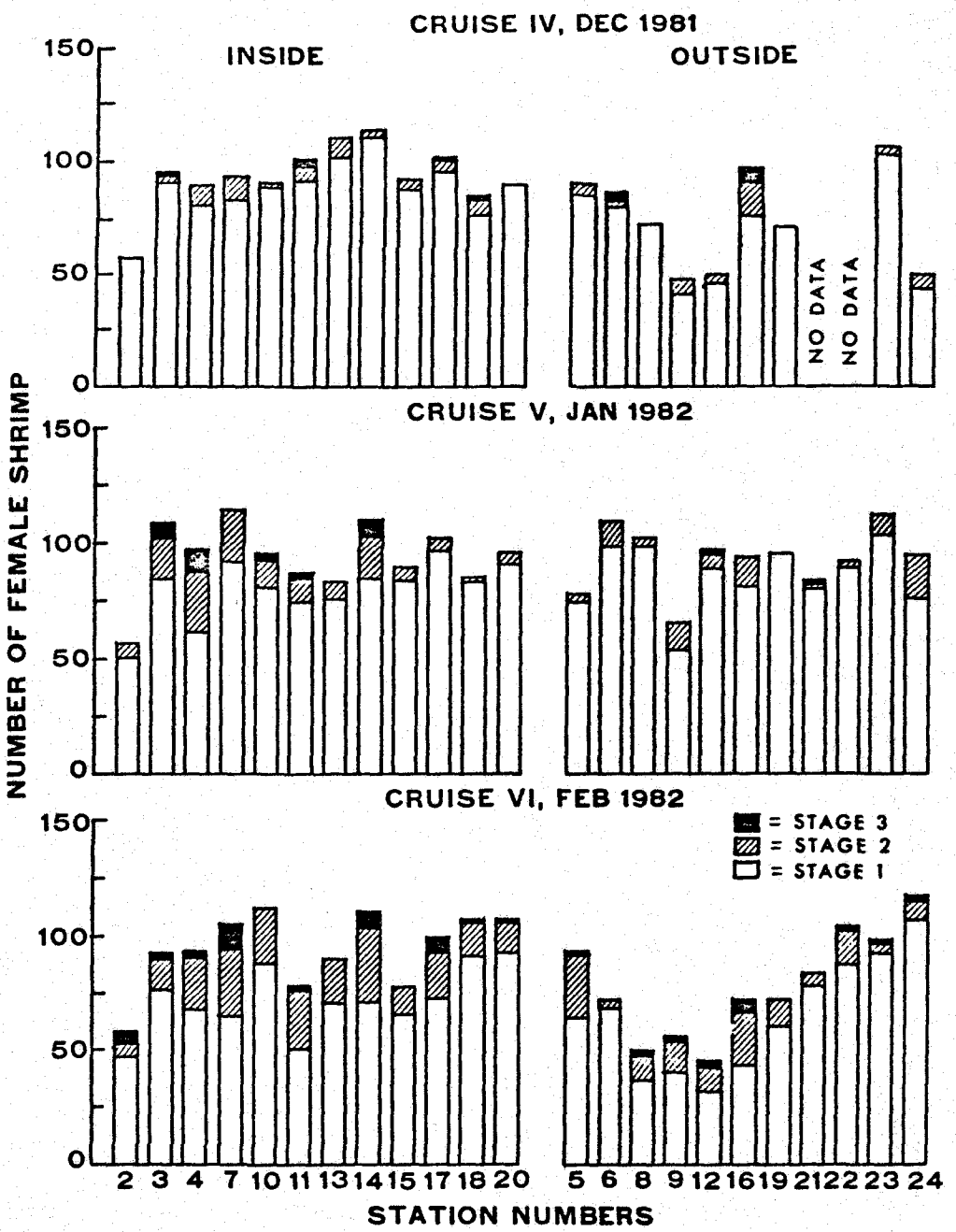

Figure 18 (Continued)

water temperatures averaging 23°C. This increase in female maturity in January is corroborated by Eldred et al. (1961) in their data, and Munro et al. (1968) further state that maturing shrimp spawn when they reach a suitable size irrespective of water temperature at the Tortugas site. Therefore, even with spawning occurring year-round in the study area, there are peaks of increased spawning activity. January represents the start of the spring peak and the low water temperatures recorded then represent only specific points in time. Water temperatures over the entire month probably were increasing, leading to the higher February readings. It should be noted, however, that the advanced maturity stages occurred throughout the study site in January and February with no particular depth predominating.

Munro et al. (1968) also reported that their spawning data appeared to correlate with moon phase, with highest activity occurring during the last half (waning) of the lunar month. With the exception of Cruise IV (December), all of the data were collected during the last half or peak lunar period. Therefore, December's results may have been altered had the data been collected during the same part of the lunar month as the other cruises.

SUMMARY

1. Twenty-three stations located inside and outside the Tortugas Shrimp Sanctuary were sampled once a month from September 1981 to February 1982 by NMFS personnel on board the MV MISS VIRGINIA, a Florida-based shrimp trawler. Hydrographic data and shrimp samples were collected at each station in order to characterize the marine environment and to better define the distribution and size frequencies of pink shrimp in and around the sanctuary.

2. Four nets were towed simultaneously and analysis of variance indicated there was no statistical difference between the weight of the shrimp catch in each net. As a result, the data were combined and mean values were used for further analysis. Two-way anova did reveal highly significant differences in the mean shrimp lengths between cruises, between stations, and in the interaction between cruises and stations. One-way anova of each cruise also indicated a highly significant difference in the mean shrimp lengths between stations of each cruise. Student-Neuman-Keuls step-wise multiple range test separated the station means into similar groups for analysis of size distribution.

3. The major objective of this study was to define the distribution of small pink shrimp in the Tortugas fishery so that the sanctuary boundaries may be modified, if needed, to better protect the small shrimp and allow them to mature to a marketable size. The results of the Student-Neuman-Keuls tests for the first six months of the study reveal a complex and variable shrimp distribution in the area. Similar distributions with

shrimp size increasing from east to west in the study area were noted during September and October. November data, however, show small shrimp (<103 mm) at the eastern stations and large shrimp at the middle stations. In December, larger shrimp (≥ 106 mm) were dominant at all stations. January and February show a reversal in the earlier size trends with larger shrimp now occurring at the eastern (shallow) stations and smaller shrimp at the western (deep) end. In each month, shrimp with mean lengths above and below 103 mm, the Florida legal limit, could be found inside as well as outside the sanctuary. Shrimp abundance (small and large shrimp) was highest inside the sanctuary with small shrimp comprising 50% or more of the population in every month except December. Large shrimp dominate the population outside the sanctuary except in January and February. It appears, therefore, that the sanctuary does protect the greater portion of the small shrimp population, but the sanctuary boundaries do not represent a clear-cut demarcation between large and small shrimp. Based on this evidence, the sanctuary does not protect the entire "nursery" area at all times, and it also includes areas with large shrimp inside the boundaries.

4. Catch per unit effort (CPUE) is defined in this study as the weight of shrimp caught in one 40 ft net during a 30 minute tow. Student-Neuman-Keuls tests on the anova for each cruise indicate a complex distribution of shrimp density across the study area. In general, the data from all six cruises displayed the same trends. Highest CPUEs occurred at stations inside the sanctuary and a general inverse relationship existed between CPUE and mean length. The highest CPUEs (as high as 50-55 lbs) usually were found at Stations F10, F13, F14, and

F17, whereas the lowest CPUEs (0.2-1.0 lbs) usually occurred at Station F2 inside the line and at various other stations outside the line.

5. The commercial tows taken by the captain of the MV MISS VIRGINIA generally clustered in the areas near Stations F10, F13, F14, and F17. The mean size of shrimp from the commercial tows were generally equivalent to the mean size of samples taken at the nearest station. Commercial CPUE, however, was usually less than the sample CPUE taken at the nearest station. Although the commercially caught shrimp were mostly larger than 103 mm, 16 of the 70 commercial tows from all six cruises contained shrimp whose mean lengths were less than 103 mm. These shrimp were not discarded, but were retained with the rest of the catch.

6. Salinity and temperature were measured at the surface and near bottom of each station for each cruise. Salinity did not vary beyond 34 o/oo-36 o/oo, except on a few occassions when it did reach as high as 38 o/oo and as low as 33 o/oo. This last value is thought to be an incorrect reading and should be disregarded. Temperature was also essentially uniform between surface and bottom at all stations on any one cruise, but it did vary between cruises. Temperature usually never fluctuated more than 1.7°C during a cruise, except for September when there was a 3°C fluctuation. Water temperature was highest in September (28°C average) and lowest in January (20.5°C average). These parameters indicate that the study area has a nearly uniform environment with regard to temperature and salinity; and changes occur mostly according to seasonal effects or occassional short-term effects (e.g. cold-fronts).

7. Macroscopic examination of shrimp ovaries revealed a pattern of reproduction in agreement with previous studies (e.g., Eldred et al., 1961; Munro et al., 1968). The warmest months of the study (September and October) had the highest percentages of females with advanced ovarian development. Lower percentages occurred when water temperature dropped below 25°C. However, January showed an increase in ovarian development over December even though water temperature was lowest in January (20.5°C). February continued the trend of increasing development and increasing water temperature. This corresponds to the beginning of the spring peak in the spawning cycle (Eldred et al., 1961).

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APPENDIX

The following data consist of numbers of shrimp caught at Stations F3-F24 and were used to calculate Tables 11, 12, and 13. The number of shrimp at each station was calculated by determining the weight of shrimp caught in all four nets and then multiplying by the number of shrimp per pound for that sample. A 3 lb. count was determined for each station. If a station did not have data from four nets, then the weight that would have been obtained had all four nets been used was calculated. The percentage of shrimp in each sample that was $<$103 mm and $\geq$103 mm was determined from the combined length/frequency histograms determined from measurements of shrimp in the inboard nets. The numbers of shrimp for stations F3-F20 in the upper half of the table were summed and the total given at the bottom of the column for Inside Sanctuary. This procedure was then repreated for stations F5-F24 in the lower half of the table and the total was given for the Outside Sanctuary value. Stations F1 and F2 were deleted for reasons explained in the text. The values in brackets for F21 and F22 of Cruise IV were calculated as an average from all the outside sanctuary stations for December since those data were not taken.

Cruise I, September 1981
Number of Shrimp/Station

Station	‹103	›103	Totals
3	21.79	39.96	61.75
4	3425.91	1854.09	5280.00
7	1776.98	827.02	2604.00
10	10316.67	1187.33	11504.00
11	746.27	567.73	1314.00
13	2908.71	1767.29	4676.00
14	8235.42	1526.58	9762.00
15	1612.32	1391.68	3004.00
17	861.13	3150.87	4012.00
18	1232.11	1697.89	2930.00
20	623.75	1200.25	1824.00
5	887.18	558.82	1446.00
6	1523.49	808.51	2332.00
8	900.07	331.93	1232.00
9	148.43	265.57	414.00
12	539.34	636.66	1176.00
16	1373.46	1106.54	2480.00
19	599.61	1114.39	1714.00
21	538.06	4757.94	5296.00
22	90.18	585.82	676.00
23	59.73	284.27	344.00
24	249.35	1346.65	1596.00
Inside	31761.07	15210.68	46971.75
Outside	6908.90	11797.10	18706.00
Total	38669.97	27007.78	65677.75

Cruise II, October 1981
Number of Shrimp/Station

Station	<103	>103	Totals
3	248.00	150.00	398.00
4	374.61	225.30	599.91
7	1244.10	734.57	1978.67
10	1955.14	1388.64	3343.78
11	983.91	528.09	1512.00
13	2842.64	2377.86	5220.50
14	604.30	330.49	934.79
15	326.43	550.57	877.00
17	403.37	1416.63	1820.00
18	870.88	1739.46	2610.33
20	208.46	703.54	912.00
5	167.14	118.92	286.06
6	325.94	141.66	467.60
8	72.90	11.60	84.50
9	259.95	351.05	611.00
12	100.99	73.01	174.00
16	1841.59	1648.10	3489.68
19	154.65	1399.61	1554.26
21	180.95	1468.87	1649.82
22	379.79	307.01	686.80
23	114.33	1255.87	1370.20
24	63.60	266.40	330.00
Inside	10061.83	10145.15	20206.98
Outside	3661.84	7042.08	10703.92
Total	13723.67	17187.23	30910.90

Cruise III, November 1981
Number of Shrimp/Station

Station	‹103	›103	Totals
3	2263.09	1430.60	3693.69
4	4729.62	2900.38	7630.00
7	1263.13	2234.19	3497.32
10	4543.11	3889.76	8432.87
11	1392.89	2347.37	3740.26
13	2293.85	2031.47	4325.33
14	1581.09	2533.29	4114.38
15	757.12	1161.88	1919.00
17	1164.81	1334.86	2499.67
18	690.38	1133.52	1823.90
20	729.25	855.75	1585.00
5	1769.08	1731.70	3500.78
6	476.09	311.91	788.00
8	289.48	579.52	869.00
9	15.51	77.49	93.00
12	283.91	978.65	1262.56
16	140.65	679.01	819.66
19	769.87	1378.50	2148.37
21	1039.07	957.63	1996.70
22	13.98	409.82	423.80
23	1259.51	664.54	1924.05
24	1270.52	1354.63	2625.15
Inside	21408.35	21853.07	43261.42
Outside	7327.66	9123.41	16451.08
Total	28736.01	30976.48	59712.50

Cruise IV, December 1981
Number of Shrimp/Station

Station	<103	>103	Totals
3	792.32	2864.68	3657.00
4	529.68	815.82	1345.50
7	446.55	1191.95	1638.50
10	1727.84	2819.16	4547.00
11	740.66	2404.67	3145.33
13	461.29	3044.00	3505.28
14	807.20	1709.80	2517.00
15	989.74	1821.89	2811.63
17	1082.56	3583.10	4665.66
18	356.06	1378.44	1734.50
20	1133.10	1827.40	2960.50
5	600.48	2006.52	2607.00
6	341.18	1409.82	1751.00
8	1025.72	2272.58	3298.30
9	73.79	417.39	491.18
12	86.65	456.35	543.00
16	39.31	1082.69	1122.00
19	150.69	609.72	760.42
21			
22			
23	393.22	821.99	1215.21
24	147.96	302.46	450.42
Inside	9067.00	23460.90	32527.90
Outside	3494.33	11463.87	14958.20
Total	12561.33	34924.77	47486.10

Cruise V, January 1982
Number of Shrimp/Station

Station	‹103	›103	Totals
3	492.92	584.58	1077.50
4	854.05	1077.35	1931.40
7	3099.69	3876.97	6976.67
10	3736.68	3759.66	7496.35
11	3670.93	3369.07	7040.00
13	4476.59	2557.19	7033.78
14	3169.21	2290.79	5460.00
15	3229.21	1599.12	4828.33
17	4991.95	2254.38	7246.32
18	6963.36	1782.26	8745.63
20	4132.90	907.10	5040.00
5	4712.63	1761.11	6473.74
6	582.00	849.30	1431.30
8	1778.62	628.28	2406.90
9	223.44	398.21	621.65
12	546.34	284.86	831.20
16	452.35	585.18	1037.53
19	1285.69	860.64	2146.33
21	4041.54	1277.79	5319.33
22	3972.04	1985.68	5957.72
23	3746.85	1183.49	4930.33
24	1007.93	732.91	1740.85
Inside	38817.51	24058.47	62875.98
Outside	22349.44	10547.45	32896.89
Total	61166.95	34605.91	95772.87

Cruise VI, February 1982
Number of Shrimp/Station

Station	‹103	›103	Totals
3	2780.93	2178.75	4959.69
4	1214.14	937.14	2151.29
7	2333.11	2379.95	4713.06
10	2792.80	2085.35	4878.16
11	251.77	375.16	626.93
13	1534.42	1406.78	2941.20
14	1113.67	1399.33	2513.00
15	1055.59	969.18	2024.77
17	1919.43	1167.57	3087.00
18	805.57	690.43	1496.00
20	1561.88	592.93	2154.82
5	1005.82	1274.76	2280.59
6	332.21	329.46	661.67
8	230.24	421.38	651.62
9	264.58	359.24	623.82
12	232.00	310.71	542.71
16	267.38	672.16	939.55
19	435.18	250.68	685.85
21	478.77	116.83	595.60
22	600.52	474.98	1075.50
23	1971.27	656.48	2627.74
24	823.12	437.78	1260.90
Inside	17363.32	14182.59	31545.90
Outside	6641.09	5304.47	11945.56
Total	24004.41	19487.05	43491.46

FIGURES

TABLES

REPORT III

A SYNOPSIS OF THE TORTUGAS PINK SHRIMP FISHERY, 1960-1981, AND THE IMPACT OF THE TORTUGAS SANCTUARY

by

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INTRODUCTION

The implementaiton of the Gulf of Mexico Shrimp Fishery Management Plan on May 15, 1981 established an area commonly known as the Tortugas shrimp sanctuary and prohibited all trawling activity within that area (Gulf of Mexico Fishery Management Council, 1980). The basis of this regulation was founded in scientific information which indicated that the sanctuary is a primary nursery area for the Tortugas shrimp stocks and that recruitment to the offshore fishery is dependent on the sanctuary. Further, Lindner (1965) and Berry (1969), utilizing growth and mortality information, indicated that the yield of pink shrimp would be greater if harvest was delayed until shrimp are larger than the minimum legal size for harvesting in Florida. Therefore, the concept of the Gulf of Mexico Fishery Management Council in re-establishing the sanctuary was to protect small, undersized shrimp from fishing. Furthermore, it was assumed that the distribution of small shrimp was confined mainly inside the sanctuary line and that outside the line shrimp were of a legal size or larger. Thus, the establishment of a permanent sanctuary would result in a greater yield (Gulf of Mexico Fishery Management Council, 1980).

This report reviews and analyzes the characteristics of the Tortugas fishery from the inception of the closure in May 1981 through December 1981 and compares this information with the historical record. These comparisons include catch, effort, size composition and catch per unit effort (CPUE). We determined whether these characteristics were affected by the regulations. This report is to be considered along with the report developed by Roberts (MS) providing details of the size distribution and abundance of pink shrimp from September 1981 to February 1982.

MATERIALS AND METHODS

Collection of detailed catch statistics describing the U.S. Gulf of Mexico shrimp fishery are available since 1956 and the procedures used to collect them are described by Klima (1980). The statistics compiled by the Southeast Fisheries Center (SEFC), Technical Information Management Services (TIMS), consisting of catch by statistical area (Fig 1), effort data (in 24 hrs of fishing, time expressed as days fished) and size composition of the catch were used to analyze the effects of the Tortugas shrimp sanctuary . Locations and amount of fishing effort expended in 24 hrs fishing were obtained by interviewing fishing vessel captains at the termination of their trips. All catch data were recorded as heads-off by species and size category, by statistical subarea, depth zone and month. These data were used to compile CPUE per 24 hrs of fishing and are reported in "Fishery Statistics of the United States (1956-1979)" and "Shrimp Landings (1956-1979)". Data from 1980 to the present are on file at the SEFC TIMS office and are available for inspection by interested parties. Mr. Ernest Snell (SEFC, TIMS) has provided specific information concerning the Tortugas shrimp fishery relative to fleet activities, changes in the fleet, number of trips, discards and specifics of catch and effort for the fishing area during 1981.

Catch data frequently follow skewed distribution, show heteroscedasticity and have non-additive components. Transformations applied to the original data are often able to alleviate these problems and permit valid statistical analysis of the data employing t-tests and 2-way analysis of variance (ANOVA) (Sokal and Rohlf, 1969). Taylor's (1961) test analyzing relationships between means and variances showed the shrimp catch data should be transformed logarith-

mically and CPUE data should be transformed by the inverse of their square roots. The analysis of these transformed data provided statistical support to what the untransformed data showed and the summaries are presented here with untransformed data.

Statistical Tests

Mean monthly catch and mean CPUEs for the 1960-1979 period were compared with the 1981 monthly data via 2-way ANOVA and Student-Newman-Keuls (SNK) tests. Additional comparisons between monthly means of the fisheries data for the five earliest years (1960-1964), the five latest years (1975-1979) and the 1981 monthly data were made by paired t-tests. The shrimp size distributions for each month were compared with each of the three historical data sets and 1981 monthly size distributions using G-tests (Sokal and Rohlf, 1969). Unless otherwise stated, tests of significance were performed at the 95% level ($P = 0.05$) (Rohlf and Sokal, 1969).

Fishery Background

The Tortugas pink shrimp (Penaeus duorarum) fishing grounds were discovered in 1949 and by 1950, a major commercial shrimp fishery had developed. Regan et al. (1959) reported a decline in the landings of larger shrimp and possible depletion of the stock caused by landings of small shrimp (70-count and above, heads off). Costello[1] has reviewed the state of Florida's regulations relating to the pink shrimp fishery and summarizes these from 1955 to the present. He identified the State's concern about possible over-exploitation and the concern over large catches of very small pink shrimp that were not saleable and were probably

[1]Costello, T. J. DOC/NOAA/NMFS/SEFC, Miami, FL; personal communication.

discarded at sea. To prevent wastage and discard of small shrimp, the Florida State Board of Conservation set regulations specifying the minimum legal size of mesh allowed in the codends of shrimp trawls used on the Tortugas grounds and also established a minimum size limit for shrimp. Florida closed a part of the Tortugas fishing grounds to fishing in 1957 to prevent large catches of small shrimp. Caillouet and Koi (1981) considered the influences of major changes in regulations concerning the fishery, in exploring possible causes of annual fluctuations in size composition of the reported catches from 1960-1978.

The Fleet

Shrimp trawlers fishing the Tortugas grounds operate out of Key West, Marathon, Fort Myers, Tampa, St. Petersburg and Tarpon Springs, FL. From January to April 1982, approximately 590 shrimp trawlers worked the Tortugas shrimping grounds. The number of trawlers decreased during the months of May-August, but by October had increased (Table 1). The major fishing season in the Tortugas runs from October through May of each year. During the summer months, the majority of the Tortugas fleet migrates to the northern Gulf, where some Florida dealers open packing houses for their established fleets (Ernest Snell)[2]. These trawlers return to the southern area by late October to again fish the Tortugas fishing grounds.

Major changes in the fleet have been the addition in 1979 of "quad-rigs" or "twin trawls" and the use of freezer holds. Approximately 90% of vessels with 350 HP engines now use quad-rigs, whereas only 60% of vessels with less than 350 HP are so equipped. The use of freezer holds by some

[2,3]Snell, Ernest J. DOC/NOAA/NMFS/SEFT/TIMS, Miami, FL; personal communication.

trawlers began in 1968. Snell[3] estimates there are approximately 50 trawlers with freezers on the Tortugas grounds during the season.

Approximately 20% of the shrimp from the Tortugas grounds that are landed in the Key West area have heads on. Much of this shrimp is headed at the dock, while a portion is marketed to retail outlets, heads on. This heads-on retail market is said to be lucrative due to the price received for the shrimp and the fact that little expense is involved in handling. Typically, the shrimp are sorted from the fish, put in bags up to 60 lbs and frozen, heads on. This product entails very little handling and can be distributed to various users along the coast. Vessels operating out of Marathon are typically freezer vessels and land their entire catch heads on.

The Tortugas fishing grounds have been described by Iversen et al. (1960). In 1960, fishing was concentrated in statistical subarea 2. These authors indicated that shrimp occur outside the regularly fished area but fishing is difficult and hazardous because of the presence of loggerhead sponges, coral and other obstructions. They clearly indicated that small clear areas are found outside the region and these are occasionally trawled with the aid of lighted buoys set out by the fishermen.

RESULTS

In reviewing the catch by statistical areas from 1960 through 1981, it is apparent that the fishery was concentrated in what is referred to as statistical subarea 2 from 1960 to approximately 1972 (Fig 2). Thereafter, the fishing grounds appear to increase considerably, with more effort exerted in statistical subarea 3 from 1972 to the

present and by 1980, statistical subarea 1 became slightly more important. Therefore, the grounds have expanded in nature from the inception of the fishery to include areas further to the north and south of Key West. The reason for this expansion is that continued trawling cleared the grounds of loggerhead sponge and coral. In fact, in 1981, almost 3½ milliom lbs of shrimp were landed from statistical subarea 3 whereas in 1960, only about 10,000 lbs were landed from this subarea.

1981 Fishery Locations

In 1981, the Tortugas pink shrimp fishery was located in three statistical subareas (1, 2 and 3). Landings from these subareas by depth zones are shown in Figs 3a-3l. Note that the majority of the catch was caught in statistical subarea 2 in January in depth zones 11-15 and 16-20 fms. A small amount of catch was also produced in the 11-15 fm depth range in subarea 3. The February catch was much less and was distributed in approximately the same areas as January. In March, large catches were produced in all three statistical subareas, with the predominant catch being found in the 6-10 fm depth range in subareas 1 and 3, with the next peak in subarea 2 in 11-15 fms. April landings were also large; however, catches were made mostly in statistical subarea 2 in the 11-20 fm depth ranges and some catch was produced in subarea 3 in the 11-20 fm depth range. A similar pattern existed in May and June but with lower catches. No catches were made in subarea 1 after June. In July, August and September, catches were concentrated in subarea 2 in the 11-15 fm depth range and continued to be low. In October, catches increased in subarea 2 and by November and December the catches were very high in subarea 2 in the 11-15 fm depth zone.

Landings

Annually, landings in statistical subareas 1 through 3 from 1960-1981 have averaged approximately 10 million lbs/yr (Fig 4). They have fluctuated from a high of slightly more than 14 million lbs in 1960 to a low of about 7 million lbs in 1972. The peak annual production occurred in 1981, with landings of almost 14.5 million lbs of pink shrimp. The small variation in annual landings, depicted by the standard deviation of ±1.6 million lbs, indicates a relatively stable fishery throughout the 21-yr period. Note also that there are only five years (1960, 1963, 1972, 1975 and 1981) in which landings fell outside one standard deviation from the mean.

The avearge monthly landings for 1960-1979 showed an annual cycle whose amplitidue ranged from a high of 1.4 million lbs in January to a low of 260,000 lbs in July. Average monthly landings from 1960-1980 were high in January, decreased considerably in February, rose slightly in March and decreased steadily to the low in July (Fig 5). Values increased very slightly in August, again in September and substantially in both October and November. December's value was about the same as November's, both being about the same as March's. It appears evident that the historical fishery is based on recruits entering the fishery in September-October and providing the supply for this fishery through March-April.

In 1981, the monthly pattern of shrimp landings with regard to magnitude was significantly different from the historical record for 1960-1980 (Fig 6). Landings were greater in January and significantly greater from March through September. We examined these data by 2-way ANOVA which clearly showed there were significant differences between years and between months (Table 2). We then grouped

the data into average monthly landings for 1960-1980 and made comparisons with the 1981 monthly landings by paired t-tests. These results indicated that 1981 was significantly different from the historical data set (t_{11} = 3.974*). In addition, we were interested to know if there was any difference in the average monthly landings between 1981 and the last five years in the fishery and the first five years for which we have statistical records. As a result, we conducted paired t-tests between the historical years (1960-1964) versus 1981 and between 1976-1980 and 1981. These tests indicated that there were significant differences between these two historical data sets and 1981 (1960-1964, $t_{(11)}$ = 2.456** and 1975-1979, $t_{(11)}$ = 3.956***). In addition, the SNK test indicated most annual landings were equivalent within statistical measures (Table 3). We also examined the average landings by month, utilizing the SNK test since the ANOVA indicated differences between months. These results indicated that through the years the landings were similar in the following pairs of months: July and August, June and September and May and October and these sequences of months were different from the remaining months. Therefore, further analyses using landings data may be grouped into these pairings (Fig 7, Table 4).

Fishing Effort

Fishing effort (1960-1981)**** averaged approximately 16.5 thousand days/yr with a standard deviation of ±1.6 thousand days. Highest effort was expended in 1961 and

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*Significant at 99% level.

**Significant at 95% level.

***Significant at 99% level.

****1980 effort data were not used because it is not available in final form.

again in 1978. Lowest effort was expended in 1971 and 1972. Effort did not fluctuate greatly throughout the 20-yr period in this fishery and remained fairly constant with some low efforts in 1971 and 1972, with no sequence of years having a high level of effort (Fig 8). The average appears to be a good indicator of the constancy of this fishery. In 1981, the effort was a little below average.

The average monthly efforts expended in statistical subareas 1-3 (combined) for the period 1960-1979 (Fig 9) generally follow the same pattern of highs and lows as the average monthly landings for the same time span. The fishing effort was generally low in July, August and September. It increased steadily through the fall months to a peak in January. Effort remained high in February and March before declining in April, May, June and July. The monthly fishing effort expended in 1981 (Fig 10) was somewhat different from the historical trend but only slightly so. The monthly fishing efforts for February and December 1981 were more than one standard deviation below the means for the corresponding months' efforts for the historical data set. Efforts in April, June, July and September 1981 were more than one standard deviation above the means from the corresponding months for the historical data set. The rest of the monthly fishing effort data set appears to be similar to the historical data set, indicating that fishing effort in all months except February and December were similar to the historical fishing effort.

Relative Abundance

The relative abundance of pink shrimp is measured by the CPUE for 24-hr fishing day and it is remarkably stable throughout the 1960-1979 period, with an average of 603 lbs/24-hr day with a standard deviation of $\pm$63 lbs/24-hr day for this time span (Fig 11). The highest CPUE was in 1960

and 1981. In 1960, the CPUE was approximately 751 lbs/24 hrs whereas in 1981, the CPUE (959 lbs/23 hrs) was significantly greater than CPUE estimates for the previous 20-yr period.

The average monthly CPUE for pink shrimp for 1960-1979 is remarkably stable from January through August. During these months, the CPUE averaged between 500 and 600 lbs/24-hr day (Fig 12). The CPUE increased appreciably in September, increased to a peak in October and dropped to slightly below the September value in November. A large amount of variation is noted in the September and October CPUE figures. This variation is probably attributable to the variability in recruitment between years, as the major recruitment of the fishery normally occurs in September and October.

The CPUE or measure of relative abundance in 1981 appears to be greater than the historical average noted in March, April and May (Fig 13). Lower CPUE was noted only in the month of November.

In analyzing the CPUE by months and between years, we ran a 2-way ANOVA that indicated there was a significant difference between years and months (Tale 5). We further analyzed the data by paired t-tests in comparison with the historical average CPUE for 1960-1979 versus 1981, the first five years of the fishery (1960-1964) versus 1981 and the last five years for which we have data (1975-1979) versus 1981. The results of these tests show there were significant differences between all comparisons (Table 5). Thus the relative abundance estimates on the Tortugas shrimp grounds was significantly greater in 1981 than in the 1960-1964 or 1975-1979 time frames.

We further analyzed the average CPUE for the 21-yr period utilizing the SNK test. These results indicated a

great amount of similarity between the average CPUE between years and identified two nonsignificant groupings of years (Table 6). The average CPUE by month was also analyzed using the SNK test, which revealed five subsets of similar months (Table 6).

Size

We inspected the percent size distribution of the commercial pink shrimp landings by month in 1981 (Fig 14a-14l). In January, the predominant size distribution was 41-50 count shrimp with approximately equal quantities in all the large size categories. In February, there did not appear to be any single dominant size group, the most frequent size classes were 21-25, 31-40 and 51-67 count shrimp. In March, there were two dominant peaks at 68-count or smaller and 51-67 count with almost no other size category being of importance to the fishery. In April, the same phenomenon was observed with two major peaks, one at 51-67 count and one at 68-count or smaller. The same sequence occurred in May, with those two dominant peaks and by June the dominant peak was 51-67 count with the other size classes still not being important. In September and October 1981, we noted a slight peak at the 51-67 count level but in October, there was a tri-modal peak ranging from 31-40 to 51-67 count and in November, no single size class dominated the catch. In December, 31-40 count shrimp dominated the catch.

We compared the differences between the 1981 percent size class distribution and the historical size class distributions for the 1960-1964 and 1976-1980 time frames, utilizing a G-test (Table 7). The results indicated there were significant size differences in the composition of the landings for all months between the 1960-1964 time frame, the 1976-1980 time frame and the 1981 values. There were also significant differences in size composition for all

months except February and September, when 1976-1980 averages were tested against 1981 values.

The major differences between the 1981 size composition and the historical size composition data is that in 1981, large catches of small pink shrimp (51-67 count and 68-count or smaller) were caught in March, April, May and June whereas the 1976-1980 period did not indicate those dominant modal groups in those months. The historical size composition data also showed dominant modal groups of small shrimp in September and October, whereas the 1981 data did not show as dominant modal groups of small shrimp. This finding indicates major shrimp recruitment in the spring of 1981 and some recruitment in the fall. The size composition in October-December 1981 is significantly different in composition from the last five years of the fishery (1976-1980); the difference is that the 1981 landings are large in size.

Catch and Fishing Effort

We have examined the landings in millions of lbs versus total projected days fished for the time frame 1960-1981, omitting 1980 data. Two years were very different than the others - 1960 and 1981 (Fig 15). The relationship shows considerable stability in the fishery, which centers around 15-18 thousand days fished with catches ranging from approximately 8 million lbs to slightly more than 11 million lbs/yr. These values encompass most of the years examined in this graph.

Low catch and effort were experienced in 1971 and 1972 and high catch and relatively high effort were experienced in 1960; low catch and a high level of effort were observed in 1961. In 1981, catches were high and effort low - very different than any other years in the fishery.

DISCUSSION

The permanent Tortugas sanctuary was established in May 1981. In trying to evaluate the management regulations, we have specifically looked at landings, effort, CPUE and size composition from May through December 1981 and have compared these catch statistics with the historical data from 1960-1979.

Monthly landings in 1981 were higher in May, June, July, August and September and lower in October, November and December when compared with average landings in corresponding months from 1960-1980. In comparing the monthly relative abundance from May-December between 1981 and the historical record, it is evident the CPUE was significantly greater from May-October and December and lower in November 1981 from the historical data. In comparing the size composition between 1981 and 1976-1980, it appears there are significant differences for all months from May-December except September. The 1981 data clearly indicates a dominant modal group from March-August. This modal group is apparently the strong spring year class than entered the fishery in March, April and May and continued to grow to a 31-40 count by August. Historically, this modal group was not evident in the first five years nor was it evident in the last five years of the fishery. The September 1981 size class data were not significantly different from the September data for 1976-1980. There appeared to be a similar amount of recruitment in September 1981 and September 1976-1980. The October size frequency distributions, however, were startlingly different in that the historical data reflected strong recruitment in both October and November, whereas the 1981 data did not reflect such recruitment.

There were large differences in the landings, CPUE and, to a degree, the size composition on the fishing grounds from May-December 1981 compared with previous years. However, it is not possible to make a determination from these data that those differences were attributed to implementation of the Tortugas sanctuary. The reason we came to this conclusion is that there was a major recruitment into the Tortugas shrimp fishery in March and April, which preceded implementation of the line. However, we speculate that the line may have contributed to the continued high CPUE and high landings as well as preservation of the dominant modal group that was recruited into the fishery in March and April and resulted in slightly larger shrimp being harvested from October-December 1981.

Questions also arise as to how many fishermen refrained from fishing inside the sanctuary, as 33 violations were documented from May 1981 through March 1982 (Fuss).[4] If considerable amounts of illegal fishing did occur, the catch results presented in this paper may be biased in terms of measures of CPUE. Further, the full benefits of the sanctuary would not be realized.

SUMMARY

Commercial landings from statistical subareas 1, 2 and 3 in 1981 greatly exceeded landings in all years of the fishery since 1960. Average landings are approximately 10 million lbs/yr; however, in 1981 landings amounted to 14.5

[4]Fuss, Charles; DOC/NOA/NMFS/SERO, St. Petersburg, FL; personal communication.

million lbs of shrimp. The landings appeared to be stable during the 21-yr period, with the exceptions of 1960-1962, 1972, 1975 and 1981, which fell outside the standard deviation of this 21-yr period.

The fishery basically begins each year in September/ October with recruitment of small shrimp to the grounds. Peak production is in December, January and February and is followed with a slight decline in March and April production, tapering off considerably in the May-August period. Monthly landings differed significantly from March through September 1981 from the same months for all other years of the fishery.

Fishing effort did not fluctuate greatly over the 20-yr period and averaged 16.5 thousand days/yr. Highest effort was expended in 1961 and again in 1978. In 1981, the effort was a little below average but within one standard deviation for the 20-yr period.

There were significant differences in the CPUE between 1981 and all other years in the fishery. The relative abundance of pink shrimp, as measured by CPUE for 24-hr fishing days, is remarkably stable throughout the 1960-1979 period with an average of 603 lbs/24-hr day. The highest CPUE occurred in 1981 with a catch of 957 lbs/24-hr day. Further, when comparing fishing effort versus catch, the fishery appears to be remarkably stable for all years except 1981.

Size distribution in 1981 was sigificantly different from the last five years (1976-1980) and the first five years (1960-1964) of the fishery. The primary difference was a large recruitment of 50-count or smaller shrimp into the Tortugas fishing grounds in March and April. This recruitment could be followed by their modal size classes through August. Historically, there is not a large spring

recruitment; however, 1981 was different and this spring recruitemnt was easily detectable in the size categories of the commercial landings. Also, the size of shrimp landed in October-December 1981 was larger than for previous years.

The catch and relative abundance, as well as the size distribution of the shrimp on the Tortugas grounds, was different in 1981 than in all other years of the fishery except perhaps 1960. Landings were higher, CPUE was higher and major recruitment of small shrimp, which could be followed throughout the fishery for several months, occurred in March and April. Establishing the sanctuary line may have protected the small shrimp which were in the area during the months of May-September, however we cannot make that determination at this time. In 1981, the usual fall recruitment probably was not as great as in previous years.

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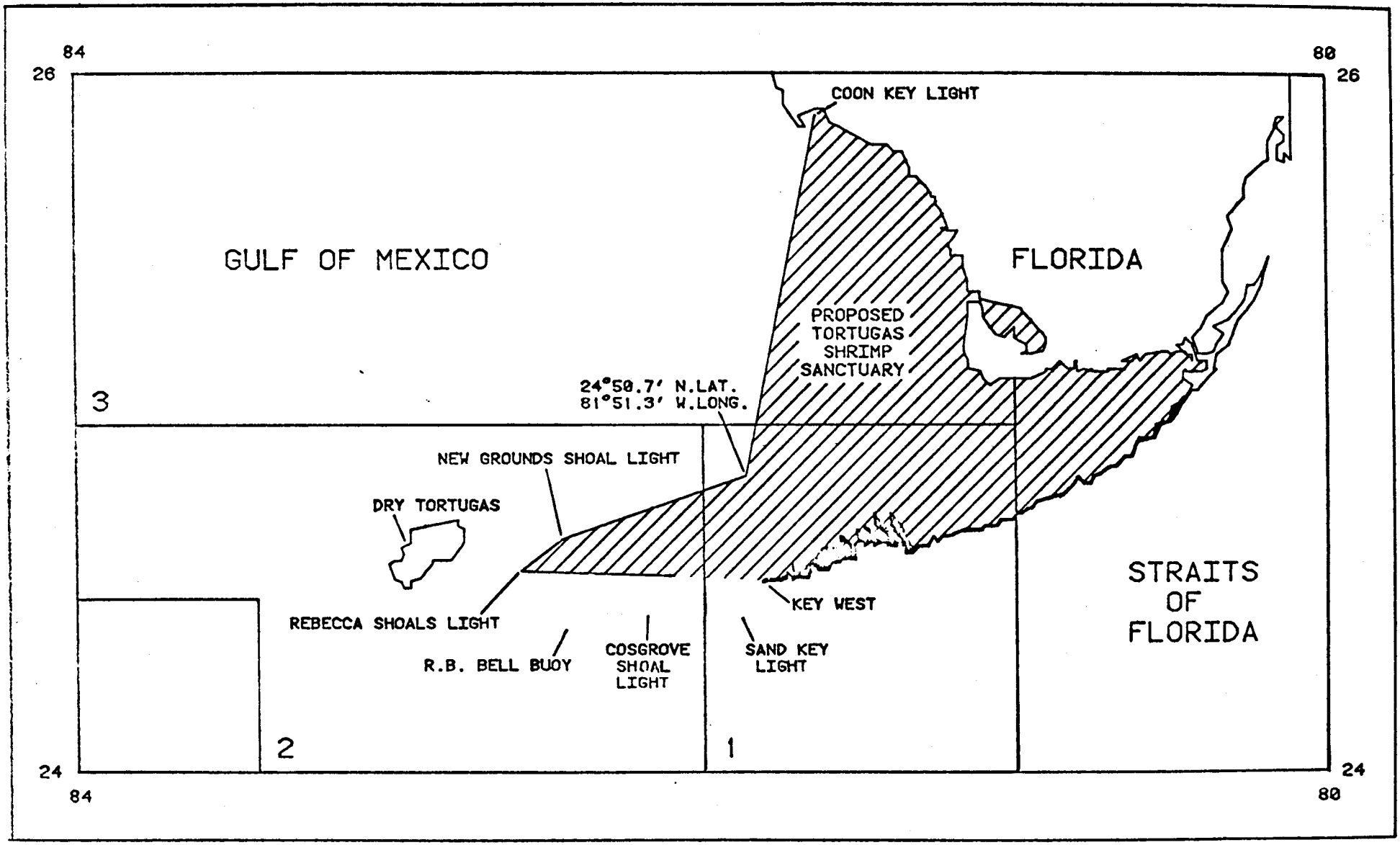
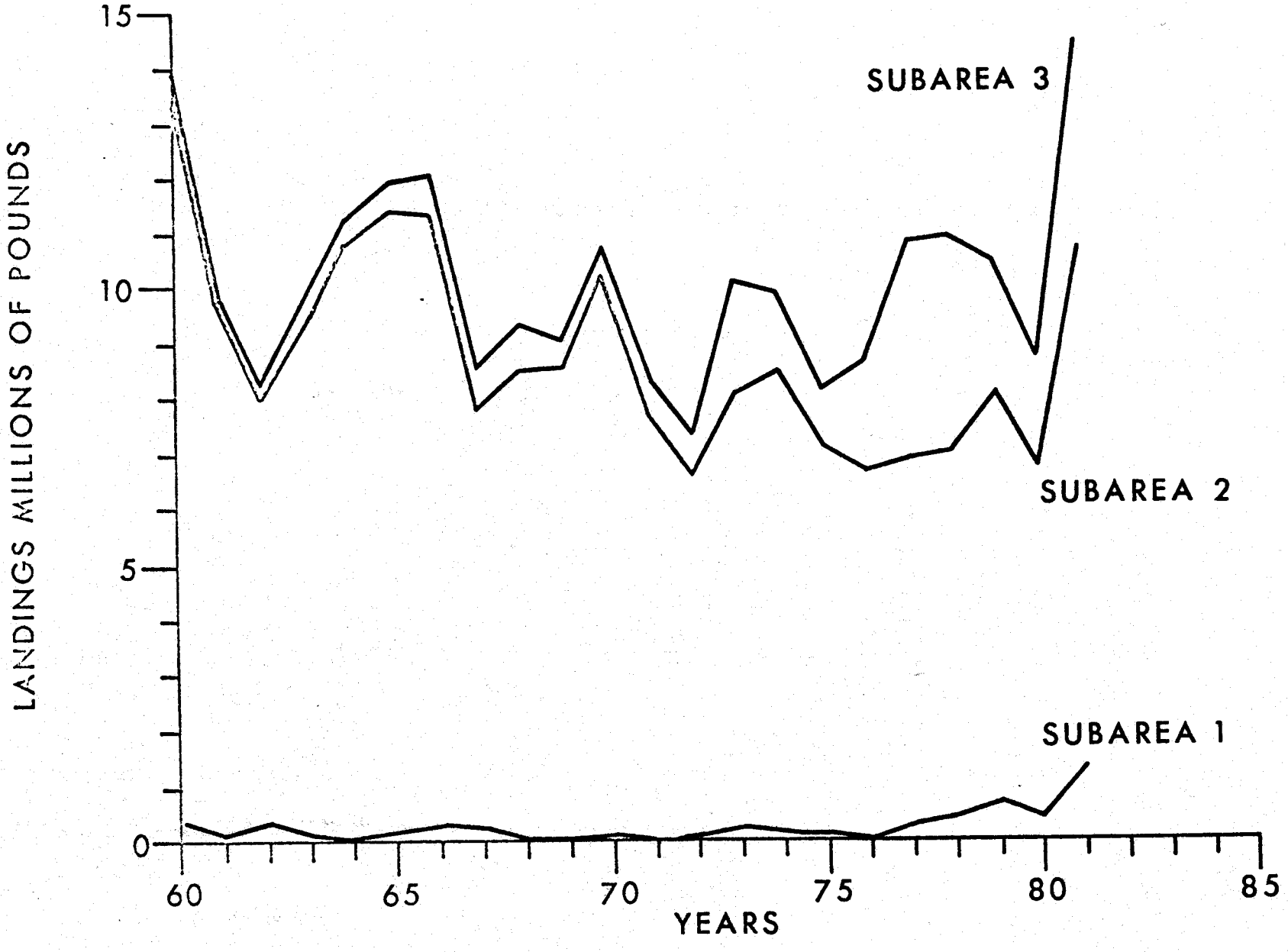


Figure 1. Chart of Dry Tortugas fishing grounds and statistical subareas.



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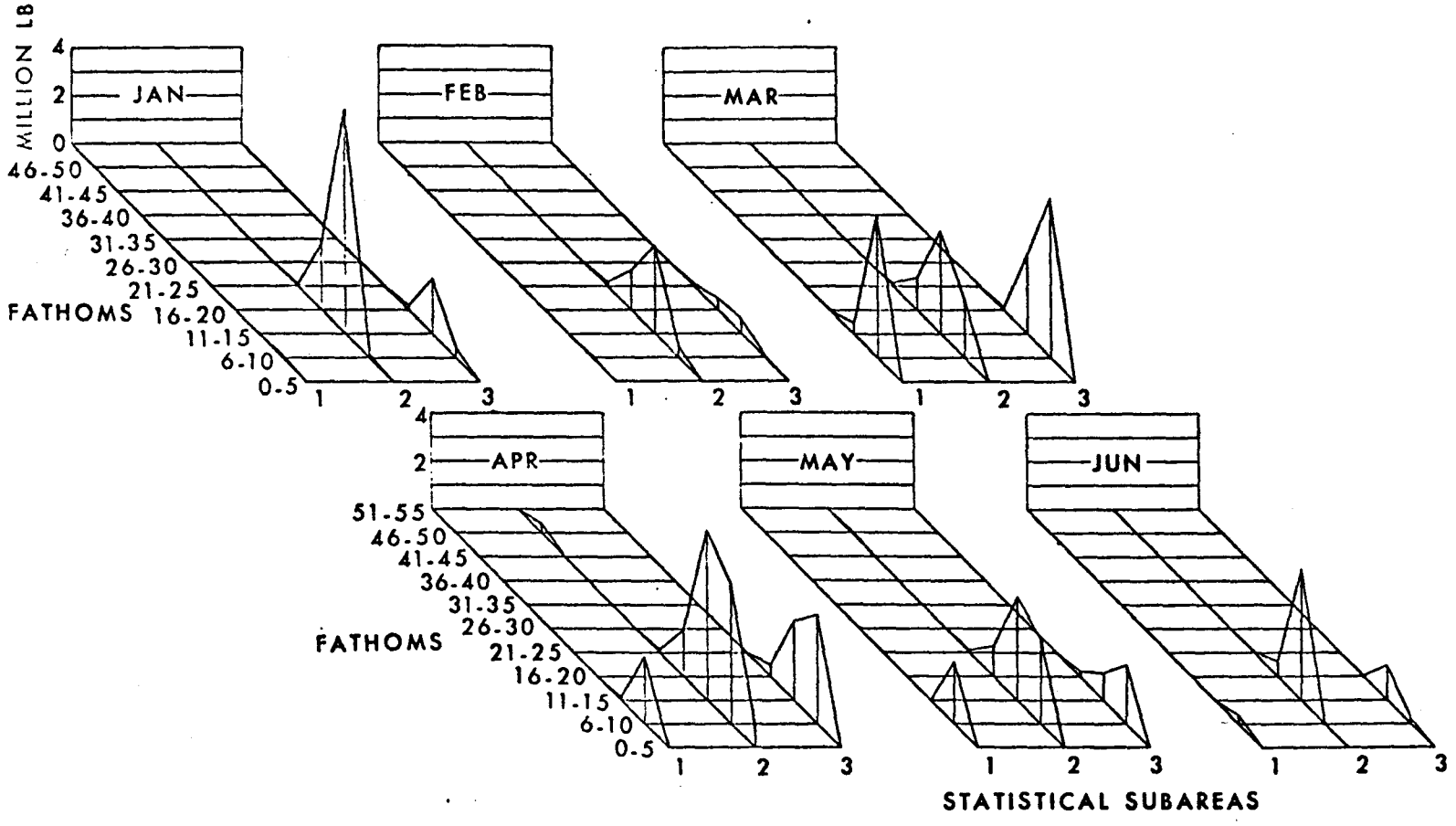
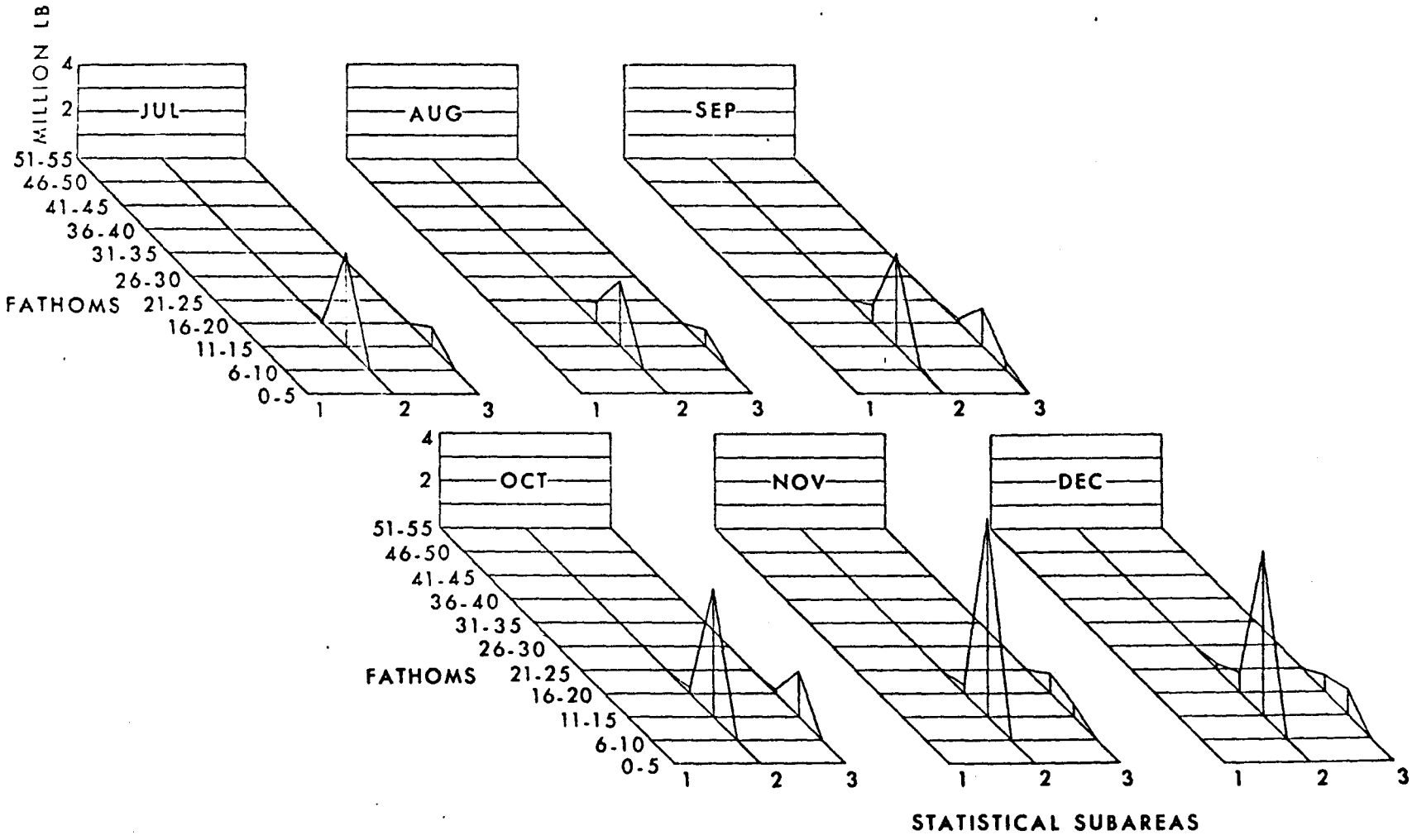


Figure 3. Landings of pink shrimp by month in 1981 by depth zones in statistical subareas 1, 2 and 3.
3a-3f



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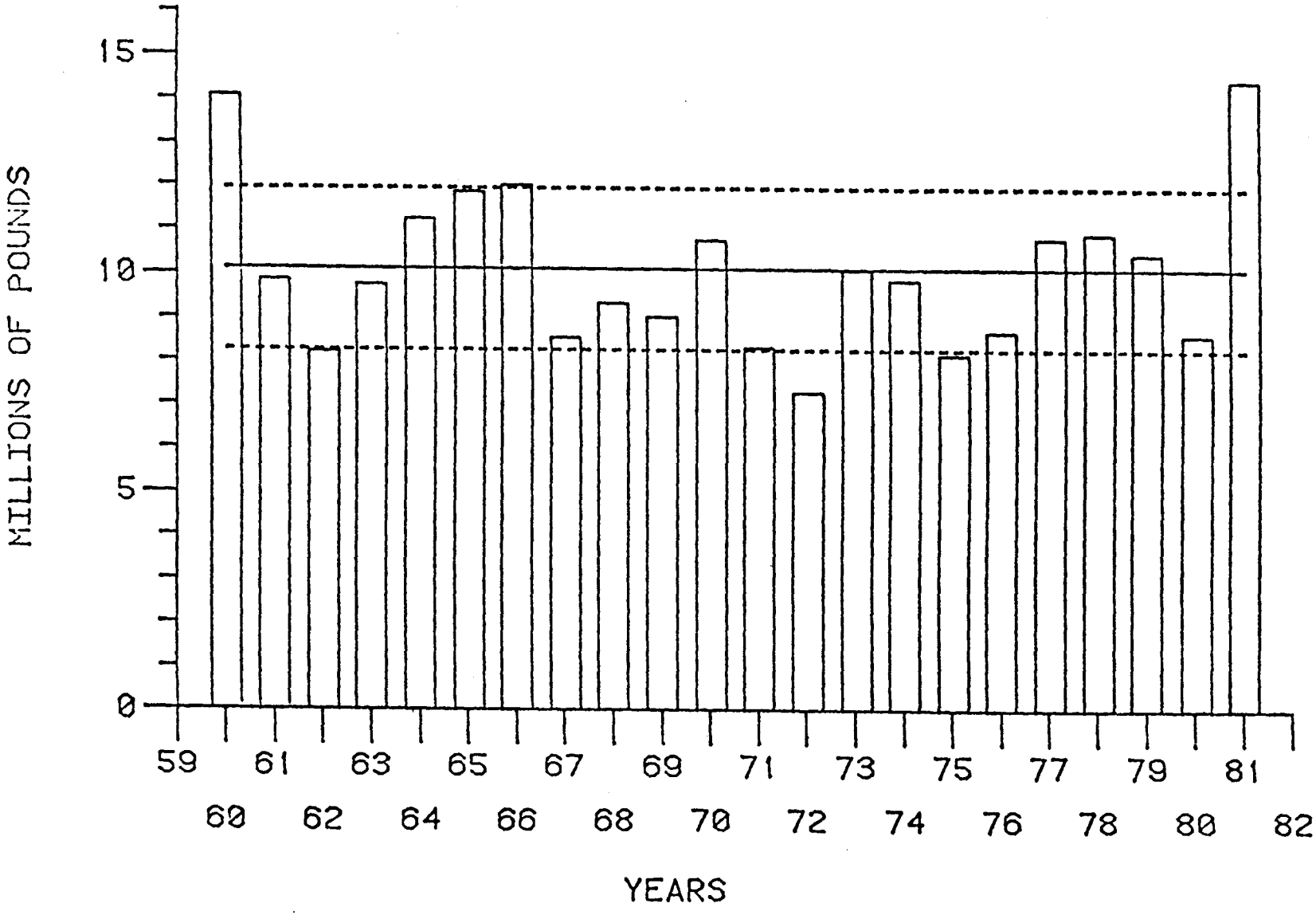


Figure 4. Annual shrimp landings in millions of pounds from statistical subareas 1, 2 and 3, 1960-1981 (solid line is average landings; broken line is one standard deviation).

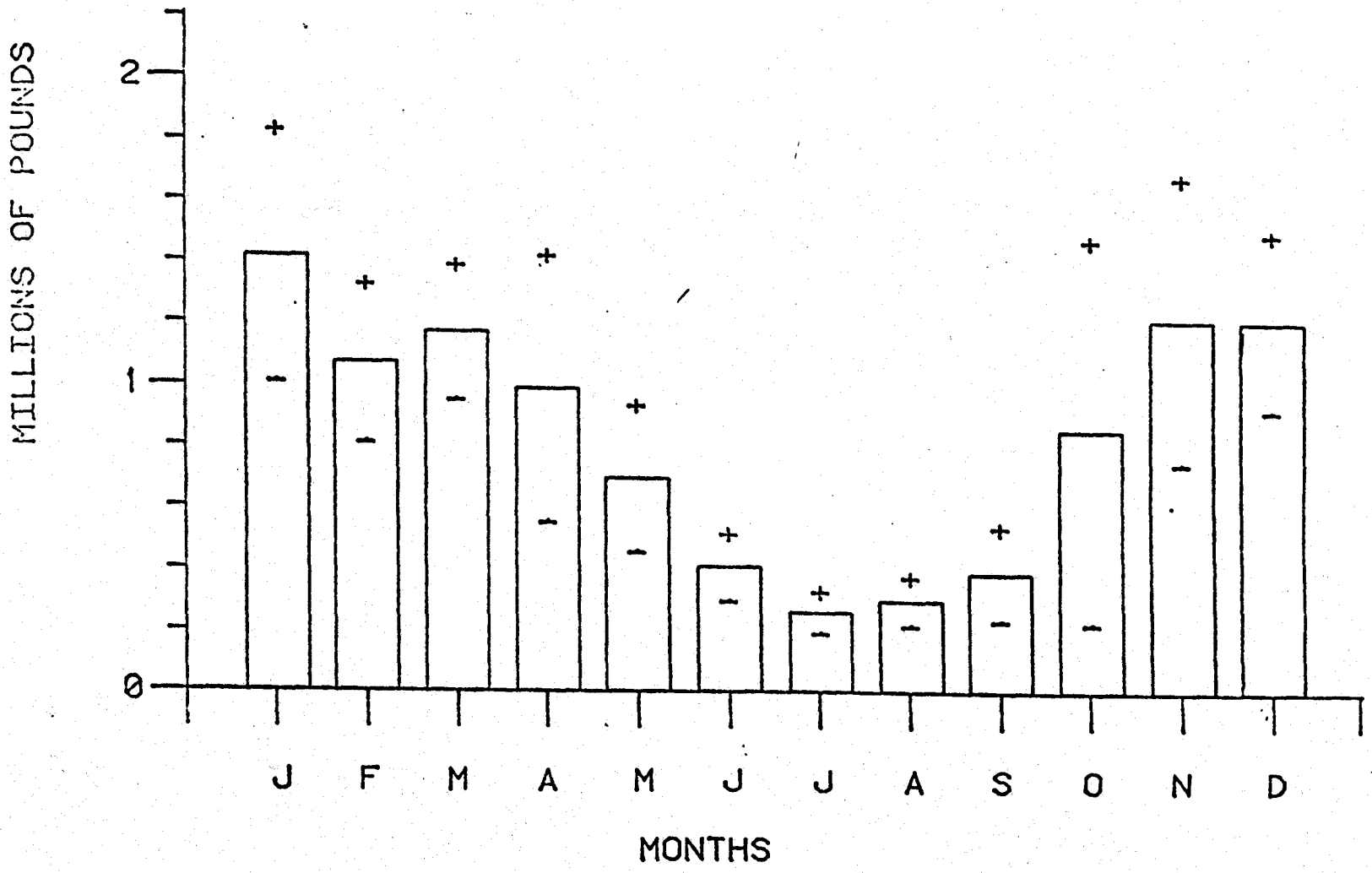


Figure 5. Average monthly pink shrimp landings in millions of pounds, 1960-1979, from statistical subareas 1, 2 and 3, ±one standard deviation.

1, 2 and 3, ±one standard deviation.

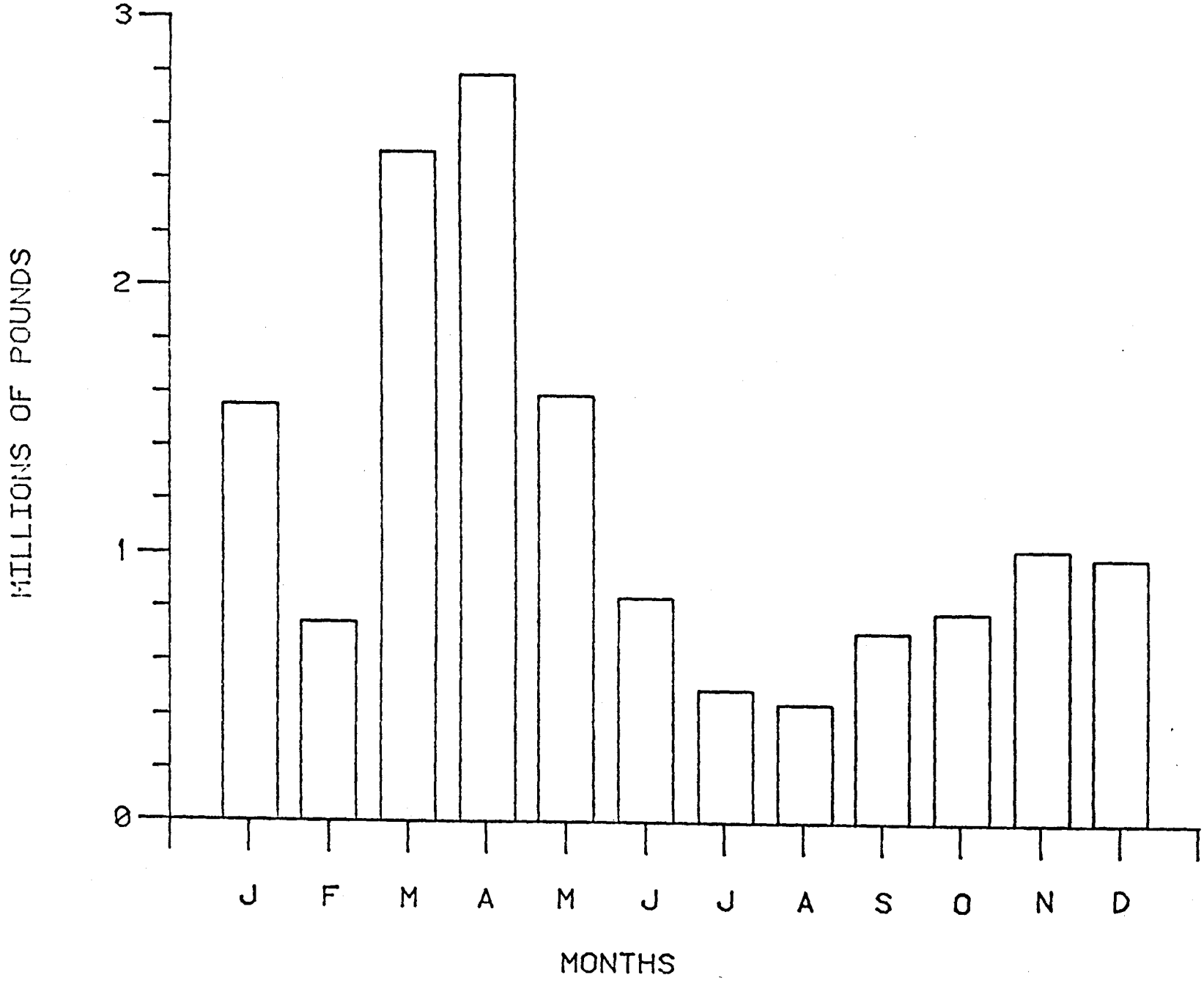
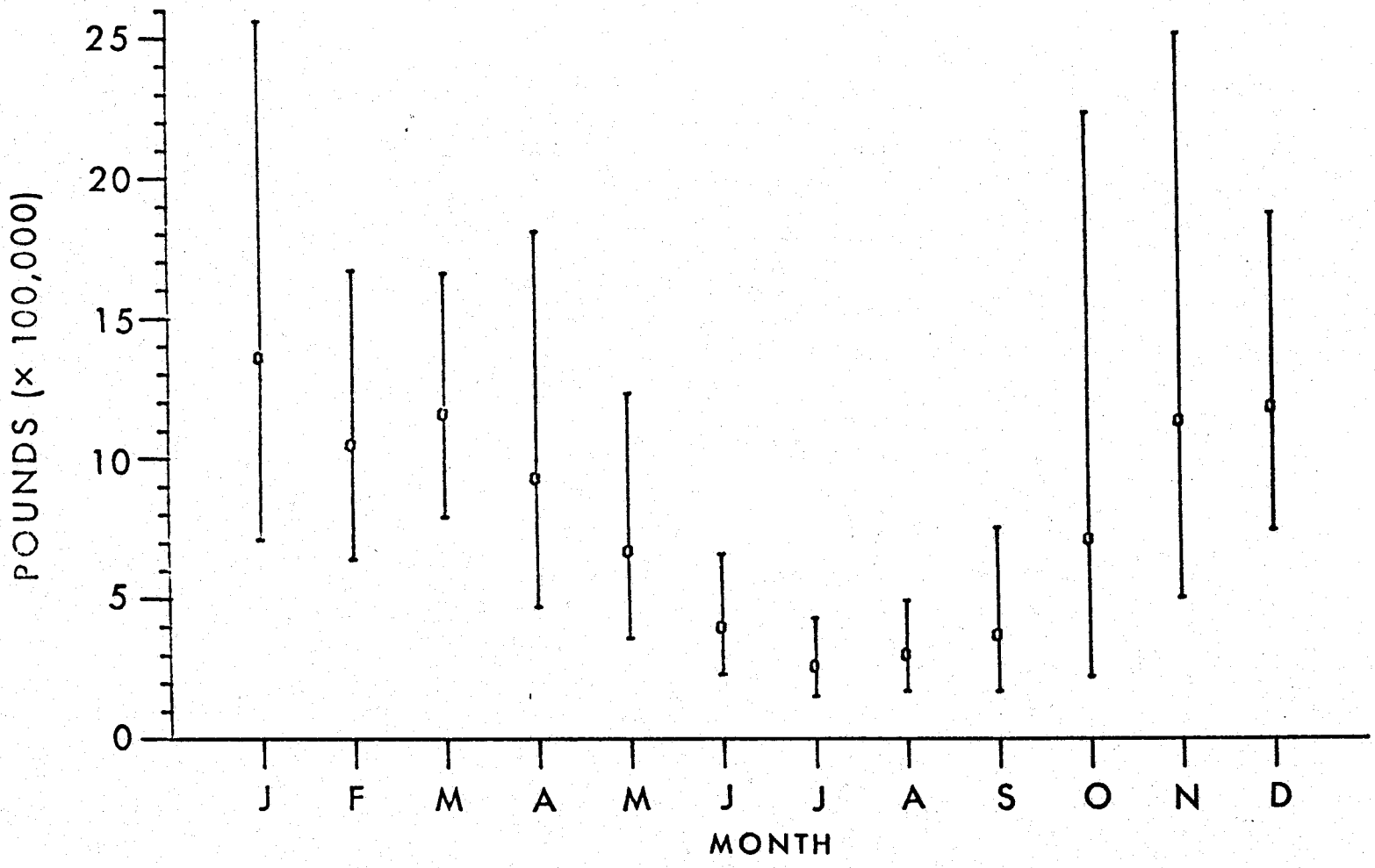


Figure 6. Monthly pink shrimp landings in millions of pounds in 1981 from statistical subareas 1, 2



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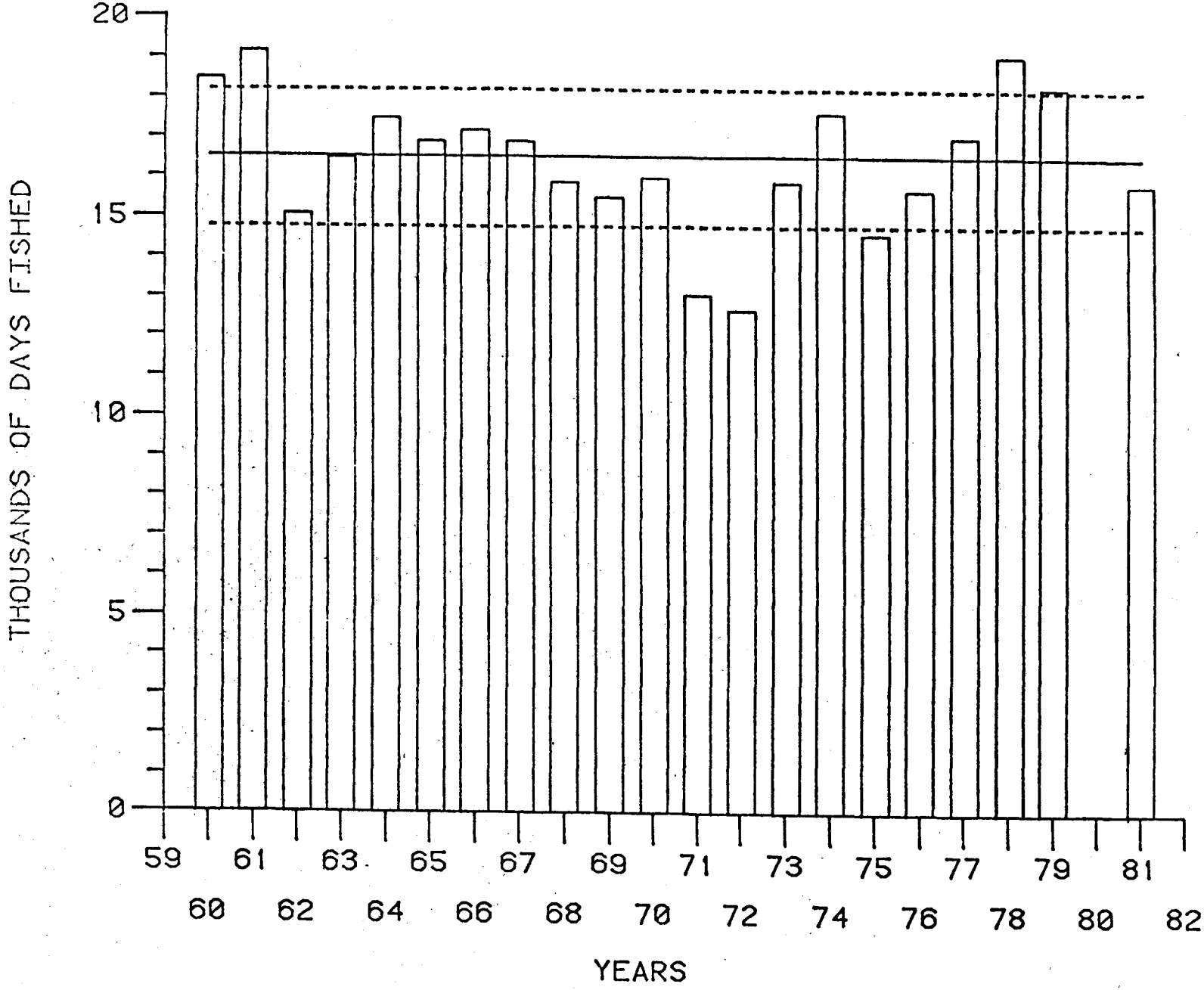


Figure 8. Fishing effort in thousands of days fished by year from 1960-1979 and 1981 (solid line is average effort and broken line is one standard deviation).

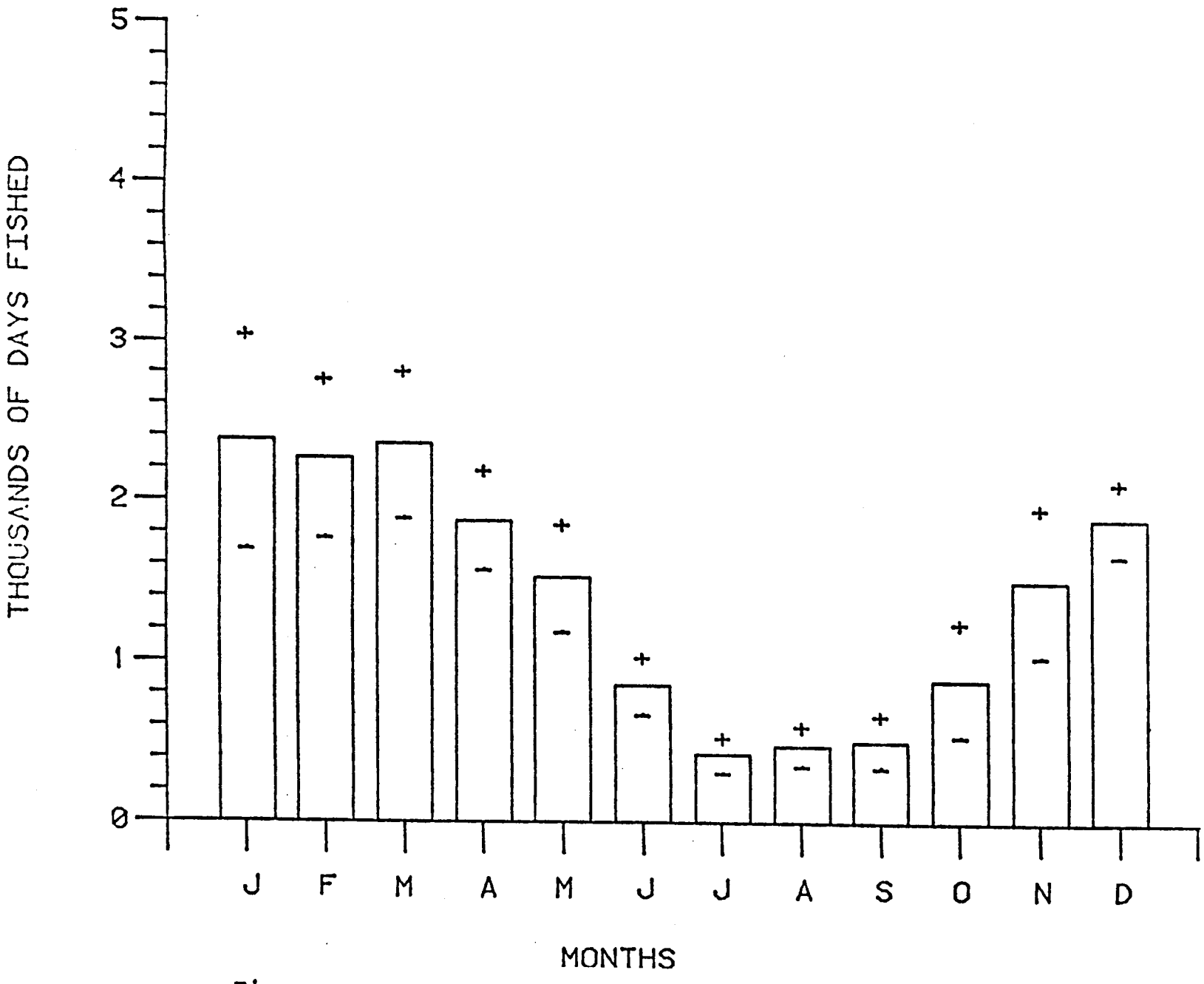


Figure 9. Average monthly pink shrimp fishing effort, 1960-1979, for statistical subareas 1, 2 and 3, ±one standard deviation.

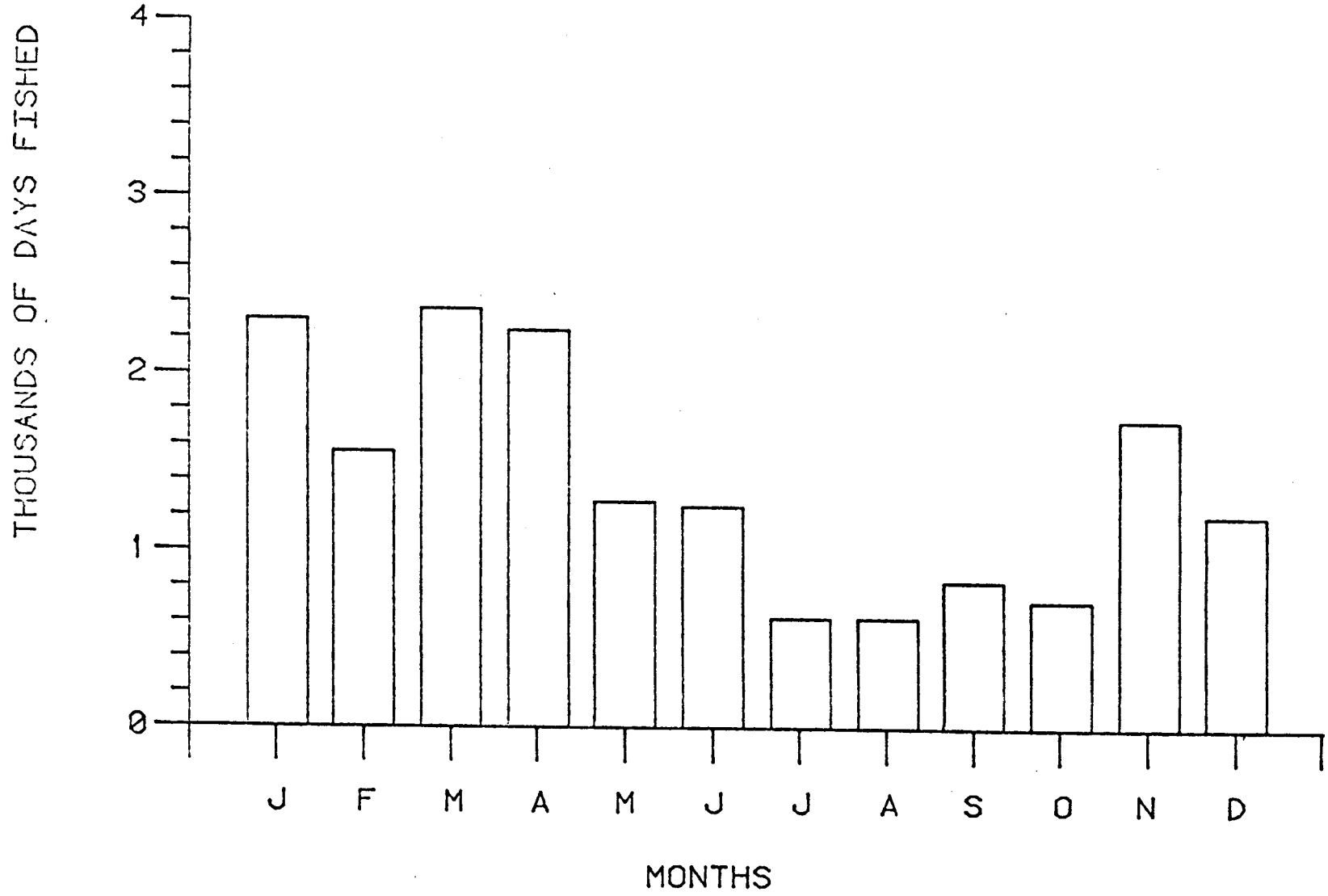


Figure 10. Average monthly pink shrimp fishing effort, 1981, for statistical subareas 1, 2 and 3.

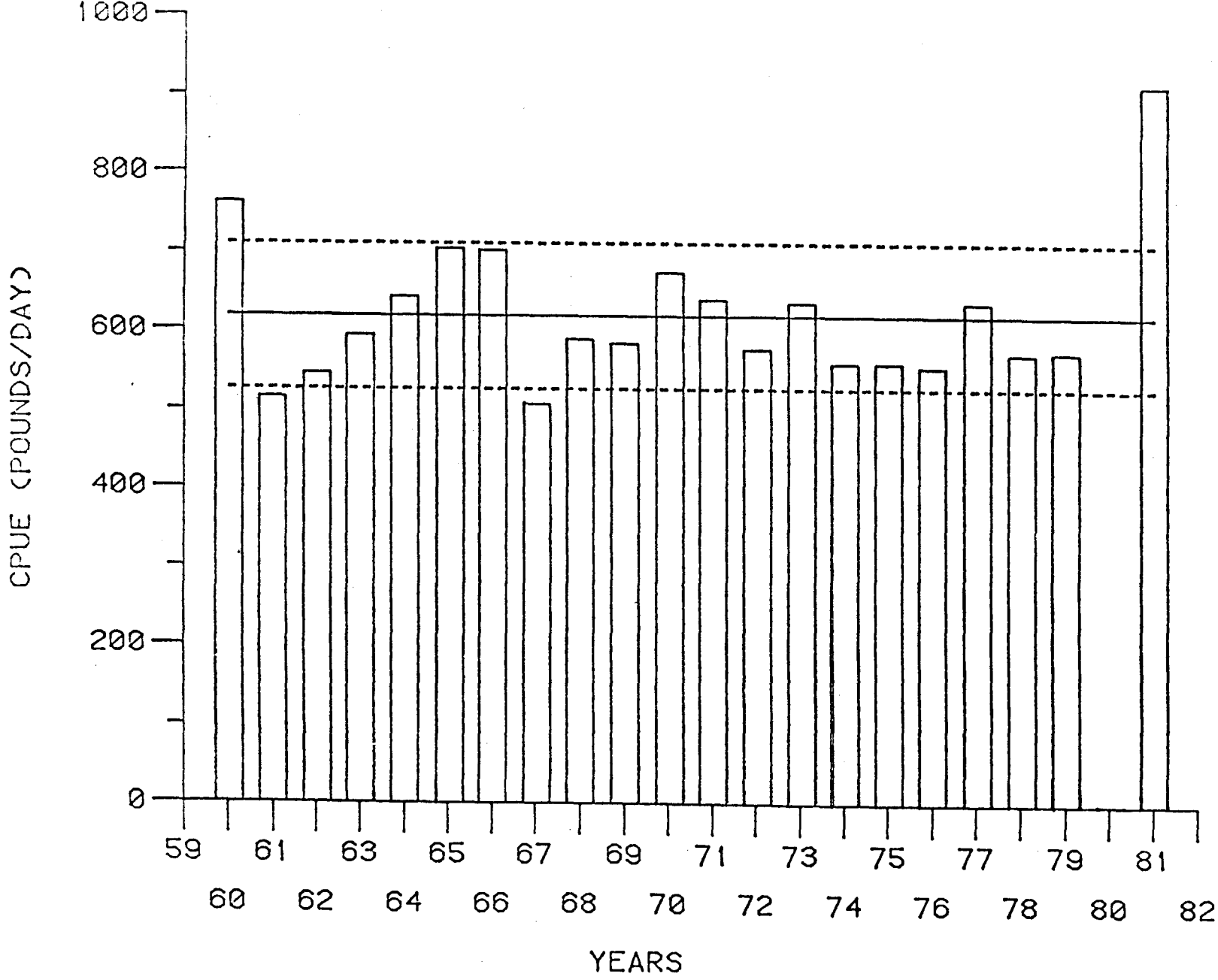


Figure 11. Catch per unit effort from 1960-1979 and 1981 in statistical subareas 1, 2 and 3 (solid line is average, broken line is one standard deviation).

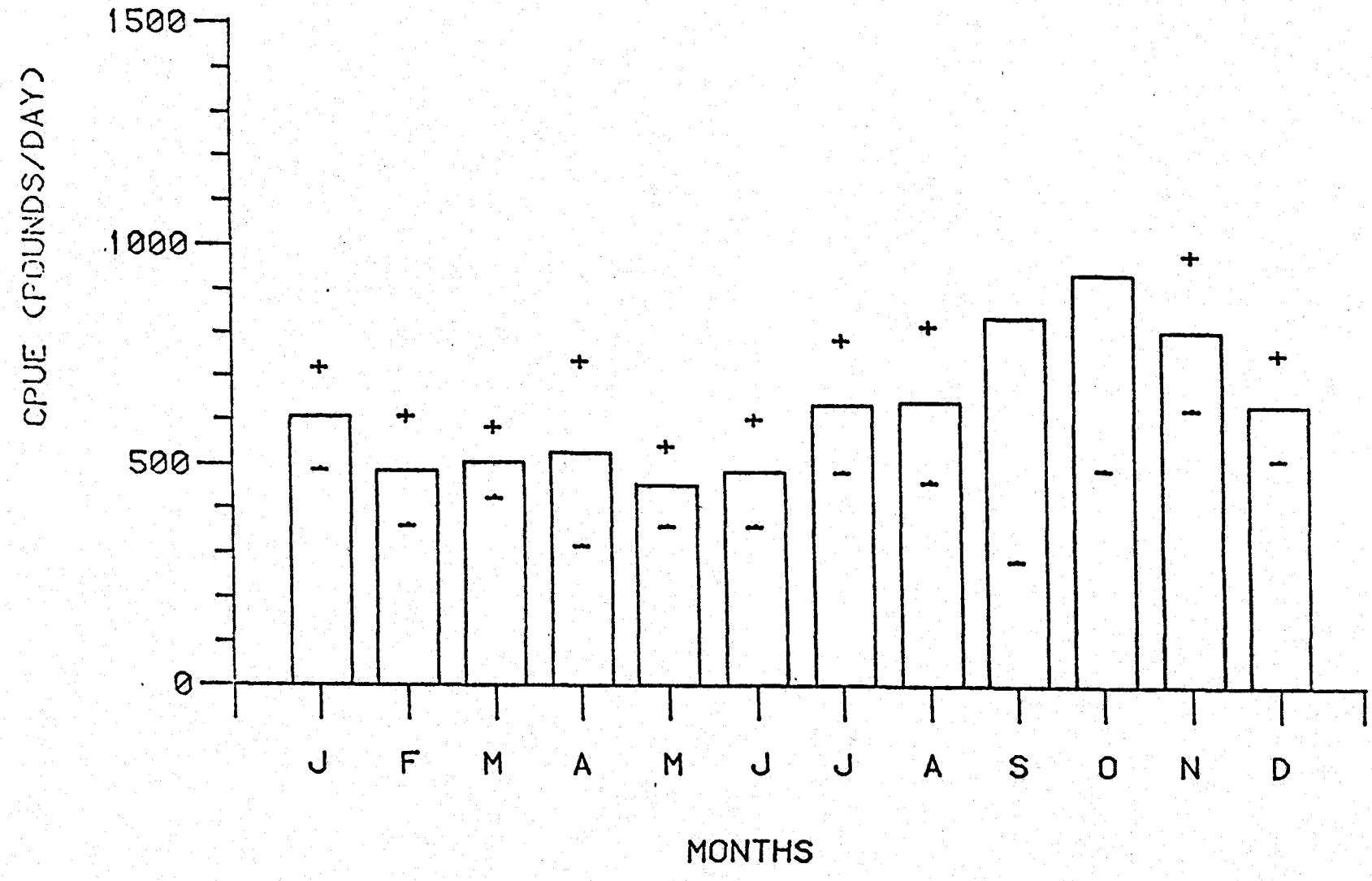
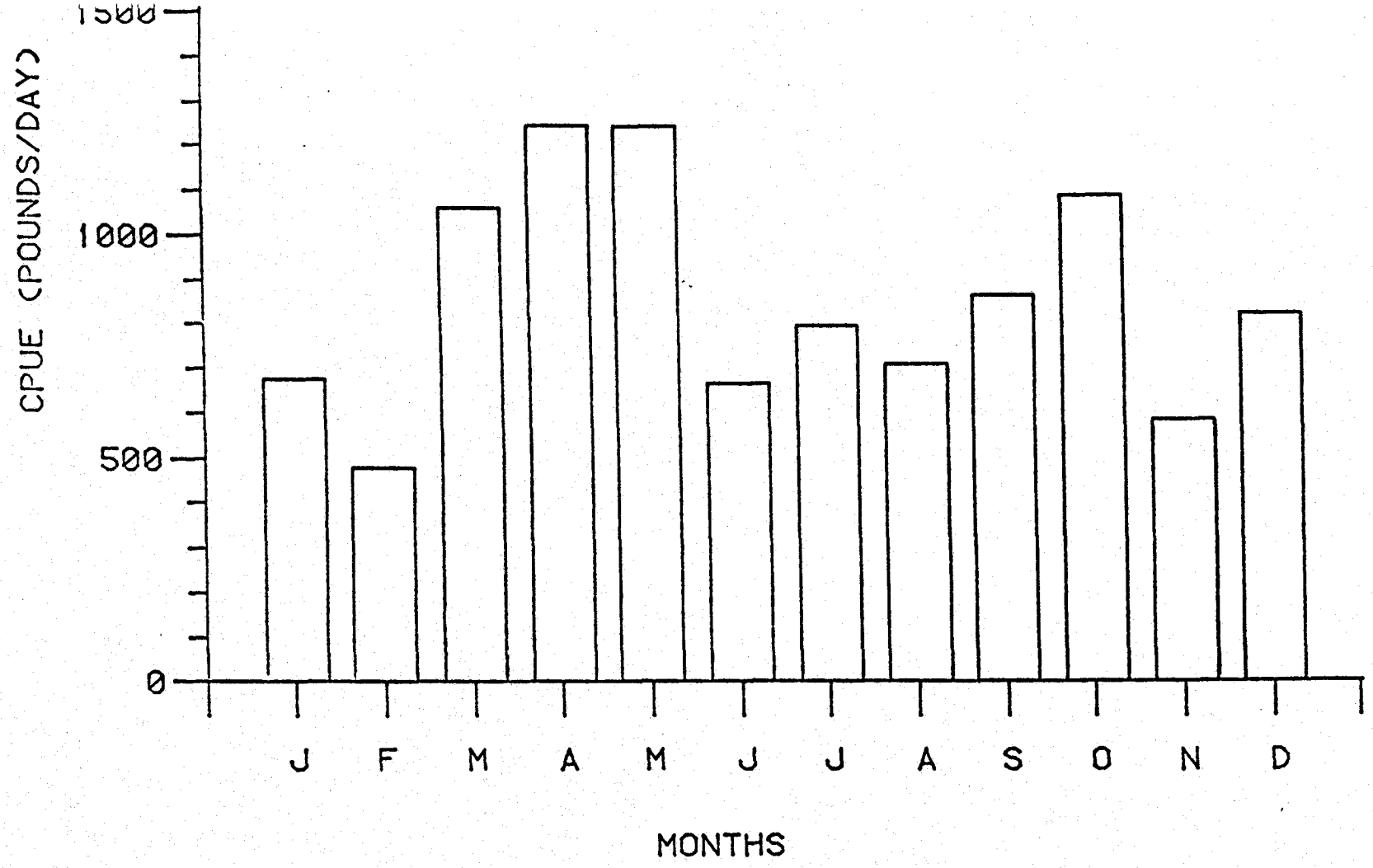


Figure 12. Average monthly pink shrimp CPUE, 1960-1979, from statistical subareas 1, 2 and 3.



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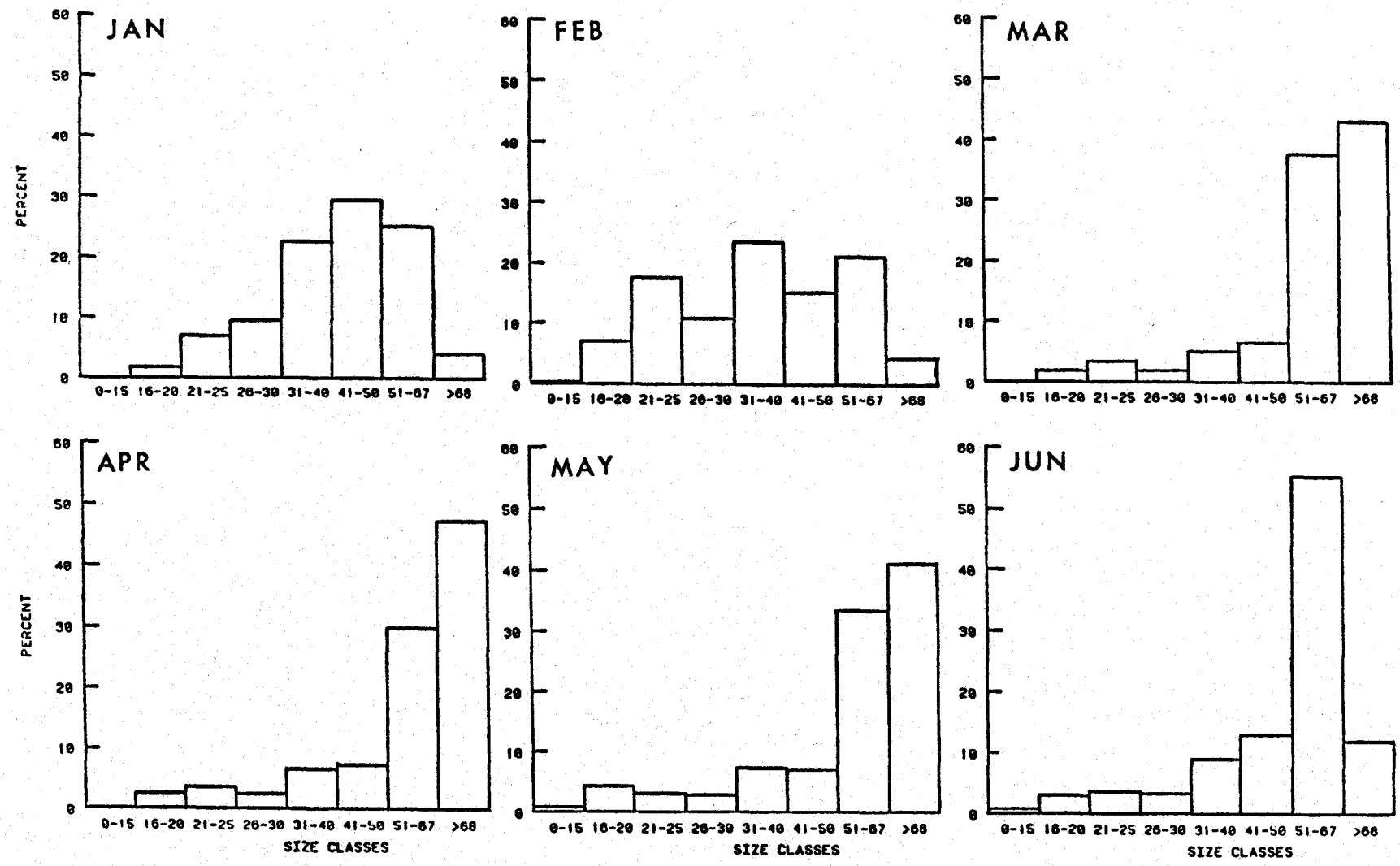

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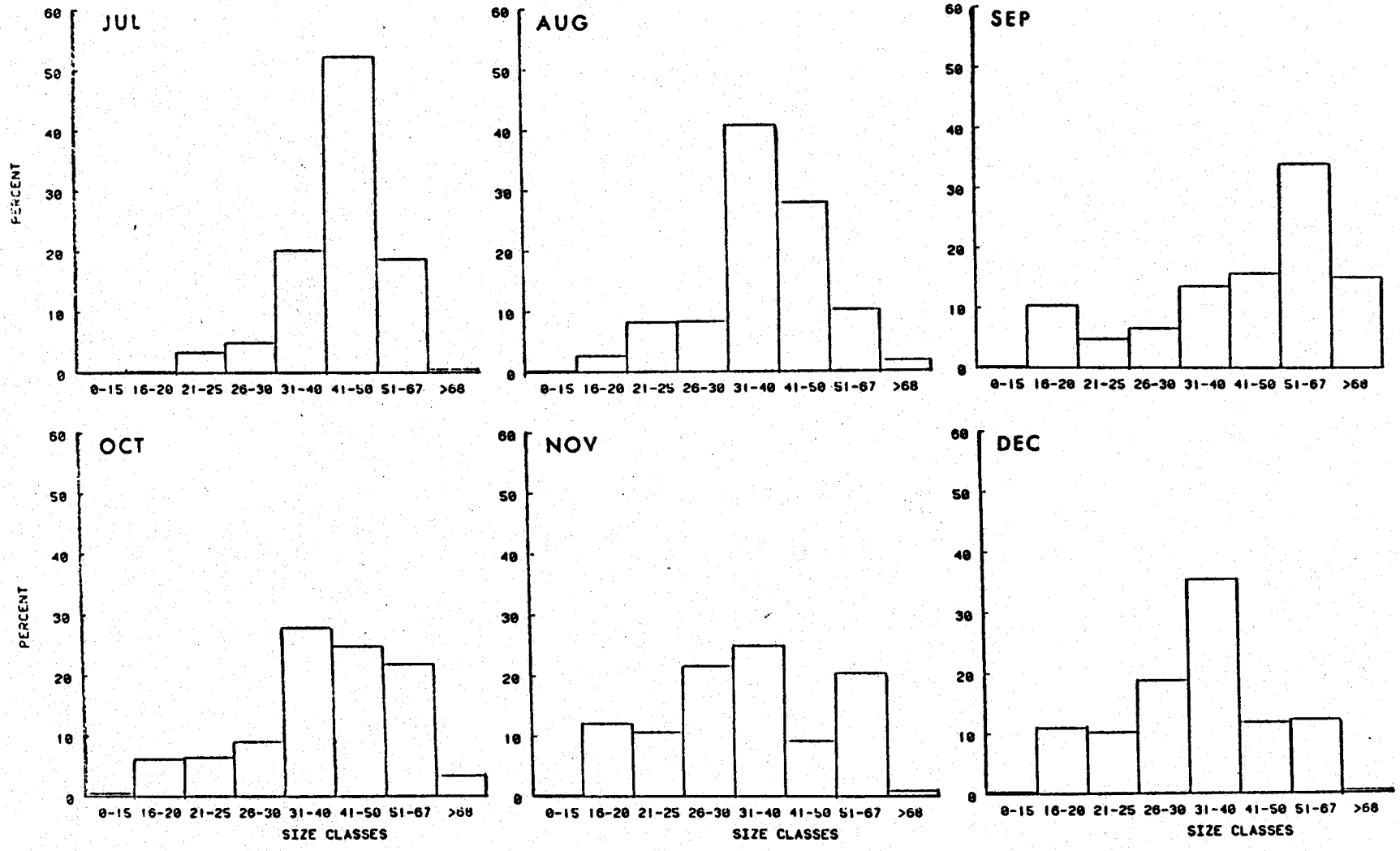

Figure 14. Percentage composition of pink shrimp by size class by month in 1981 from statistical subareas 1, 2 and 3.

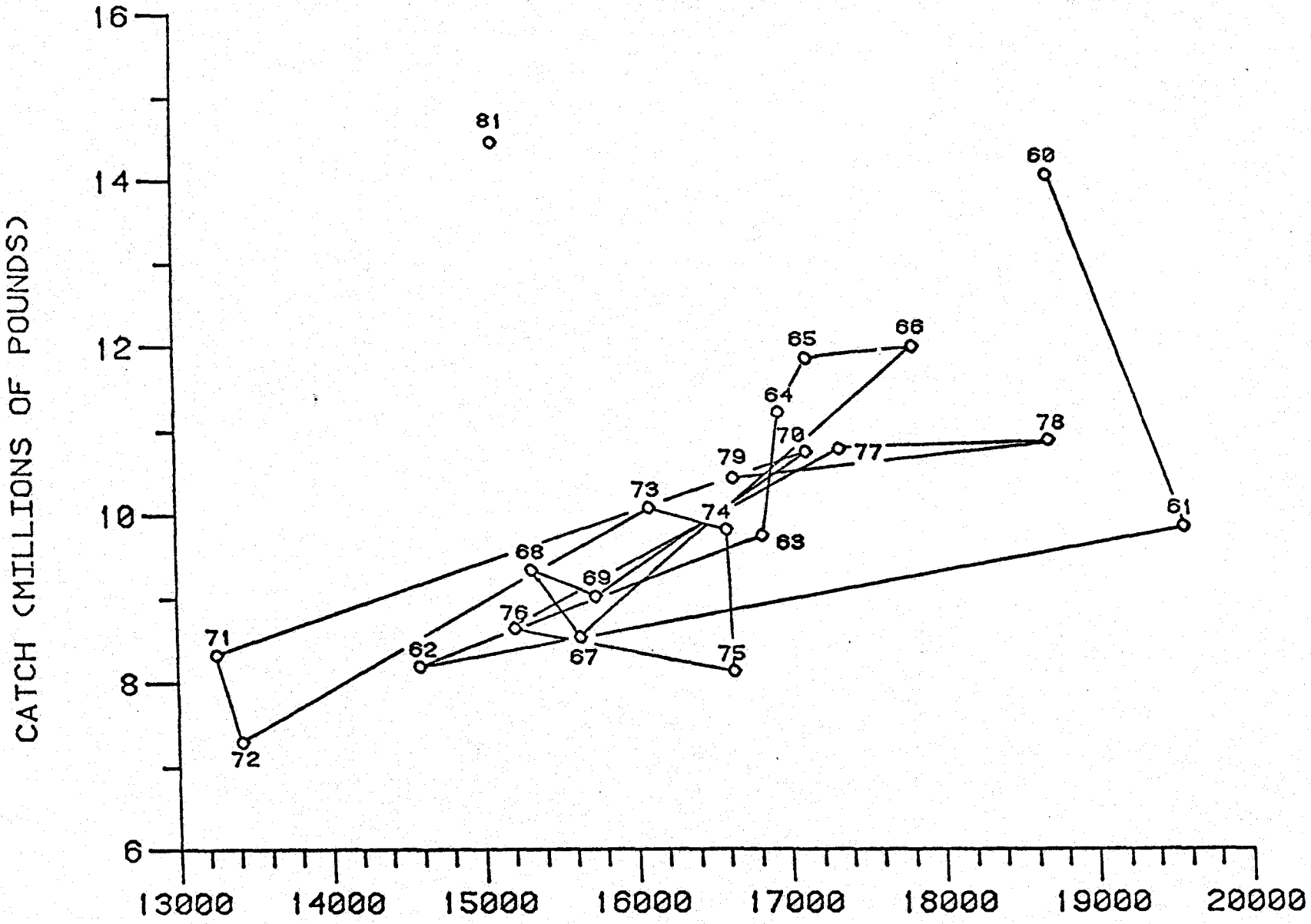

Figure 15. Catch versus fishing effort for 1960-1979 and 1981 from statistical subareas 1, 2 and 3.

Table 1. Number of vessels unloading shrimp caught in statistical subareas 1, 2 and 3 in 1981.*

Month	Key West, FL	Ft. Myers, FL
January-April	355	235
May	178	138
June	131	129
July	76	11
August	77	6
September	90	18
October	186	33
November	197	60
December	218	96

*Ernest Snell, DOC/NOAA/NMFS/SEFC, Miami, FL; personal communnication.

Table 2. Results of a 2-way analysis of variance (ANOVA) of monthly landings from 1960 through 1980.

Source	Degree of Freedom	Mean Square Error	F
Years	20	0.3668	3.378***
Months	11	7.4069	68.2213***
Error	220	0.1086	
Total	251		

***= significant at 99% confidence level ($P<0.01$).

Table 3. Maximum nonsignificant ranges of average landings by year from the Student-Newman-Keuls tests.

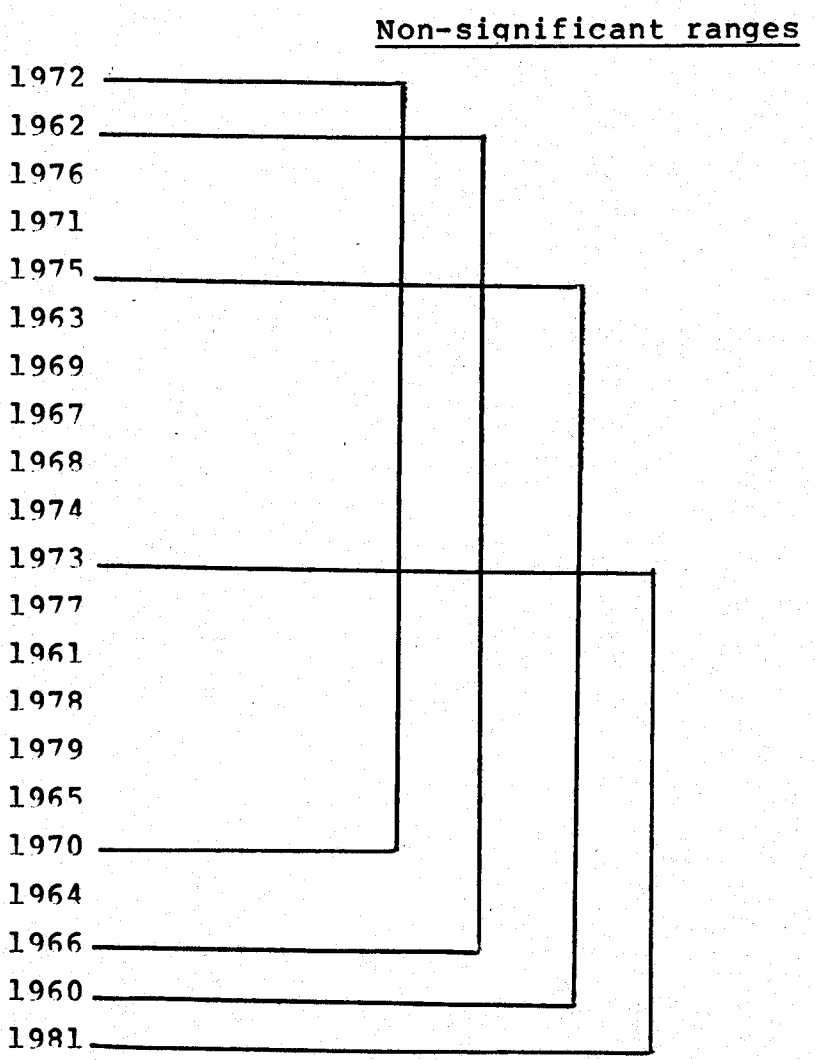

Table 4. Maximum nonsignificant ranges of average landings by month from Student-Newman-Keuls tests.

Non-significant ranges
July
August
September
June
May
October
April
February
November
December
March
January

Table 5. Analyses of CPUE data from the Tortugas pink shrimp fishery.

A. Results of a 2-way ANOVA testing monthly CPUE for the period 1960-1979 and 1981.

Source of Variation	Degree of Freedom	Mean Square Error	F
Years	20	0.00007	2.3128***
Months	11	0.00035	12.5219***
Error	220	0.00003	
Total	251		

B. Results of paired t-tests for mean monthly CPUE for selected groups of years versus monthly CPUEs for 1981.

1960-1979 vs 1981	$t_{(11)} = 3.114^{***}$
1960-1964 vs 1981	$t_{(11)} = 2.476^{*}$
1975-1979 vs 1981	$t_{(11)} = 4.718^{***}$

* = P<0.05
** = P<0.001
*** = P<0.0001

Table 6. Results of Student-Newman-Keuls test showing the maximum nonsignificant ranges (by lines) in pink shrimp mean annual CPUEs 1960-1981, excluding 1980.

A. Mean annual CPUEs, 12 months each.

Non-significant range

1981
1960
1966
1964
1971
1970
1965
1979
1973
1974
1967
1963
1968
1978
1976
1969
1962
1977
1972
1961
1975

B. Mean monthly CPUES, 21 years each.

Non-significant range

October
November
September
December
July
August
January
March
April
June
February
May

Table 7. G-test comparisons of composition by size categories of pink shrimp landings from statistical subareas 1, 2 and 3.

Month	1960-1964 vs. 1976-1980 G. values	1960-1964 vs 1981 G. values	1976-1980 vs. 1981 G. values
September	27.0	28.9	16.9
February	28.2	16.6	12.3 N.S.
March	26.0	48.3	68.8
April	24.9	18.4	65.8
May	27.4	34.9	85.8
June	20.0	52.3	32.8
July	34.7	73.7	51.5
August	83.7	66.5	59.5
September	46.7	45.7	7.6 N.S.
October	20.6	46.8	21.5
November	22.9	78.0	19.3
December	12.6	23.6	18.0

Significant values: $X^2.05(6) = 12.59$

$X^2.01(6) = 16.812$