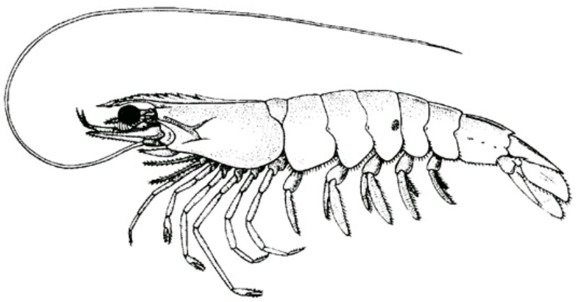
NOAA TECHNICAL MEMORANDUM NMFS-SEFSC-542

Life History, Diet, Abundance and Distribution, and Length-Frequencies of Selected Invertebrates in Florida Bay, Everglades National Park, Florida

Allyn B. Powell[1], Michael W. Lacroix[1], Robin T. Cheshire[1], and Gordon W. Thayer[2]



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NOTICE

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Abstract

This report presents information on the life history, diet, abundance and distribution, and length-frequency distributions of five invertebrates in Florida Bay, Everglades National Park. Collections were made with an otter trawl in basins on a bi-monthly basis. Non-parametric statistics were used to test spatial and temporal differences in the abundance of invertebrates when numbers were appropriate (i. e., ≥ 25). Invertebrate species are presented in four sections. The sections on *Life History*, and *Diet* were derived from the literature. The section on *Abundance and Distribution* consists of data from otter-trawl collections. In addition, comparisons with other studies are included here following our results. The section on *Length-frequency Distributions* consists of length measurements from all collections, except 1984-1985 when no measurements were taken. Length-frequency distributions were used, when possible, to estimate life stage captured, spawning times, recruitment into Florida Bay for those species which spawn outside the Bay, and growth. Additional material from the literature was added when appropriate.

Introduction

Florida Bay is a shallow lagoon roughly encompassed on the north by the mainland of the Florida peninsula, and on the east and south by the Florida Keys, and to the west by the Gulf of Mexico (Fig.1). The precise boundaries of Florida Bay vary because of the open connection of the Bay with the Gulf of Mexico. Here, we define Florida Bay as that portion which is situated within the boundaries of Everglades National Park, covering an area of approximately 1700 km^2 (Anonymous, 1995). An excellent summary of the description of the Florida Bay ecosystem is given by Fourqurean and Robblee (1999), which is a source of information for this introduction.

A latticework of carbonate mud banks and shallow basins (1-3 m deep) connected by channels is characteristic of the Bay. Approximately 200 small mangrove-lined islands, or keys, occur in the Bay. The carbonate mud banks restrict tidal flow from the Gulf of Mexico on the west while the Florida Keys isolate all but the southern portion of the Bay from tidal cycles of the Atlantic Ocean. Tides along the western margin of the bay range 61 cm; whereas, on the east adjacent to the Florida Keys tides range 17 cm. Within most of the central and northeastern portions of the Bay, tides are generally wind driven. Southwest winds produce relatively higher tides, while northeast winds, which are dominant in winter, produce relatively lower tides (Anonymous, 1995; Fourqurean and Robblee, 1999).

Basins, banks, and channels in Florida Bay are dominated by the seagrass *Thalassia testudinum*, followed by *Halodule wrightii*, and *Syringodium filiforme*. The distribution and abundance of seagrasses within the Bay is not uniform. Generally higher seagrass standing crop, higher seagrass short-shoot densities, and higher seagrass species diversity are found in western Florida Bay and channels throughout the Bay. Eastern Florida Bay has a relatively low standing crop of seagrasses (Thayer and Chester, 1989).

In the late 1980's environmental changes occurred in Florida Bay. Dense stands of *Thalassia* experienced major die-offs. Turbidity increased and subsequent algal blooms further reduced the penetration of light into the water column (Fourqurean and Robblee, 1999). This habitat change occurred rapidly, and may have been a consequence of long-term stressors, including chronic hyperhaline conditions, over development of seagrass beds, silting of the Bay due to lack of hurricanes and abnormally, warm summer and fall temperatures (Fourqurean and Robblee, 1999). For a detailed account of the changes in seagrass distribution and abundance prior to and after the die-off of seagrasses and a conceptual model of seagrass die-off in Florida Bay, see Hall et al. (1999), Thayer et al. (1999) and Zieman et al. (1999).

These environmental changes have resulted in modifications of aspects of the ecology of the Bay beyond seagrasses. Some resident populations of sponges, which provide nursery habitat for spiny lobster, have also experienced die-offs. Landings of pink shrimp which use seagrass beds in Florida Bay as a nursery area have also declined. Thus, modifications in the ecology of the Bay can have far reaching impacts on its fishery resources since various life history stages utilize the Bay as a nursery area or as a transient or a permanent residence. This compilation of life history information for invertebrates which we collected throughout the bay between 1984-2001 will provide future researchers and managers with information needed to evaluate changes in life history structures that may occur as a result of natural or anthropogenic environmental changes.

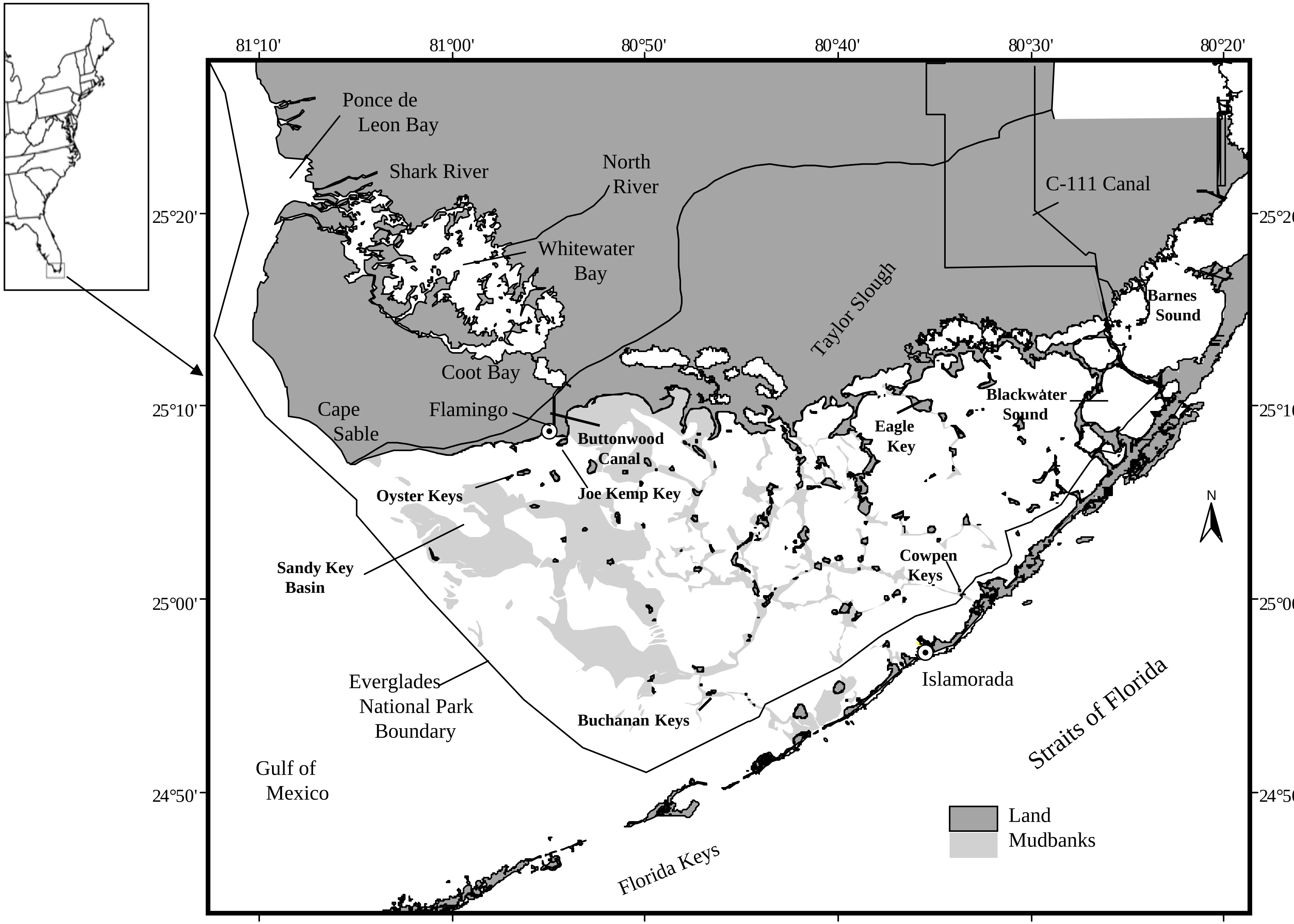

Figure 1. Florida Bay bordered by the Everglades National Park boundary and extending from Cape Sable to Barnes Sound.

A review of the life history of juvenile and small resident fishes in Florida Bay[1] contains a more comprehensive treatment of introductory material, sampling methods, abundance and distribution of seagrasses, and temperature and salinity data both spatially and temporally.

Methods

Field and laboratory methods

Sampling strategy. Two methods of stratifying Florida Bay were employed. For the first, sampling occurred in basins in three strata. During the period May 1984-June 1985 and July 1994-January 1999, sampling during each trip was conducted at 18 basin stations equally divided among three strata–East, Central, and West (Fig. 2). Sampling locations in the basin strata were determined using a grid system. Each grid cell was approximately 1800 m on a side. Six cells were randomly chosen for each basin strata and samples were taken at approximately the center of the cell where possible.

For the second method, we modified our sampling beginning in March 1999 to conform with the South Florida Ecosystem Restoration Prediction and Modeling (SFERPM), Program Management Committee's (PMC) subdivision designations. Florida Bay was stratified into six subdivisions (Fig. 2). Sampling locations in the basin strata were determined using a grid system. Each grid cell was 1800 m on a side. Because the number of trawlable squares in each subdivision were not equal, the number of stations to be sampled were weighted by trawlable area. Thirty-six stations were randomly chosen (Gulf: 4; Western: 3; Central: 10; Atlantic: 7; Northern: 3; Eastern: 9). Samples were taken at approximately the center of the cell where possible. Because of the change in the stratified design in 1999, caution should be used when comparisons are made between May 1984-January 1999 and March 1999- January 2001 as more extensive sampling from 1999 through 2001 may result in biased comparisons.

Collection methods: 1984-2001. Collections were made with an otter trawl in basins on a bi-monthly basis (January, March, May, July, September, and November). From the initial sampling trip in May 1984 through January 1999, a two-boat (5 m long), otter trawl was employed. In March 1999, the two boats were replaced with one 5.5 m boat for safety reasons. This required re-calibrating the opening of the mouth of the otter-trawl to calculate area sampled. The otter trawl had a 3.4 m head rope, 3.8 m foot rope equipped with a 3 mm galvanized tickler chain, 6 mm mesh in the body, and a 3 mm tailbag.

The otter trawl was towed at a speed of approximately 2.0 m^{-sec} for 2 min, unless the net was clogged with detritus. A floating marker was deployed at the beginning and end of each tow and the distance between buoys was measured with an optical range finder. The area covered by each trawl transect was calculated knowing the distance towed and the mouth opening of the net. Densities (numbers 1000 m^{-2}) were used as an index of abundance.

Collections were also made in channels with an otter trawl, but these data are not presented here as sampling occurred only through 1996. However, data from channels were used for length-frequency distributions. Temperature, salinity and seagrass data are reported

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[1] Powell, A. B., G. W. Thayer, M. Lacroix, and R. Cheshire. in press. Juvenile and small resident fishes of Florida Bay, a critical habitat in the Everglades National Park, Florida. NOAA Professional Paper NMFS.

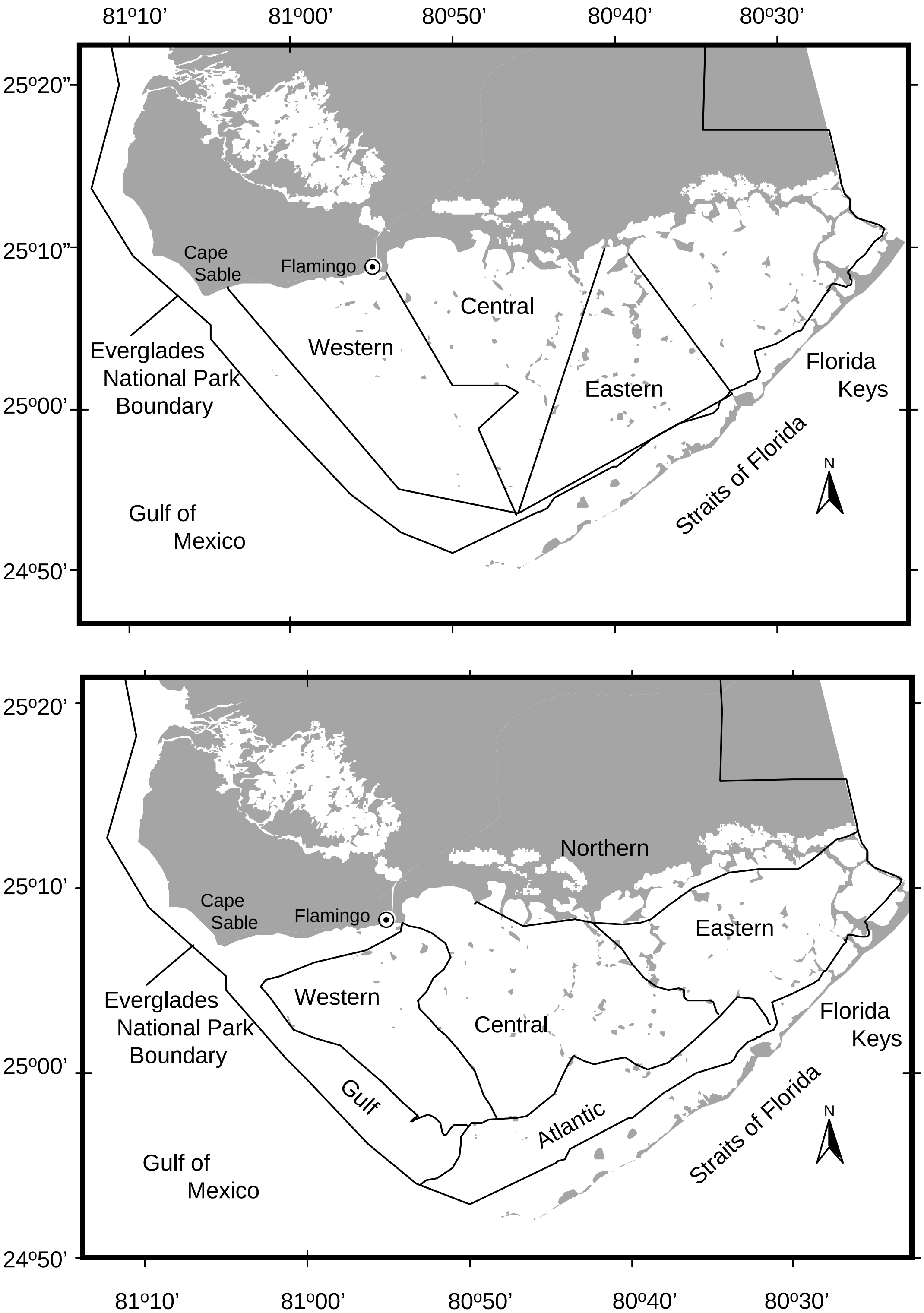


Figure 2. Location of strata (top) and subdivisions (bottom).

elsewhere[1].

Processing of specimens. Selected invertebrates were preserved in 10% formalin, transferred to 95% ethyl alcohol, identified to species in the laboratory and then weighed. Measurements for invertebrates were as follows: bay scallops (*Argopectin*) in TL; shrimp (*Penaeus*) in TL including rostrum; spiny lobster (*Panulirus*) in TL, with conversions from carapace length (CL) made according to Matthews et al., (2003); portunid crabs (*Callinectes*) in carapace width (CW) including spines.

Data analysis and presentation A non-parametric Kruskal-Wallis test (Sokal and Rohlf, 1981) with $\propto = 0.05$ was used to test differences in mean densities (numbers 1000 m^{-2}) of a given species among years, months, stratum, and subdivision for otter-trawl, bi-monthly, basin collections (1984-2001; see Table 1 for the designation of sampling periods). Levels of species abundance were arbitrarily assigned to the following categories: very abundant, ≥ 10,000 total collected; abundant, < 10,000 and ≥ 1,000; common, < 1,000 and ≥ 100; uncommon, < 100.

Species data are presented in four sections. The sections on *Life History*, and *Diet* were derived from the literature. The section on *Abundance and Distribution* consists of data from bi-monthly otter-trawl collections (1984-2001). In addition, comparisons with other studies are included here typically following our results. The section on *Length-frequency Distributions* consists of length measurements from all collections, except 1984-1985 when no measurements were taken. Length-frequency distributions were used, when possible, to estimate life stage captured, spawning times, recruitment into Florida Bay for those species which spawn outside the Bay, and growth. Additional material from the literature was added when appropriate.

The graphic presentation of data was dependent on raw numbers of invertebrates collected. We included GIS generated two-panel (< 100 total invertebrates; e.g., Fig. 9) or six-panel figures (≥ 100 total invertebrates; e.g., Fig. 3) depicting their distribution. Also included for these species were figures (bar graphs) depicting the mean densities (numbers 1000 m^{-2}) by year, month, and strata/subdivision (e.g., Fig. 4).

Results and Discussion

Argopecten irradians (bay scallop)

Life history. Bay scallop range along the Atlantic from Cape Cod, around the tip of Florida, into the Gulf of Mexico. Based on commercial landings, they are most abundant in the coastal areas of Massachusetts, Rhode Island, New York, North Carolina, and the Gulf coast of Florida (Patillo et al., 1997). In Florida, spawning occurs form August to October as summer water temperatures decline. Eggs are demersal, larvae are pelagic and planktonic. Juveniles (< 20-30 mm TL) attach to surfaces suspended off the bottom. They use a variety of substrates for attachment, but beds of segrasses have been reported to be the preferred settlement substrate. Maturity is reached by the end of the first year and is a function of age not length. Bay scallop generally spawn only once during their lifetime, when they reach the end of their first year. Adults range from 60-70 mm TL.

Diet. Bay scallops are filter feeders at all life history stages and feed primarily on phytoplankton although they also consume zooplankton, suspended benthic particles, bacteria, and detritus (Patillo et al., 1997).

Abundance, and distribution. Bay scallop were common (n = 383) in otter-trawl collections in basins (Figs. 3 and 4). Temporally, there were differences in mean densities among years and months. Differences among years 1994-1998 and 1999-2001 could be partially attributed to the change in sampling design (Fig. 3), but there was a constant increase in mean densities from 1994 through 1998. Comparisons between pre- and post-seagrass die off (1984-1985 vs. 1994-1995) were not possible as no data were collected for this species in 1984-1985. Bay scallop were collected at greatest densities in July (Fig. 4), but were collected at a greater percentage of stations in March. Spatially, there were no differences in mean densities among strata, but there was among subdivisions, the latter possibly a result of our extensive sampling that included eastern Florida Bay (Fig. 3). This species had a patchy distribution in that highest densities occurred in the Western and Eastern subdivision, and was generally absent from north central Florida Bay (Fig. 4) where hyperhaline conditions are common (Orlando et al., 1997). Channels in Florida Bay do not appear to be essential habitat for bay scallop, as it was rarely collected there (personal observation).

Populations in Florida Bay might be at their physiological limits, and could be subjected to highly variable recruitment and survival. Barber and Blake (1983) reported that the bay scallop in west central Florida was operating at its energetic limit. Increased metabolic rate as a result of increased temperatures, coupled with limited food availability, could limit the southern range of population viability.

Length-frequency distributions. Spawning appeared to occur in Florida Bay at least during winter, spring, and summer (Fig. 5). We collected relatively few "market size" (50 mm TL) scallops and adults (60-70 mm TL). Based on March through June data, growth was grossly estimated at 10 mm in TL per month, which is greater than previously reported (3.8-8.0 mm in TL; Patillo et al., 1997). If our estimate is credible, then the bay scallop in Florida bay could attain sexual maturity within approximately 6-7 months.

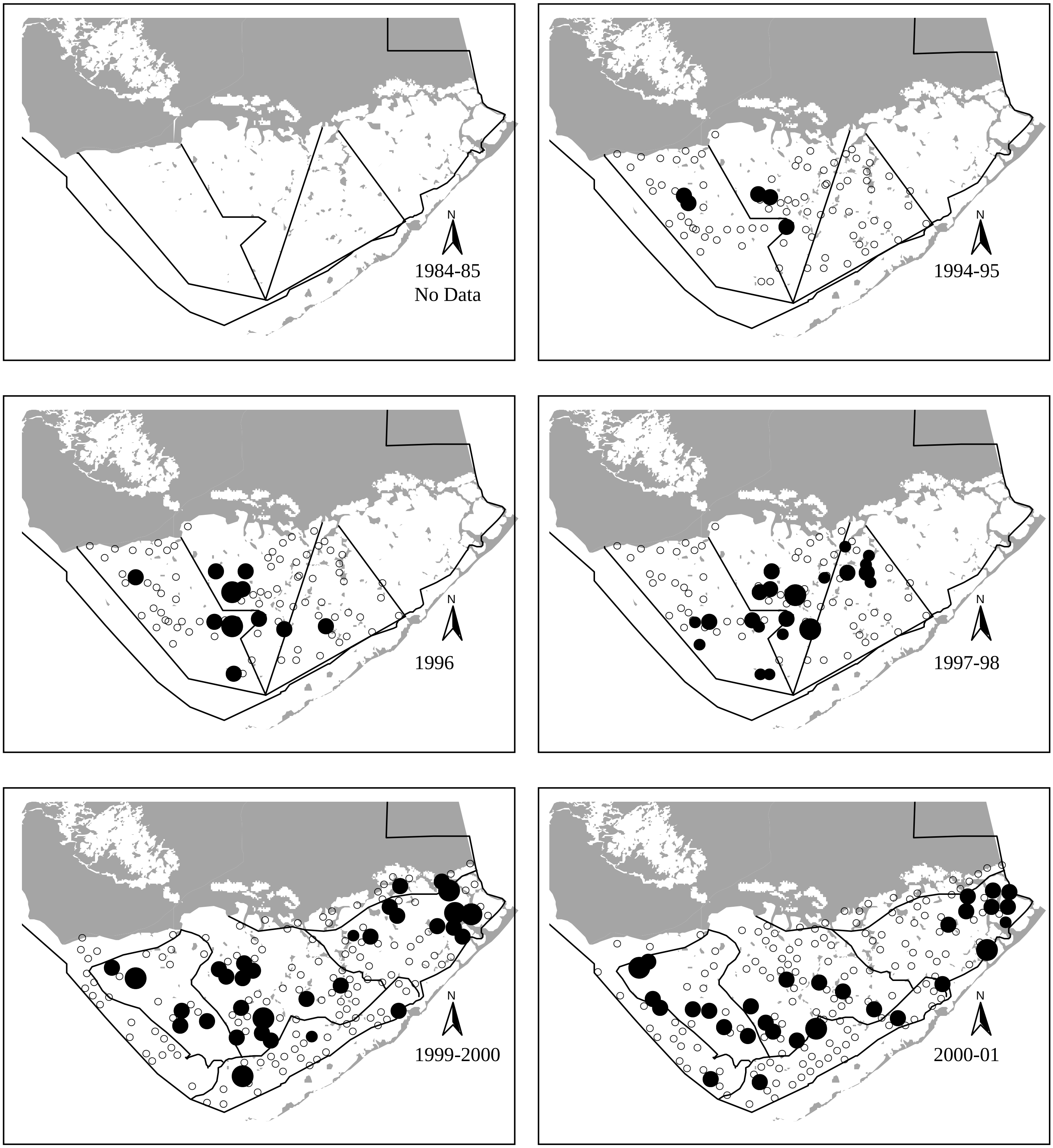
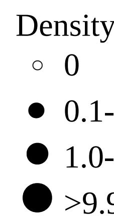


Figure 3. Mean densities (numbers 1000 m^{-2}) of bay scallop, *Argopectin irradians*, from bi-monthly, otter-trawl collections in Florida Bay basins. Florida Bay is divided into three strata from 1984-1998 and six subdivisions from 1999-2001. For designation of strata and subdivisions see Fig. 2.



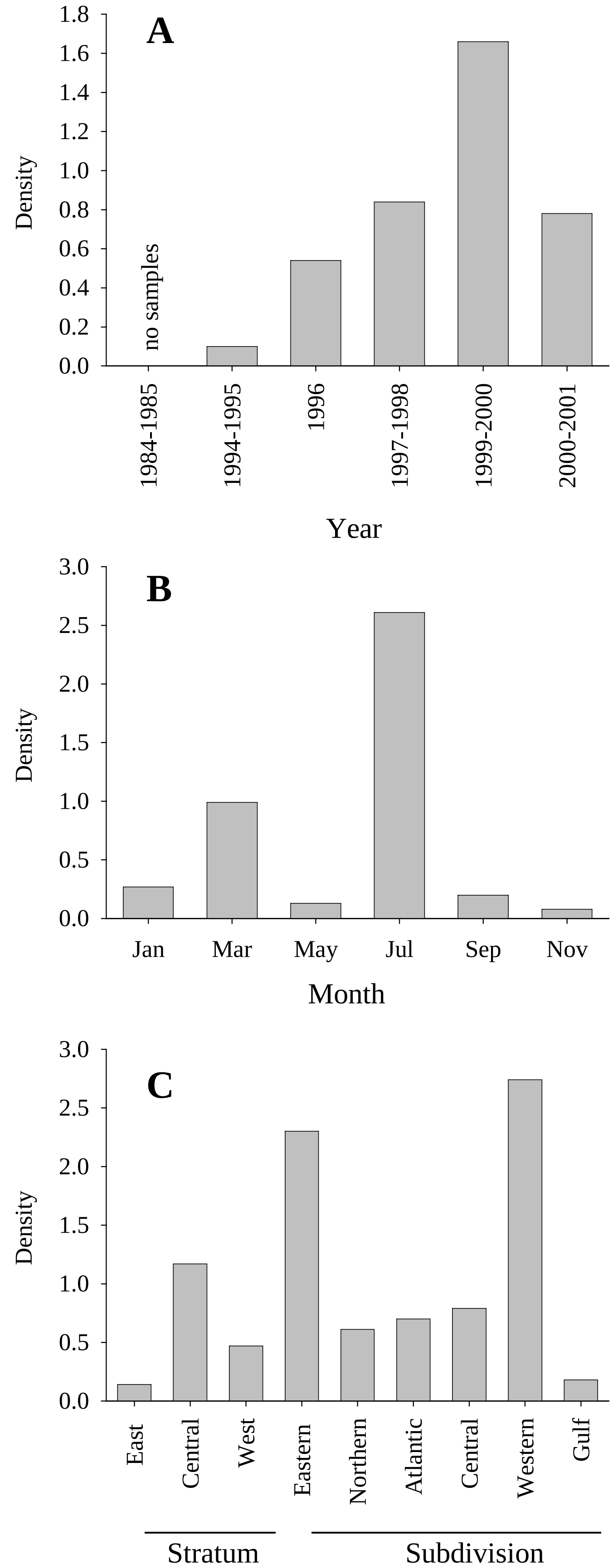


Figure 4. Mean densities (numbers 1000 m^2) of bay scallop, *Argopectin irradians* from bi-monthly, otter-trawl collections in Florida Bay basins by (A) year, (B) month, and (C) stratum/subdivision. Florida Bay is divided into three strata from 1984-1989, and six subdivisions from 1999-2001. For designations of strata and subdivisions see Fig. 2.

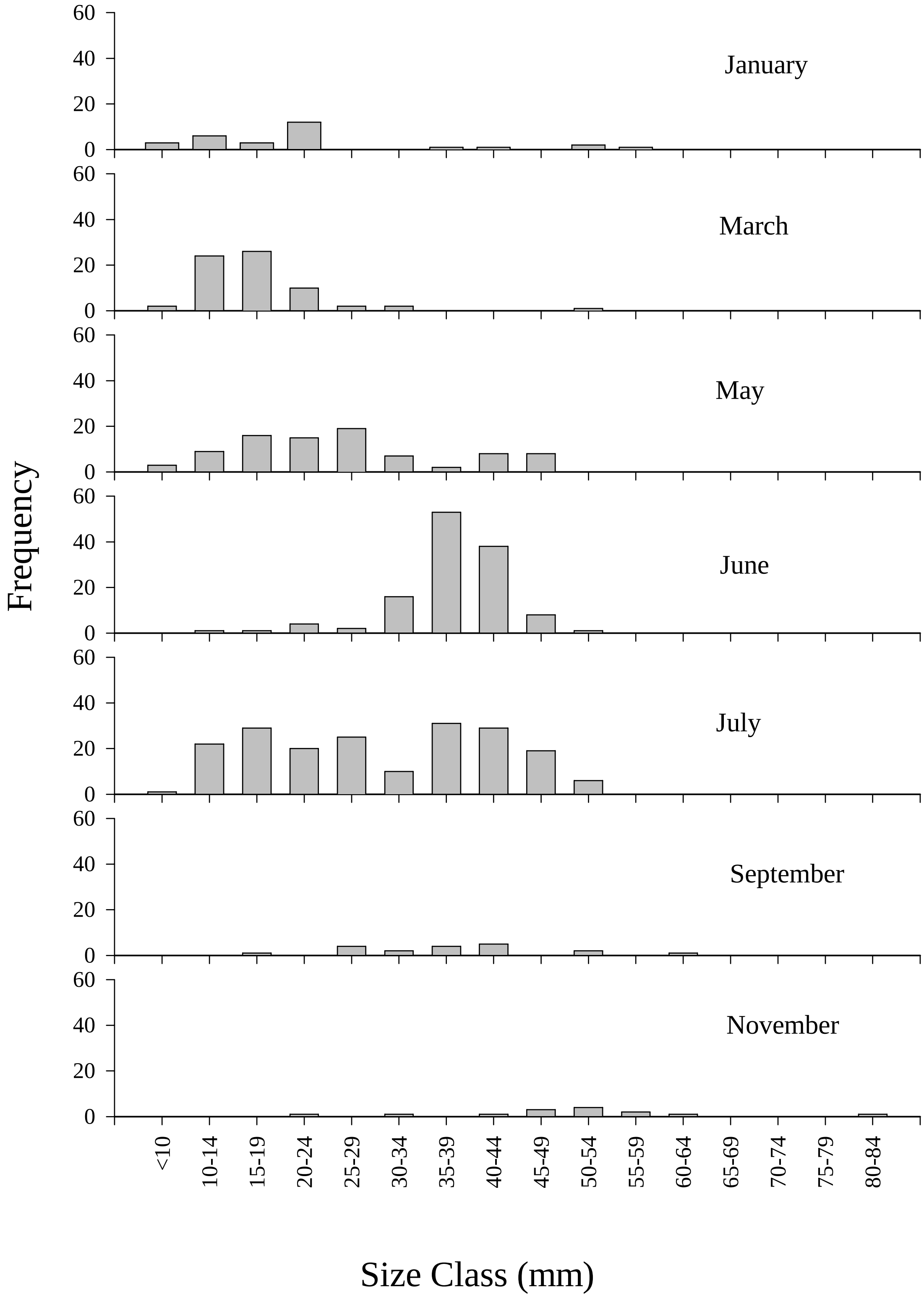


Figure 5. Monthly length-frequency distributions of bay scallop, *Argopectin irradians*.

Farfantepenaeus duorarum (pink shrimp)

Life history. Pink shrimp range from lower Chesapeake Bay around the tip of Florida and in the Gulf of Mexico to the tip of the Yucatan Peninsula. Major centers of abundance are southwestern to northwestern Florida and the southeastern Bay of Campeche. A minor center of abundance is in the Beaufort area of North Carolina (Williams, 1984). Pink shrimp spawn offshore throughout the year in the northern grounds of the Dry Tortugas, about 150 km west of Florida Bay, the latter is the main nursery area for this species. Although spawning occurs throughout the year, the highest frequency of ripe females occurs from April through July. Eggs are demersal, larvae planktonic to the postlarval stage. Postlarvae and juveniles are demersal in estuarine nursery grounds. Females attain sexual maturity at 85 mm TL; males at 74 mm TL (Bielsa et al., 1983; Patillo et al., 1997; Criales et al., 2003).

Diet. Pink shrimp have been classified as opportunistic omnivores (Odum and Heald, 1972). In Florida Keys seagrass beds, juvenile pink shrimp feed mainly on the seagrass shrimp, *Thor floridanus*, the most common decapod in Florida Bay (Holmquist, 1989a; 1989b; Sheridan et al., 1997; Matheson et al., 1999), but also consume bivalves, calcareous algae, detritus, copepods, and seagrass fragments (Schwamborn and Criales, 2000). In the Whitewater Bay-Shark River estuary, the diet of pink shrimp varies with locality and season that is related to food availability and habitat structure, and during ontogeny that is related to the increasing size of chelae and mouthparts. Spatial variation in prey has been linked to spatial differences in macrobenthic flora and fauna (Schmidt, 1993). A major difference between the diets of pink shrimp in Schmidt's study compared to other studies was the importance of ophiuroid brittlestars, especially to larger shrimp.

Abundance and distribution. Pink shrimp were abundant (n = 8544) in otter-trawl collections in basins (Figs. 6 and 7), despite the fact this species is nocturnally active (Patillo et al., 1997). Temporally, there were differences in mean densities among years and months. On an annual basis, pink shrimp densities oscillated. Highest densities were observed in 1994-1995 following the die-off of seagrasses (Figs. 6 and 7), and a period when its favored food item (seagrass shrimp) had markedly declined (Matheson et al., 1999). Lowest densities of pink shrimp were observed in May; highest in the fall (Fig. 7). Spatially, differences in mean densities were observed among stratum and subdivision. Pink shrimp were most abundant in western and north central Florida Bay (Figs. 6 and 7). The north-central portion of the Bay, which was most affected by seagrass die-off (Robblee et al., 1991), was inadequately sampled during the period 1984-1998, but recent sampling indicated relatively high densities of pink shrimp in this area (Fig. 6). However, this could be related to an overall decline in salinity in this area (Boyer et al., 1999).

Contrary to our findings, similar densities of this species were reported for Florida Bay mudbanks between 1984-1986 and 1994-1996 (Matheson et al., 1999). In concordance with our findings, juveniles of this species also have been reported by others to be most abundant in Florida Bay between September and December, then with decreasing water temperatures they move from Florida Bay to the Dry Tortugas fishing grounds (Patillo et al., 1997).

Temporal variation in recruitment to the fishery appears to be a result of numerous factors that modulate a nearly constant supply of eggs from the Tortugas. Ehrhardt and Legault (1999) examined commercial landings in the Dry Tortugas to estimate recruitment to the fishing grounds relative to environmental conditions in Florida Bay. They concluded that although recruitment could be a function of parent stock size, environmental variables related to habitat in Florida Bay and movement of juveniles from the Bay to the Dry Tortugas, as well as transport of eggs and larvae from their spawning grounds to their nursery area, influence recruitment into the Dry Tortugas fishery. Rainfall and water discharge appeared to influence juvenile pink shrimp abundance. Pink shrimp recruitment to the fishery was reduced from 1982-1993, a period correlated with a general drought, lower turbulence and a general warming of the environment. For the latest years of their study (1994-1995), recruitment increased, which could indicate favorable conditions for pink shrimp in Florida Bay during that period. Their findings are in concordance with ours. Browder et al. (1999), using a modeling approach, found a strong relationship with sea-surface temperature, and to a lesser extent rainfall, water level and wind speed, and juvenile densities in Florida Bay to abundances at the Dry Tortugas. The importance of egg and larval transport from the Dry Tortugas into Florida Bay was documented by Criales et al. (2003). Based on these studies, it is obvious that multiple factors contribute to the abundance of juvenile shrimp in Florida Bay and, eventually, recruitment of pink shrimp to the fishery.

Length-frequency distributions. Pink shrimp appeared to recruit into Florida Bay during spring and fall (Fig. 8). Criales et al. (2003) reported that pink shrimp enter Florida Bay mainly during spring and summer following an April through July spawning peak in the Dry Tortugas. They reported the size at entry to approximate 9-10 mm TL or 20-d old. Because our gear was not efficient in collecting new recruits due to extrusion, our length-frequency distributions do not adequately depict the relative magnitude of those recent recruits. In the Whitewater Bay-Shark River estuary, Schmidt (1993) observed bi-modal recruitment (June-July, and October) that corresponded to bimodal catches of pink shrimp from the Tortugas fishery. We encountered very few sexually mature pink shrimp (75-84 mm TL), and it appeared they emigrated out of the Bay throughout the sampling period. Growth of pink shrimp is complex and is a function of temperature and size (Browder et al., 1999) and is, therefore, difficult to extract growth from length-frequency distributions; especially when larger, older shrimp are constantly emigrating.

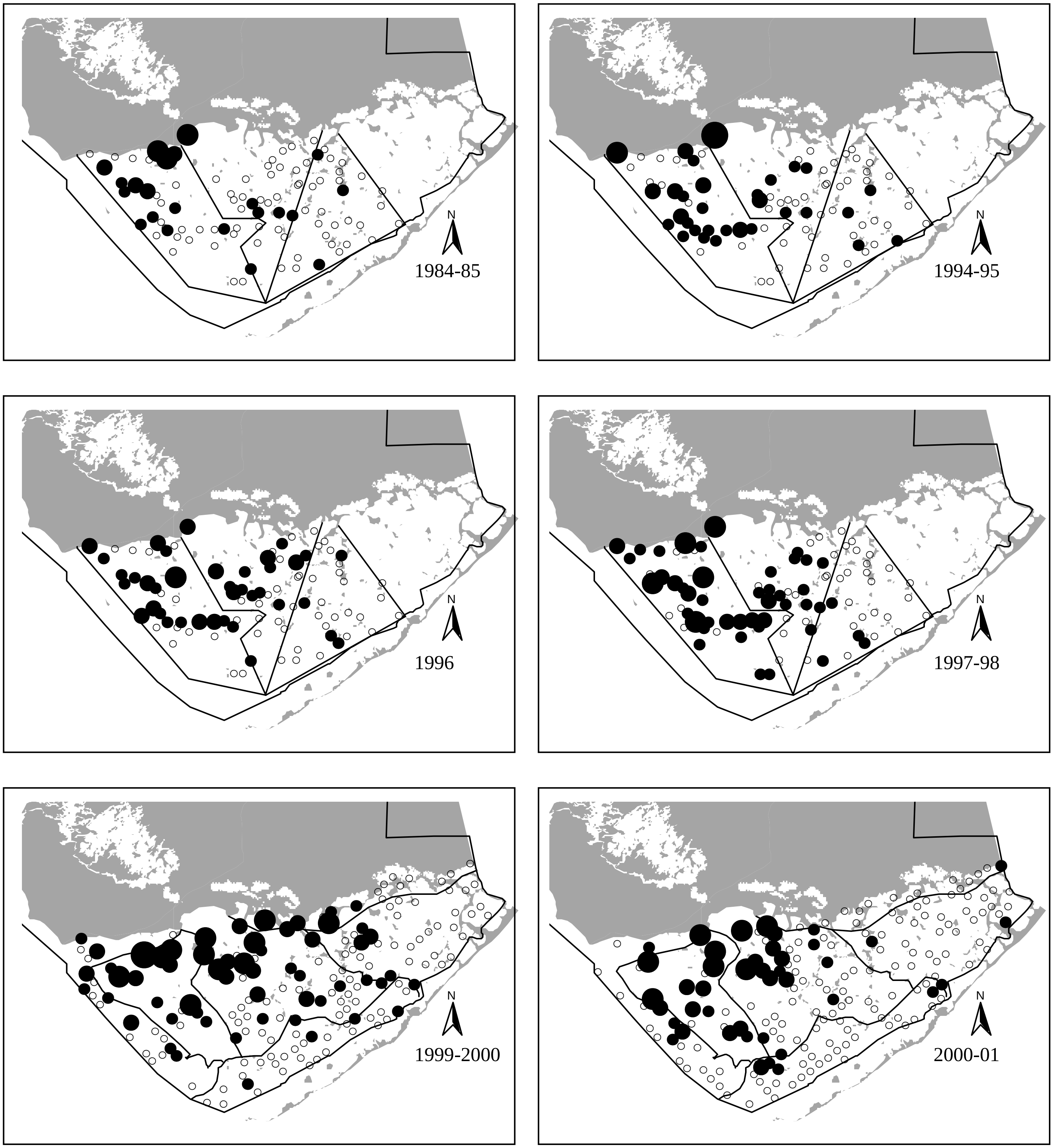


Figure 6. Mean densities (numbers 1000 m^{-2}) of pink shrimp, *Farfantepenaeus duorarum*, from bi-monthly, otter-trawl collections in Florida Bay basins. Florida Bay is divided into three strata from 1984-1998 and six subdivisions from 1999-2001. For designation of strata and subdivisions see Fig. 2.

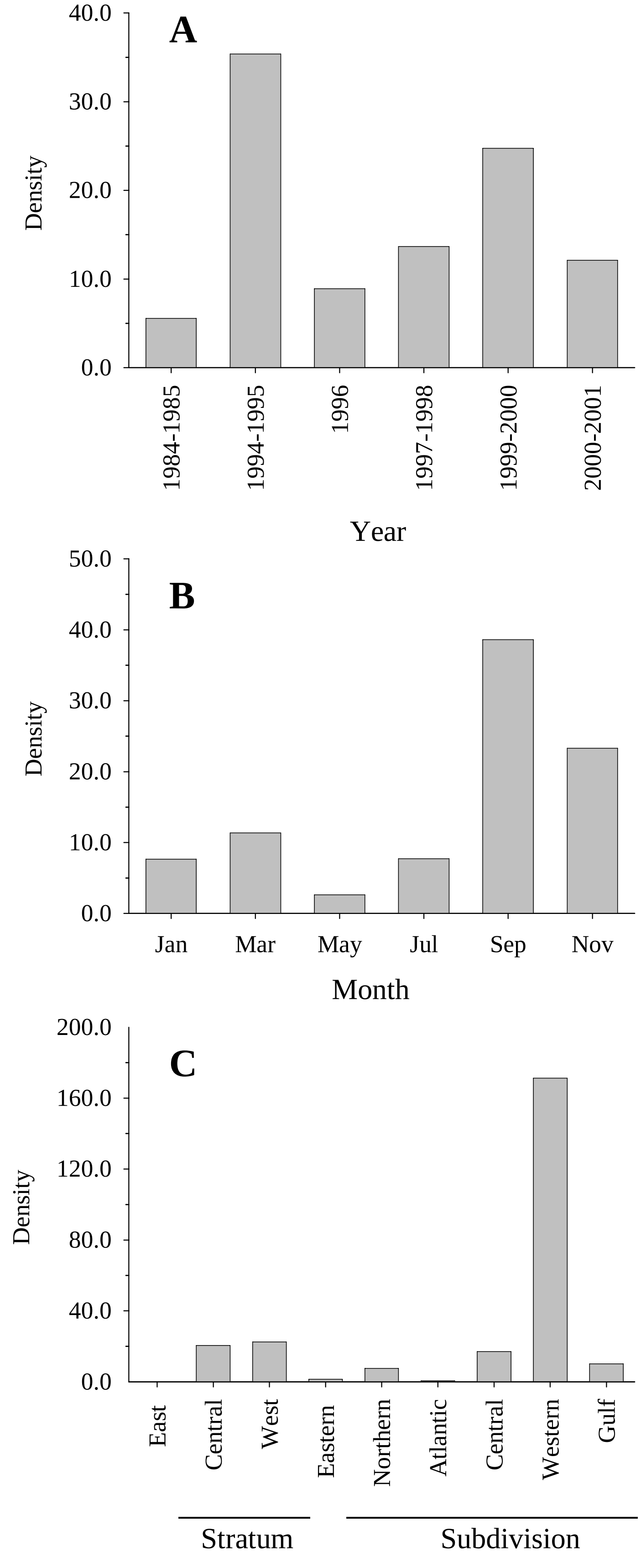


Figure 7. Mean densities (numbers per 1000 m^2) of pink shrimp, *Farfantepenaeus duorarum*, from bi-monthly, otter-trawl collections in Florida Bay basins by (A) year, (B) month, and (C) stratum/subdivision. Florida Bay is divided into three strata from 1984-1998 and six subdivisions from 1999-2001. For designations of strata and subdivisions see Fig. 2.

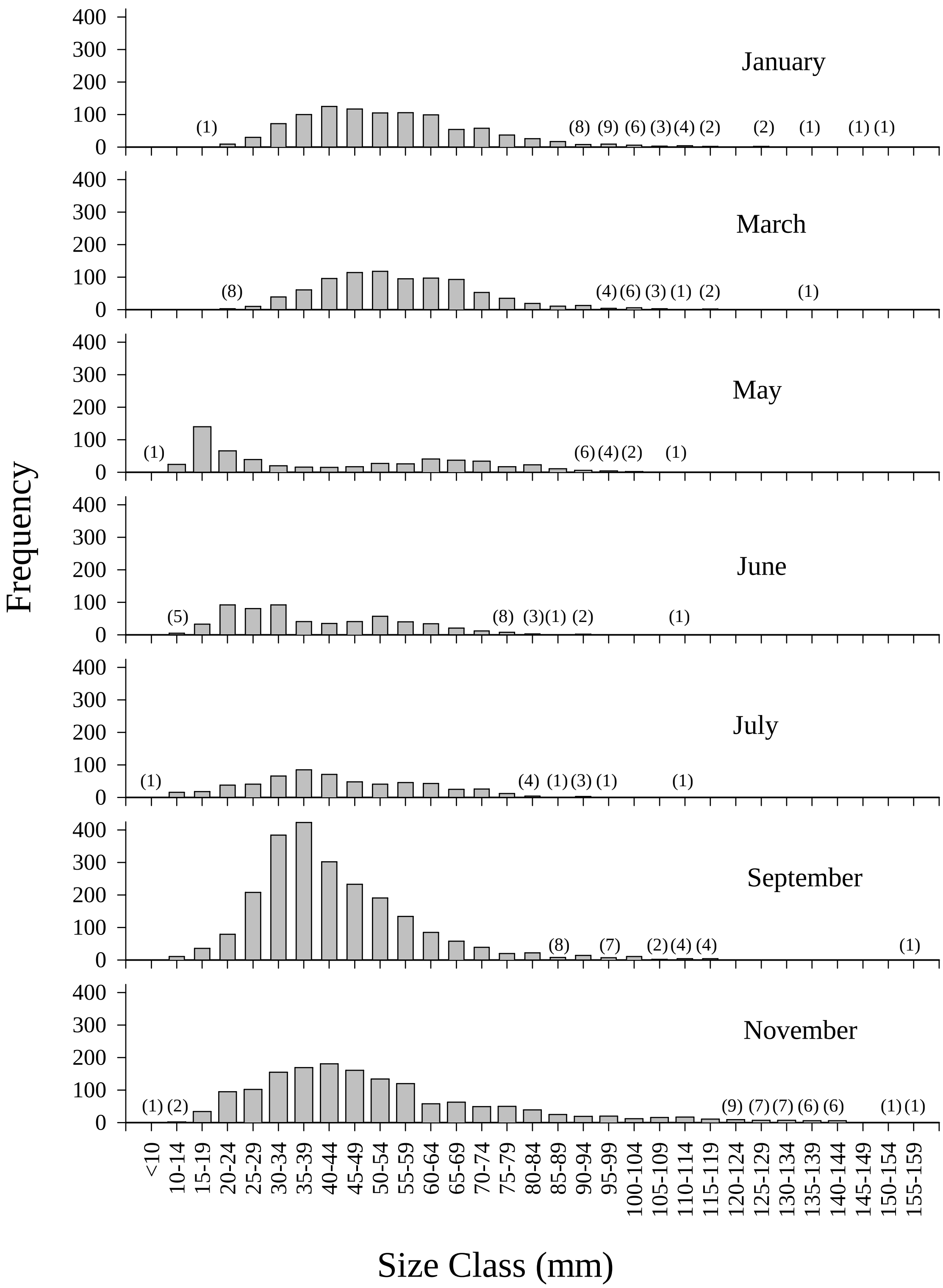


Figure 8. Monthly length-frequency distributions of pink shrimp, *Farfantepenaeus duorarum*. Values are shown for numbers < 10 for clarity.

Panulirus argus **(Caribbean spiny lobster)**

Life history. Spiny lobster range from North Carolina throughout the Gulf of Mexico and West Indies to Brazil and Bermuda. Largest concentrations occur in southern Florida, the Caribbean and West Indies southeast to Brazil and Bermuda (Williams, 1984). In Florida, spiny lobster spawn during late spring and summer in offshore waters along deep reef fringes. Larvae are planktonic and settlement is rapid when they encounter suitable inshore habitat. Local recruitment into Florida Bay does not seem possible because of the long larval duration (6-12 months) and dispersive offshore currents. This implies that Florida Bay recruits come from upstream sources in the Caribbean (Yeung and Lee, 2002). At approximately 50-80 mm CL (147-227 mm TL), sub-adult lobsters emigrate to coral reefs or other offshore habitats where they become sexually mature. Maturity occurs when females attain a length of approximately 200 mm TL (Williams, 1984; Marx and Herrnkind, 1986; Childress and Herrnkind, 1994).

Diet. Spiny lobster are nocturnal feeders that prey on a variety of slow-moving or sedentary animals including gastropods, bivalve mollusks, crustaceans and echinoderms (Marx and Herrnkind, 1986).

Abundance and distribution. Spiny lobster were uncommon (n = 24) in otter-trawl collections in basins (Figs. 9 and 10), but were common (n = 100) in otter-trawl channel collections (A. Powell, personal observations). Too few individuals were collected in basins to determine if there were spatial and temporal differences in distribution, but they were only collected in the western and southern half of Florida Bay. Juveniles have been taken year round in a targeted spiny lobster nursery area in Florida Bay (Forcucci et al., 1994), but their juvenile habitat was not targeted by us.

Spiny lobster had a contracted distribution that was centered in the south central part of the Bay (Fig. 9). Recently settled juveniles, < 15-20 mm CL (53-67 mm TL), apparently are restricted to complex substrate, especially hard bottom covered by the red macroalgae, *Laurencia* spp.,while post-algae juveniles, 15-20 to 70-80 mm CL (53-67 to 200-227 mm TL) require crevices under sponges, octocorals and other structures. Hence, fluctuating abundances of macroalgae, along with the availability of shelter for post-algae stage spiny lobster, limits their distribution, and creates bottlenecks that limit recruitment to subsequent life history stages (Marx and Herrnkind, 1986; Childress and Herrnkind, 1994; Forcucci et al., 1994).

Length-frequency distributions. Length-frequency distributions were based mainly on lobsters we collected from channels; hence, the distributions of recently settled juveniles (< 50-59 mm TL) that require macroalgae and hard bottom (algal phase) are lacking and do not depict a valid recruitment pattern as we did not target their specific habitat (Fig. 11). The majority of lobster we collected were post-algal stage juveniles (50-220 mm TL) including nomadic juveniles (ca. >133 mm TL). Growth of spiny lobster could not be estimated from our distributions, but growth is relatively rapid in Florida Bay ($\bar{x}$ = 15.8 mm in TL week $^{-1}$) and is a function of size and season (Forcucci et al., 1994).

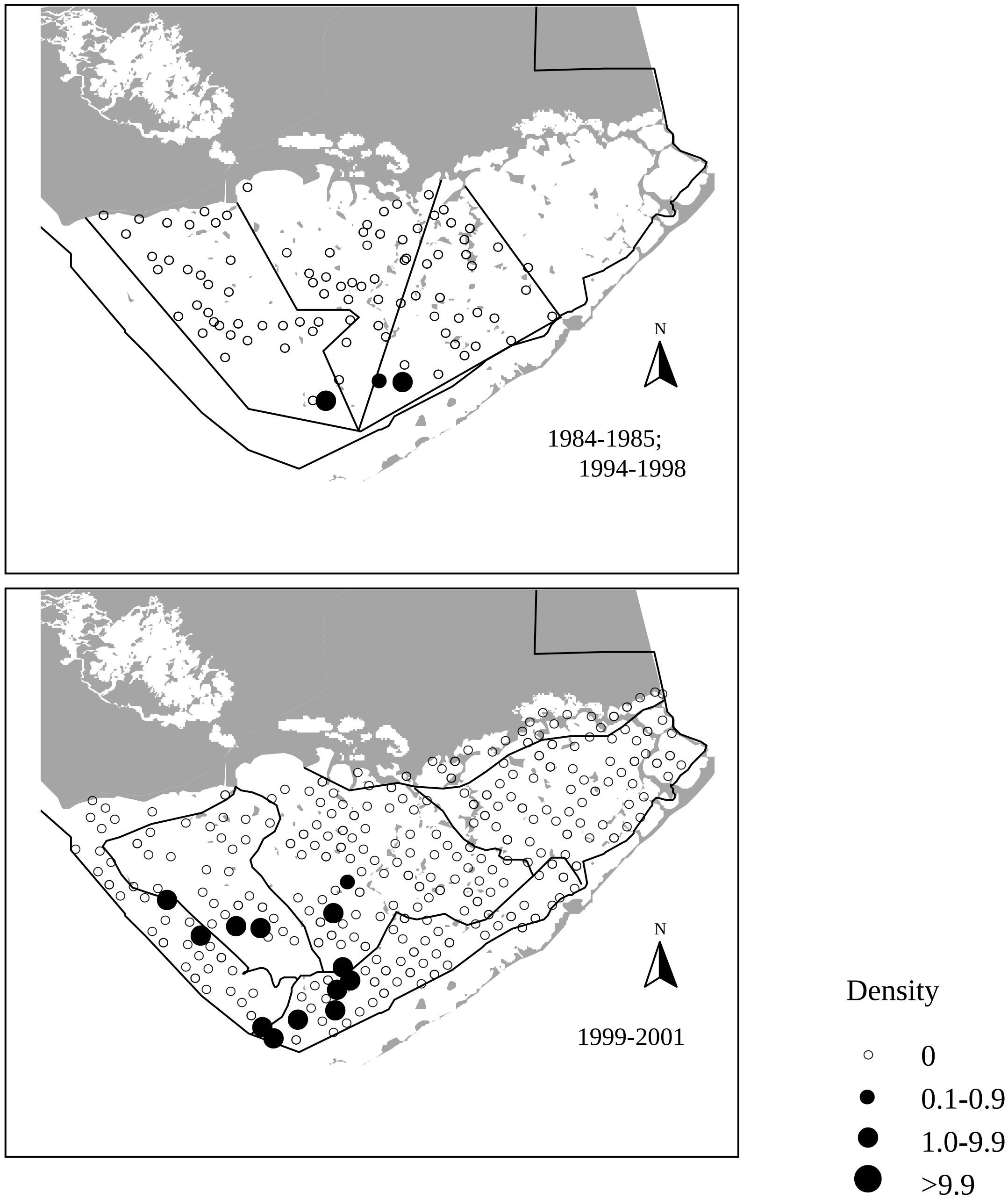


Figure 9. Mean densities (numbers 1000 m^{-2}) of spiny lobster, *Panulirus argus*, from bi-monthly, otter-trawl collections in Florida Bay basin. s Florida Bay is divided into three strata from 1984-1998 and six subdivisions from 1999-2001. For designation of strata and subdivisions see Fig. 2.

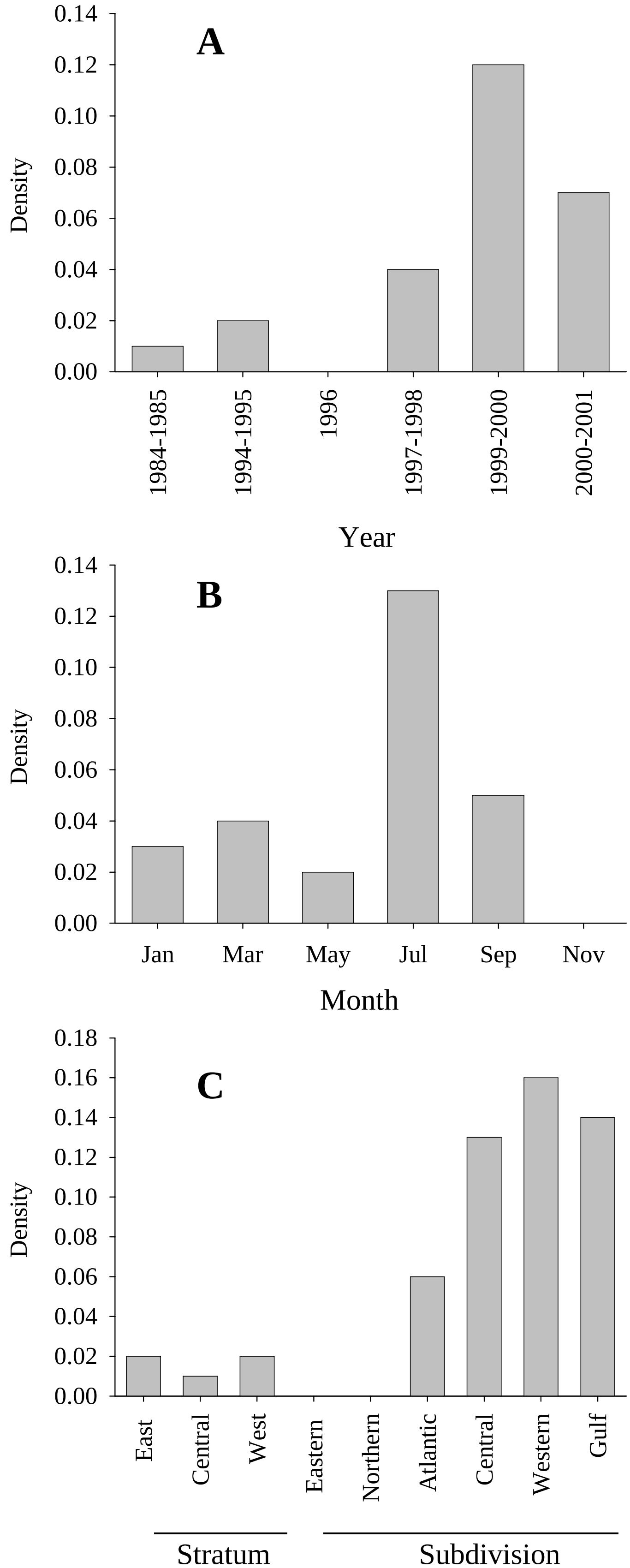


Figure 10. Mean densities (number per 1000 m^2) of spiny lobster, *Panulirus argus*, from bi-monthly, otter-trawl collections in Florida Bay basins by (A) year, (B) month, and (C) stratum/subdivision. Florida Bay is divided into three strata from 1984-1998 and six subdivisions from 1999-2001. For designations of strata and subdivisions see Fig. 2.

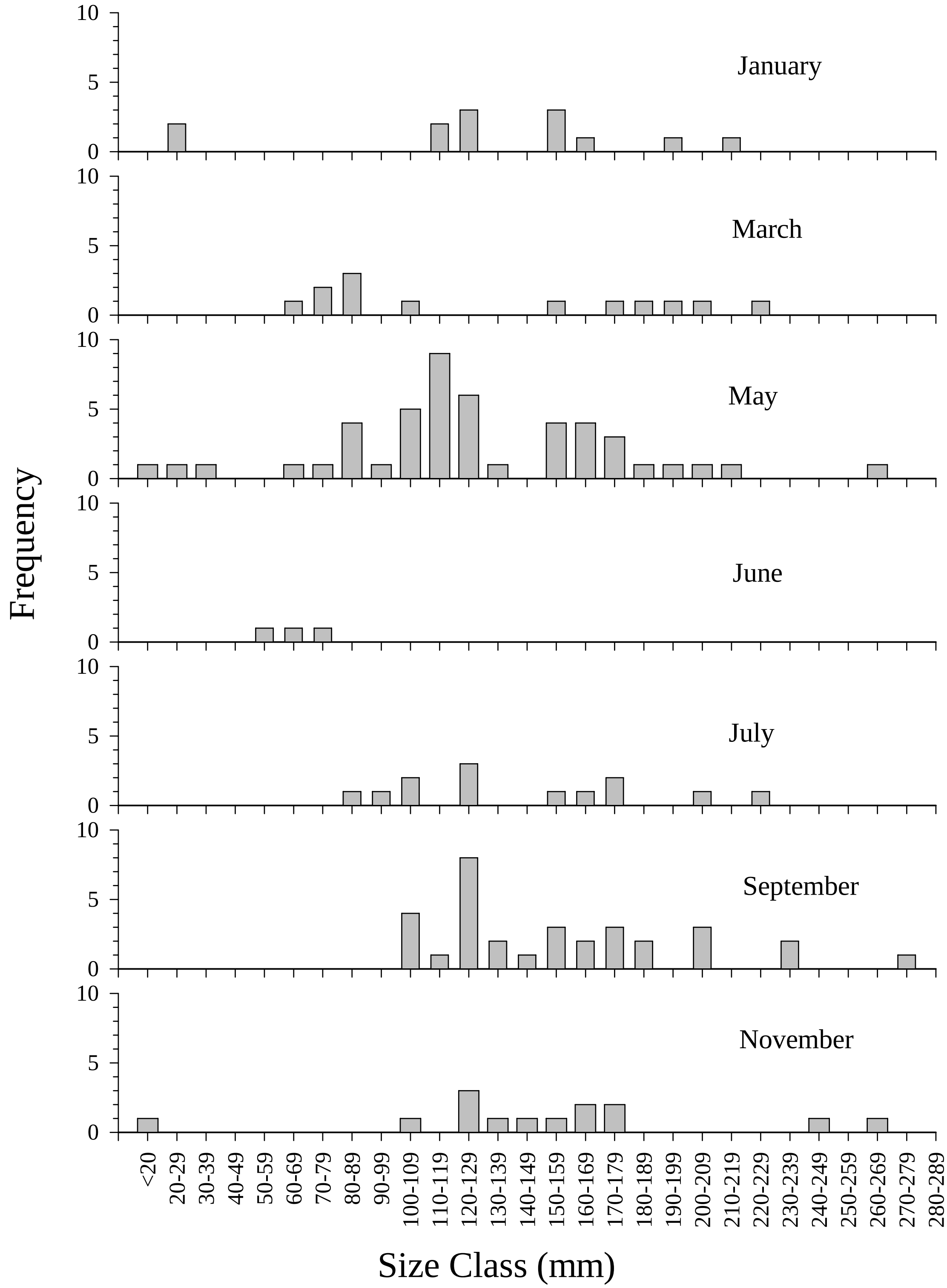


Figure 11. Monthly length-frequency distributions of spiny lobster, *Panulirus argus*.

Callinectes ornatus (ornate crab)

Life history. Ornate crab are tropical and range from Virginia to south Florida and northwest Yucatan to Brazil and also Bermuda. They are generally found on sandy or muddy bottom, and young are also found on shell and sponge bottoms (Williams, 1984). Ornate crabs have a protracted spawning season, and most likely they spawn throughout the year in Florida Bay (Williams, 1984). Spawning also occurs throughout the year in Brazil with peaks in summer and autumn (Mantelatto and Fransozo, 1999). Spawning habits are not well known for this species, but we believe they are similar to the blue crab (see below). Both males and females mature at approximately 95 mm CW (Haefner, 1990).

Diet. Ornate crabs are opportunistic feeders with a general preference for mollusks and crustaceans, but dietary composition is linked to prey availability and life history stage (Mantelatto and Christofoletti, 2001). In a small tropical lagoon, the diet of ornate crabs was clustered into three size groups (21-30, 31-80 and 81-100 mm CW). Of the dietary items, shrimp and detritus decrease in importance with crab size. Bivalves and gastropods were absent in the smallest size group and increase in importance with crab size. In the intermediate size group, there was a lower proportion of amphipods compared to the smallest sizes and a larger proportion of fish and crabs compared to the largest sizes (Stoner and Buchanan, 1990). In Brazil, juvenile ornate crabs fed on more sedentary and calcareous items (foraminiferans, annelids, bryozoans, echinoderms and sediment) than did adults, with the latter consuming more plants, crustaceans, and fish (Mantelatto and Christofoletti, 2001).

Abundance and distribution. Ornate crabs were common (n = 116) in otter-trawl samples in basins (Figs. 12 and 13). Temporally, mean densities differed among months and years. Highest densities were observed in 1984-1985 and 1996, with a downward trend from 1996 to 2000-2001, and highest densities occurred in spring, lowest in winter (Fig. 13). Spatially, we observed differences in densities among strata, but not subdivisions, which is difficult to explain. Speculatively, and assuming that crab megalopae enter Florida Bay from Gulf of Mexico and Straits of Florida waters, it appeared that the distributional patterns could be related to differential recruitment from these areas. For example, in 1984-1985, recruitment appeared to be mainly from Atlantic waters; in 1994-1995 from Gulf of Mexico waters (Fig. 12).

Contrary to our findings, Holmquist et al. (1989b) found ornate crab populations maintain substantial numbers throughout winter in Florida Bay. On Florida Bay mud banks, Holmquist et al. (1989a; 1989b) collected this species almost entirely at sites adjacent to the Florida Keys, and rarely at a site adjacent to the Gulf of Mexico. In a tropical lagoon, the ornate crab, relative to other portunids was most abundant near inlets and less abundant at stations farthest from inlets (Buchanan and Stoner, 1988). In their study, there were no differences in salinity or temperature within the study area, but sediments differed slightly. Based on the findings of Stoner (1980), Holmquist et al. (1989a; 1989b), and, to a lesser extent, this study, it appears that ornate crabs enter estuaries and settle out fairly rapidly if suitable habitat is available.

Length-frequency distributions. Although it has been reported that this species probably spawns throughout the year (Williams, 1984), we did not collect small crabs (< 20 mm CW) in March, May, or July (Fig.14). The majority of crabs we collected were sexually mature (ca. > 45 mm CW) , and the widest range of size classes occurred in fall. The largest were within the range of maximum sizes (males, 130 mm CW; females 107 mm CW) reported by Williams (1984).

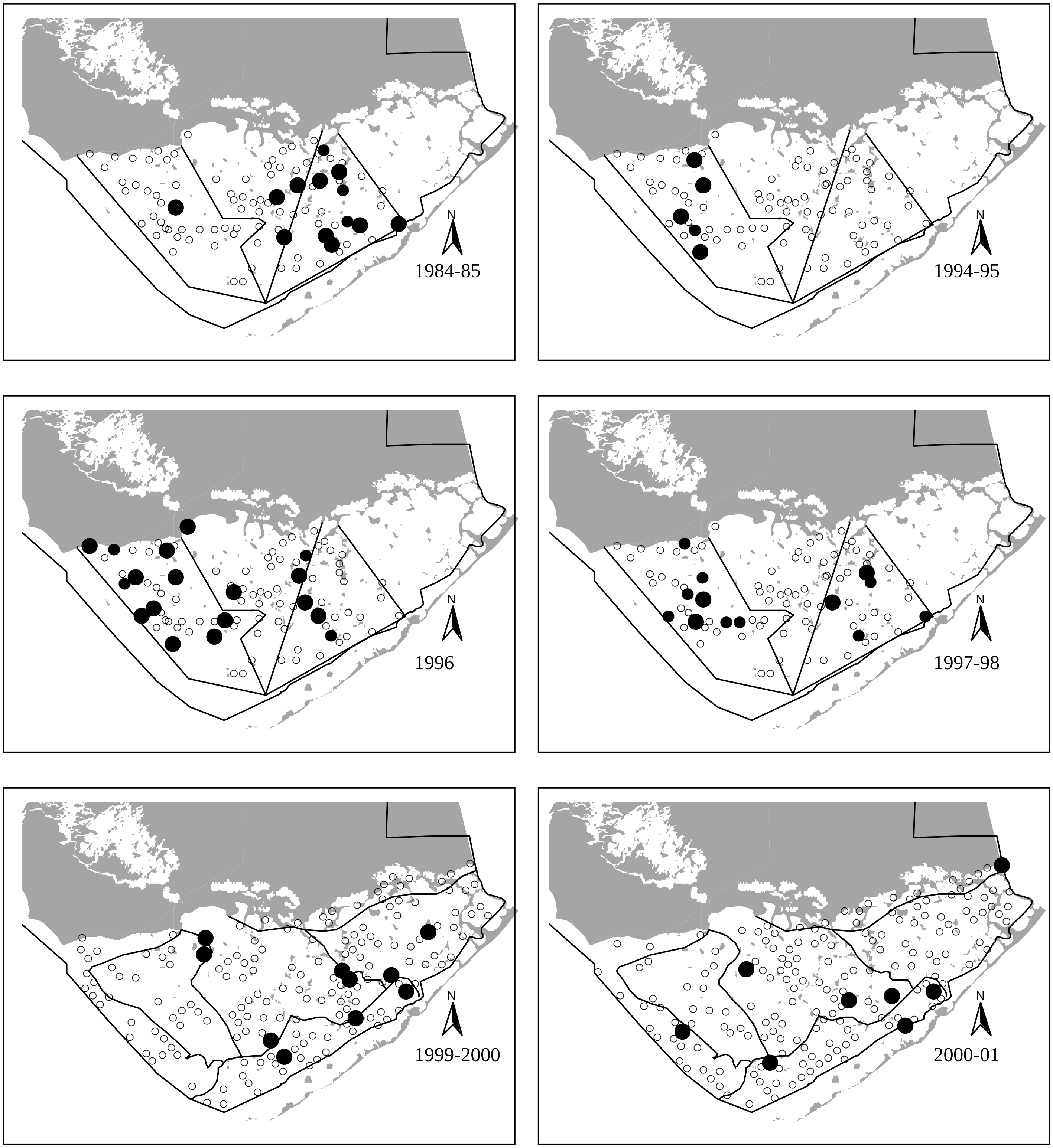


Figure 12. Mean densities (numbers 1000 m^{-2}) of ornate crab, *Callinectes ornatus*, from bi-monthly, otter-trawl collections in Florida Bay basins. Florida Bay is divided into three strata from 1984-1998 and six subdivisions from 1999-2001. For designation of strata and subdivisions see Fig. 2.

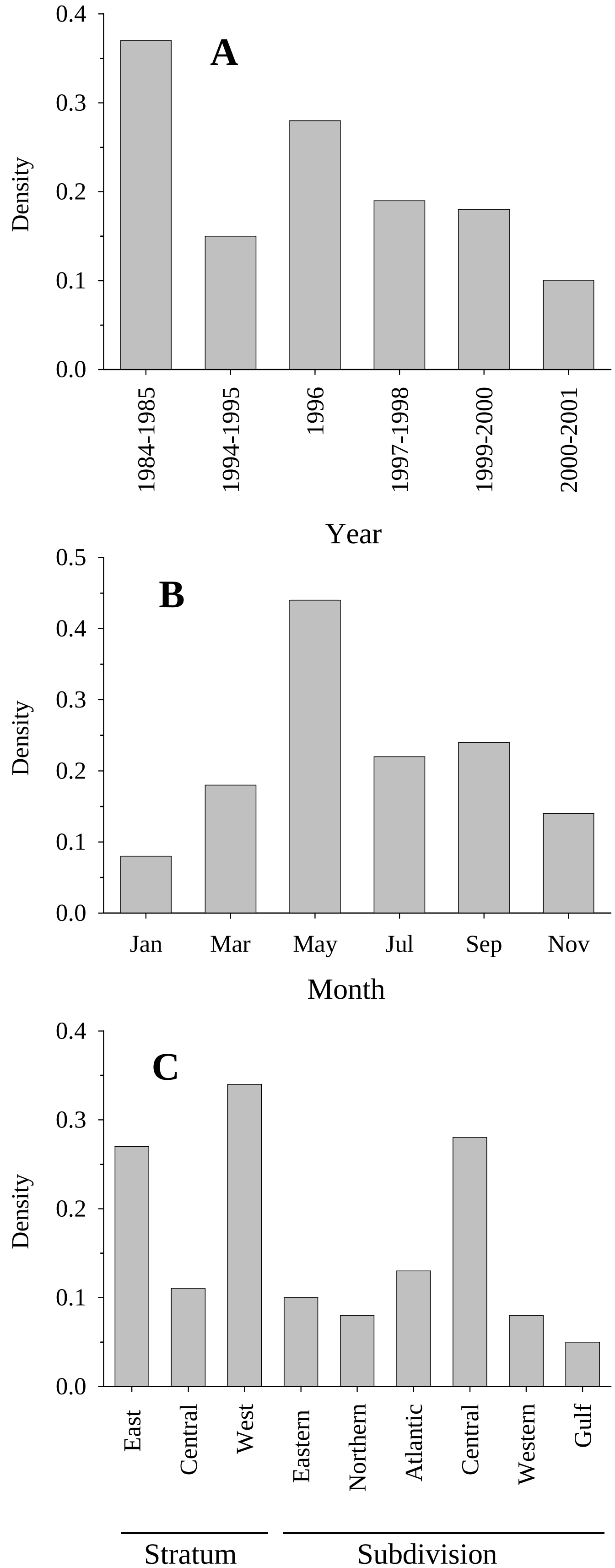


Figure 13. Mean densities (number per 1000 m^2) of ornate crab, *Callinectes ornatus*, from bi-monthly, otter trawl collections in Florida Bay basins by (A) year, (B) month, and (C) stratum/subdivision. Florida Bay is divided into three strata from 1984-1998 and six subdivisions from 1999-2001. For designations of strata and subdivisions see Fig. 2.

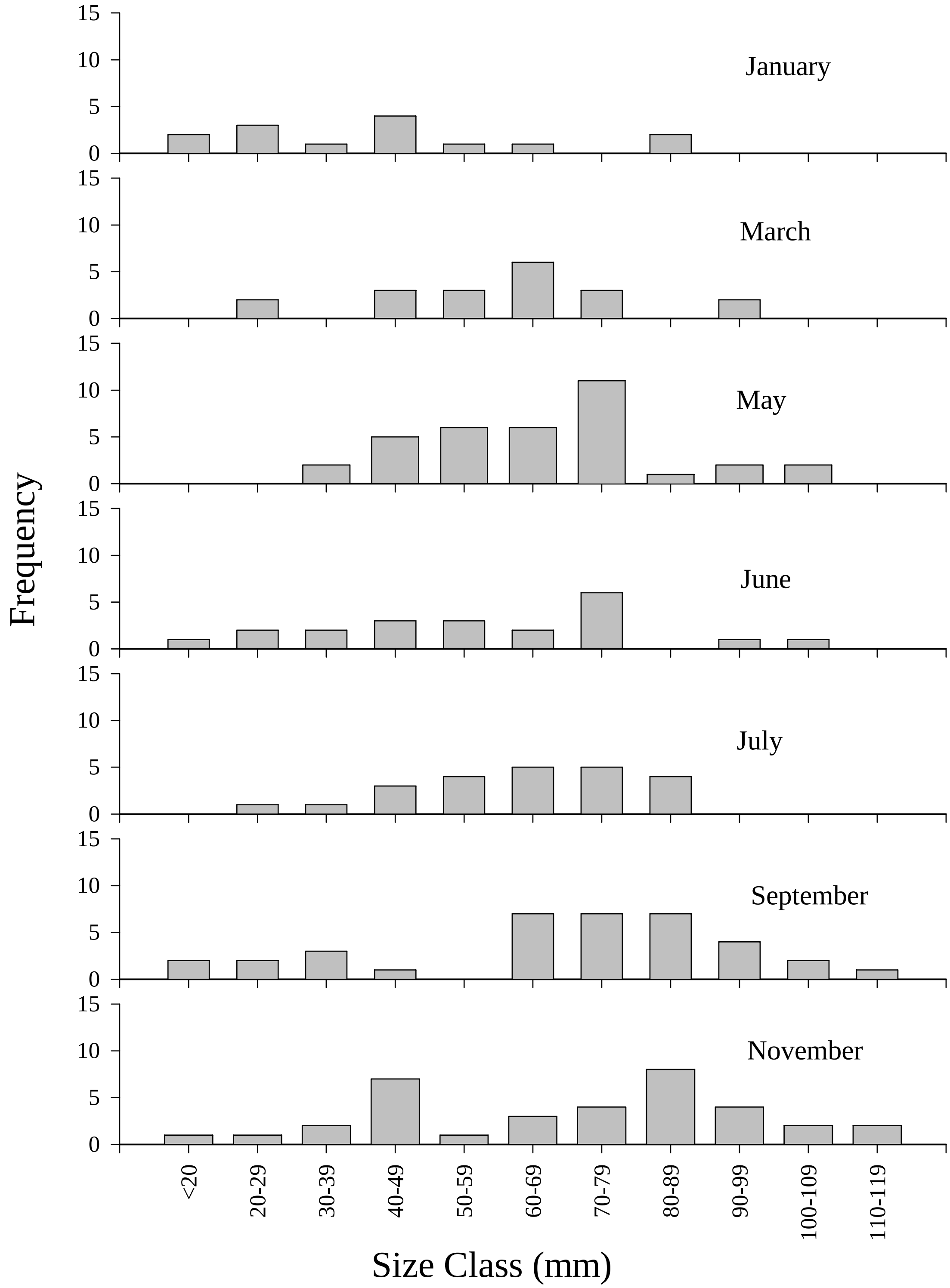


Figure 14. Monthly length-requency distributions of ornate crab, *Callinectes ornatus*.

***Callinectes sapidus* (blue crab)**

Life history. Blue crab range from Cape Cod to northern Argentina, including Bermuda and the Antilles. It occurs north of Cape Cod to Nova Scotia during favorable warm periods (Williams, 1984).

There is a considerable amount of literature on the reproduction and life history of the blue crab that has been summarized by, at least, Van Den Avyle and Fowler (1984), Perry and McIlwain (1986), and Patillo et al. (1997). Much of the material presented here is from those three publications. Blue crab have a protracted spawning period, and in the northern Gulf of Mexico larvae have been collected in all months except January and February, but their occurrence is low from December to April. Eggs hatch near the mouths of estuaries and larvae (zoea) are carried offshore. Newly hatched larvae are 0.25 mm CW and generally develop through seven zoeal molts. After the last zoel stage (1 mm CW) larvae metamorphose into a megalopal larval stage. They enter the estuaries as megalopae and the molt to the first juvenile stage there. In Louisiana waters, 100% of the males are mature by 130 mm CW, and 100% of females by 160 mm CW; 50% of the males by 110-115 mm CW, and 50% of females by 125-130 mm CW.

Diet. Blue crabs in a northern Florida estuary are classified into three size groups based on their seasonal and spatial differences in diet composition and diversity. Basically, feeding habits are dependent on food availability and change during ontogeny. Crabs, < 31 mm CW, feed mainly on bivalves, and plant matter (plus 14 other items), those 31-60 mm CW feed mainly on, in descending order: bivalves, fish, gastropods, and plants (plus 12 other items), and crabs > 60 mm CW feed mainly on bivalves, fish, xanthid crabs, and blue crabs (plus nine other items) (Laughlin, 1982).

Abundance and distribution. Blue crabs were common (*n* = 161) in otter-trawl collections in basins. Temporally, there were differences among years, but not months. Densities were similar for four of the six annual periods, but relatively low in 1996 and high in 1999-2000 (Figs. 15 and 16). Spatially, there were differences in mean densities among subdivisions, but not among strata. This species was relatively abundant in all subdivisions, except the Atlantic subdivision. On the other hand, Holmquist et al. (1989a) almost exclusively collected blue crabs on mud banks at a site adjacent to the Florida Keys within our Atlantic subdivision. Based on preference by juveniles for mud substrate (Perry and McIlwain, 1986), Florida Bay probably provides only marginal habitat for this species.

Our abundance data suggested that recruitment of blue crabs into Florida Bay is highly variable. Various authors have suggested either predation or recruitment bottlenecks influence the abundance and distribution of blue crabs. Heck et al. (2001) suggested that post-settlement loss to predators is a dominant factor influencing the abundance of blue crabs in a Gulf of Mexico estuary. Hovel et al. (2002) suggested that proximity to and dominance of tidal flow through inlets might contribute to differences in distribution as a result of different recruitment patterns. Etherington and Eggleston (2003) offered two dispersal mechanisms that determine blue crab distribution. Pre-settlement dispersal results in high abundances within more seaward habitats, and early post-settlement dispersal expands the distribution of juveniles. In their case, there was a strong relationship between juvenile densities and specific wind characteristics. The mud banks in Florida Bay restrict circulation in the Bay, particularly the central and northeastern section (Fourqurean and Robblee, 1999). Despite this impediment, blue crab were well distributed in the central and northeastern section, at least in later years, and least abundant at seaward habitats; i.e., Atlantic and Gulf subdivisions (Figs. 15 and 16). We believe their distribution and abundance in the central portion of the Bay in recent years compared to earlier years might be linked to pre- and post- recruitment physical processes.

Length-frequency distributions. Based on the occurrence of the smallest size classes, it appeared that blue crabs recruitment mainly occurred in November, with a lesser amount in September, minimal from January through June, and no recruitment in July (Fig. 17). A wide range of sizes was observed throughout most of the sampling period, but smaller than the maximum sizes, (approximately 205 mm CW) reported by Williams (1984).

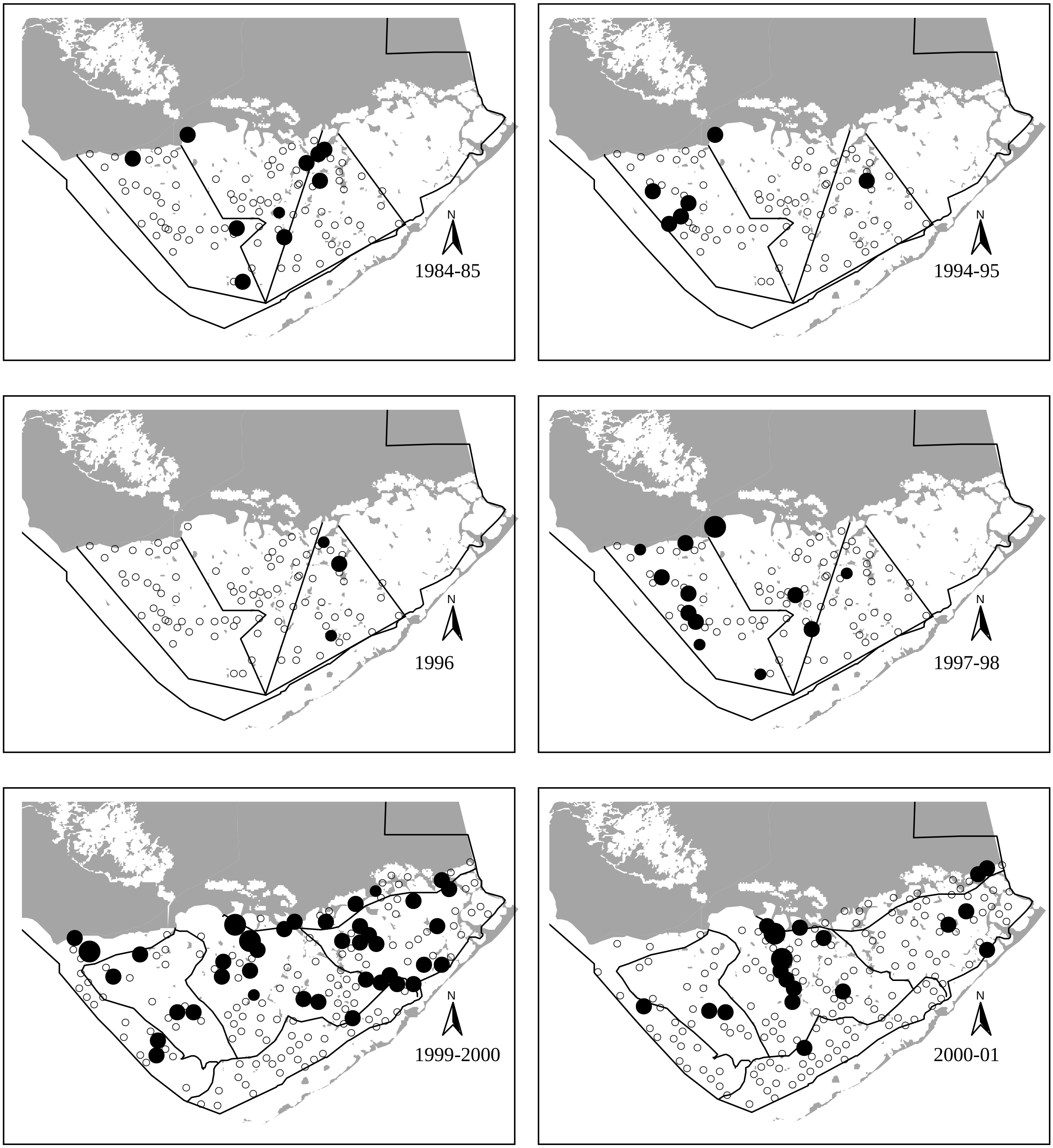


Figure 15. Mean densities (numbers 1000 m^{-2}) of blue crab, *Callinectes sapidus*, from bi-monthly, otter-trawl collections in Florida Bay basins. Florida Bay is divided into three strata from 1984-1998 and six subdivisions from 1999-2001. For designation of strata and subdivisions see Fig. 2.

Density
○ 0
● 0.1-0.9
● 1.0-9.9
● >9.9

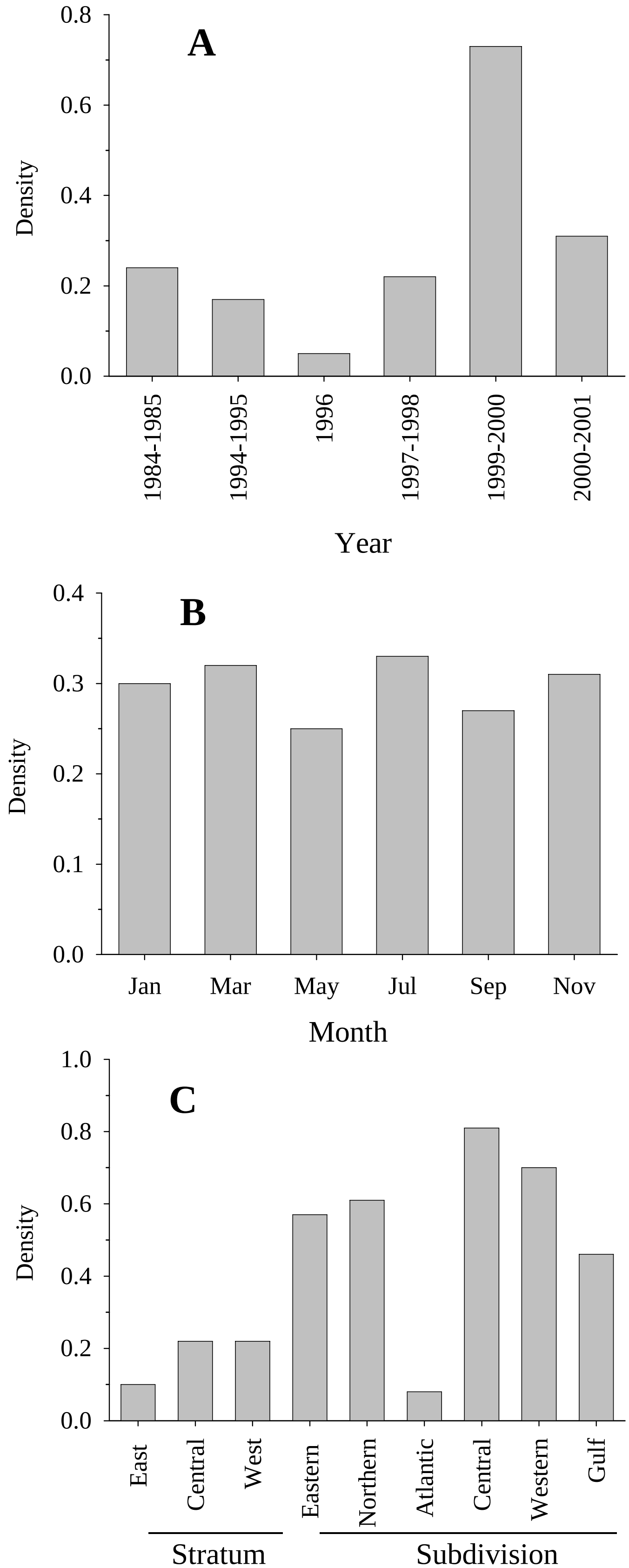


Figure 16. Mean densities (number per 1000 m^2) of blue crab, *Callinectes sapidus*, from bi-monthly, otter-trawl collections in Florida Bay basins by (A) year, (B) month, and (C) stratum/subdivision. Florida Bay is divided into three strata from 1984-1998 and six subdivisions from 1999-2001. For designations of strata and subdivisions see Fig. 2.

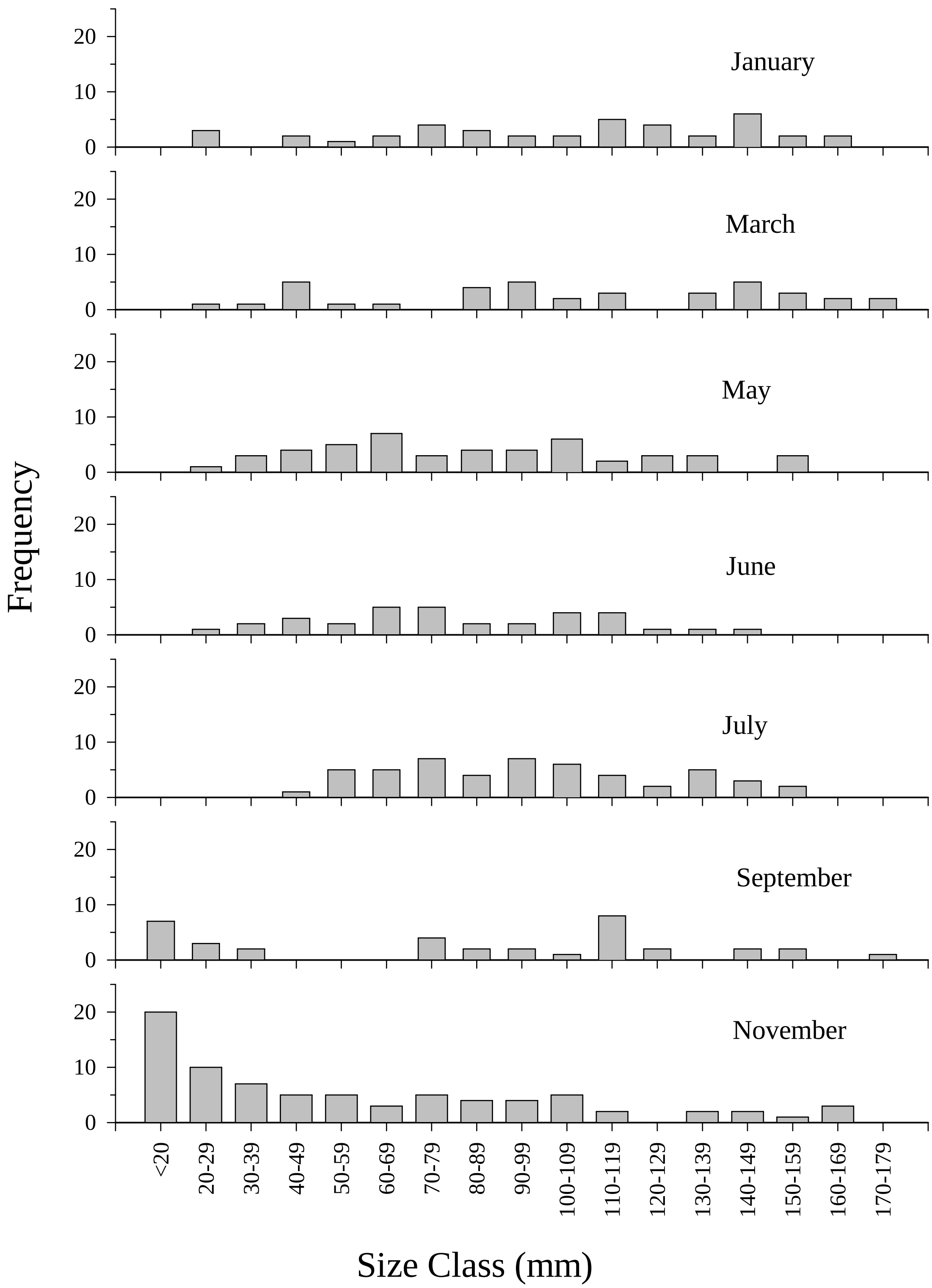


Figure 17. Monthly length-frequency distributions of blue crab, *Callinectes sapidus*.

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