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Management Recommendations for Juvenile Spiny Lobsters, *Panulirus argus* in Biscayne National Monument, Florida

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ABSTRACT

The distribution, abundance, growth, and migration of spiny lobsters, *Panulirus argus*, in southern Biscayne Bay, Florida, were investigated from 1975 to 1978, using skin and SCUBA diving techniques and roller frame trawls. Impacts of fishery activities were also documented. The abundance of post-larval to medium-sized juvenile *P. argus* 8.5 to 60 mm carapace length (CL), caught in bait shrimp trawls was only one third as great in 1976-78 as it was in 1968-69. Most larger juvenile lobsters (50-75 mm CL) in the Bay were concentrated in rocky dens along the western shore of Elliott Key and in the tidal creeks between the Keys. Data on growth and migration were collected from 1,688 observations of 534 of the 5,080 *P. argus* tagged during the study. Growth rates varied with season and condition of individual lobsters. Uninjured *P. argus* (38 to 83 mm CL) showed a mean annual growth rate of 26.5 mm CL, whereas injured lobsters of the same size grew only 16.1 mm CL per year. Recaptures from recreational divers and professional trap fishermen showed that juveniles from Biscayne Bay contributed to fishery harvest from Lake Worth (135 km north) to Key West (190 km southwest) within six months of leaving the Bay. Fishing activity, primarily by recreational divers, was intense in the Bay and tidal creeks, where over half of the legal-sized lobsters ($>$ 76.2 mm CL) were removed during the first two days of the 1977-78 season. Injuries in the Bay/creeks population increased from less than 30% to over 50% coincident with the fishing season. The ratio of tags returned by recreational and professional fishermen suggested that recreational harvest was about 14% of the total Florida landings. The lobster fishery in Biscayne Bay significantly altered the density and age structure of the population. If all lobster fishing in the Bay and tidal creeks were prohibited to create a lobster nursery sanctuary, this action would eliminate the direct fishery-related alteration of the lobster population density and age structure. It would also reduce growth inhibiting injuries, which in turn, would decrease mortality associated with reduced growth rates and increase the yield per recruit for a large portion of the Florida lobster fishery. Increasing diurnal shelter in the Bay by establishing an artificial reef showed that shelter was not a major limiting factor on the Bay population of juvenile *P. argus*, in spite of the fact that large concentrations of lobsters (up to $5/m^2$) were maintained for 18 months in the artificial habitats. The results of this study suggested that declines in Florida lobster landings may be associated with reduced post-larval recruitment and fishing activity in nursery areas. A prohibition on all lobster harvest in Biscayne Bay and the tidal creeks in the monument should be imposed to protect juvenile lobsters and increase fishery yield in adjacent areas.

INTRODUCTION

Spiny lobsters (Palinuridae) have complex life cycles. Larval, early juvenile, and adult stages of the Florida spiny lobster, Panulirus argus, are ecologically dissimilar, and are found separately in relatively discrete habitats. The planktonic phyllosoma larvae spend several months in the open ocean before metamorphosing into actively swimming post-larvae, called puerulii (Lewis, 1951). Puerulii swim into shallow coastal waters where they settle onto the bottom, assuming the demersal existence they will follow the rest of their lives. Post-larval and small juvenile spiny lobsters are found scattered throughout seagrass beds, particularly in shallow inshore areas like Biscayne Bay. Larger juveniles concentrate around rocky outcrops, sponges, and groups of sea urchins for shelter during the day (Khandker, 1964; Davis, 1971; Berrill, 1975). Nightly, they forage on adjacent grassbeds and open sand areas for small mollusks, echinoids, and crustaceans (Herrnkind, et al., 1975). Mature lobsters are generally associated with coral reefs, or other hard bottom, offshore to depths in excess of 150 m. The transition from inshore juvenile habitat to adult habitat offshore is sometimes made by means of spectacular mass migrations, marked by long queues of lobsters (Herrnkind and Cummings, 1964; Herrnkind, 1969). These three major stages in the lobster life cycle (larval, juvenile, and adult) are so different that each may be considered a discrete unit for habitat management. The U.S. National Park Service manages nearly one third of the juvenile spiny lobster habitat in Florida, including about 100 km^2 of Biscayne Bay in Biscayne National Monument, and over 1,000 km^2 of Florida Bay in Everglades National Park, and approximately 50 km^2 in Fort Jefferson National Monument at Dry Tortugas.

Presently, there is an active fishery for spiny lobsters in Biscayne National Monument, in accordance with the act establishing the Monument, Public Law 90-606, and Florida law (Fl. Stat. 370.14). Both recreational and commercial fishermen may harvest lobsters, with a minimum size of 3 inches (76.2 mm) carapace length (CL), between July 26 and April 1. There is also a special two day sportsman's season on July 20-21, during which a six lobster per person per day limit is imposed. The recreational catch is taken primarily by divers using gloves. Bully nets are also used, but spears, grains, hooks, grabs, or similar devices , are not permitted. The commercial catch is taken primarily with top entry, wooden slat traps.

The purposes of this report are to document the effects of fishery harvest on the juvenile spiny lobster population in the Biscayne Bay area of Biscayne National Monument, and to recommend a management strategy that will conform with Service policy to perpetuate naturally functioning native ecosystems and support the Florida lobster fishery in accordance with the intent of Public Law 90-606.

METHODS

In order to evaluate the effects of fishery activity on lobsters in Biscayne Bay it was necessary to define their movement patterns, population dynamics, and growth rates, and to understand the factors limiting these characteristics.

During 1976 and 1977, spiny lobsters were captured by hand, bully net, or snare and marked with spaghetti tags. Data on size (CL), growth (measured as change in CL), injuries, molt condition, and location were recorded. The details and efficacy of this tagging procedure were reported elsewhere (Davis, 1978). Assistance in recapturing tagged lobsters was requested equally from recreational divers and commercial fishermen through posters displayed at local dive shops and fish processing centers, and with news releases to local and regional media. Handouts describing the tags in both Spanish and English were widely distributed.

Periodic (weekly to monthly) visual surveys of lobster dens were conducted by divers in southeastern Biscayne Bay at 17 stations on the west coast of Elliott Key from Caesar's Creek to Sands Cut (Fig. 1) from 1975 through 1977. Diver surveys of the entire Monument were conducted seasonally. At selected stations, primarily the Elliott Key Marina, lobsters were classified by their tagged status, or the inability of the observer to determine tag status, during these surveys. Water temperature and salinity were also recorded during surveys.

Lobsters were also captured, tagged, and released from bait shrimp trawlers operating at night in the southern Bay. Paired 3.9 m roller frame trawls were towed from 10 to 45 minutes. The number, size, sex, and injuries of the lobsters caught were recorded, as well as the duration and location of the tow and the water temperature and salinity.

Growth of spiny lobsters takes place as the result of a series of molts, during which measurable changes in size occur discontinuously. The rate of growth is dependent on both the magnitude of change in size with each molt (molt increment) and the frequency of molts (intermolt period). In this study, growth rate was expressed as change in carapace length per week, since nearly all observations of marked lobsters were made at weekly intervals. To reduce the variability inherent in measuring the discontinuous changes in carapace length that resulted from random observations of growth during the molting cycle, all changes in size were summed for each class of observations (i.e., winter, summer, injured, or uninjured), and divided by the sum of the time intervals recorded for that class of observations. So that:

$$\text{Growth Rate} = \frac{\Sigma Y}{\Sigma X};$$

Where $Y = \Delta$ in CL,

and X = number of weeks between CL measurements,

and Growth Rate = mm/week

In order to evaluate the potential of diurnal shelter as a limiting factor on the lobster population in Biscayne Bay, and to provide undisturbed habitat for the Elliott Key Marina lobster population during extensive marina rehabilitation in 1977, a grid of artificial habitats was constructed adjacent to the Marina in the summer of 1976. Each habitat consisted of nine standard 20 cm x 20 cm x 41 cm concrete building blocks arranged in a hollow pyramid (Fig. 2). The habitats were deployed in six rows of 25, on two meter centers. Because of the similarity of the habitats, the regularity of their distribution, and the high density of lobster occupancy, the entire complex was called the "ghetto." The nine block pyramid design was selected after comparisons of occupancy rates with three other block designs and one meter lengths of 10 cm diameter black polyvinyl-chloride (PVC) pipe bound together. Weekly censuses of the various habitats were conducted from December, 1975 to May, 1976. During that time, the nine block pyramids averaged over two lobsters per block (21 lobsters per habitat), while solid cubical designs averaged only 0.5 to 0.7 lobsters per block, and the PVC pipe clusters rarely contained more than four lobsters.

RESULTS AND DISCUSSION

Diver surveys at the 30 locations shown in Figure 1 revealed distinct patterns of lobster distribution, movements and condition. In the western Bay, the few lobsters encountered were small (15 - 50 mm CL), and generally scattered through dense turtlegrass, *Thalassia testudinum*, in small den sites, or under sponges throughout the year. Along the western shore of Elliott Key, in the eastern Bay, groups of larger juveniles (35-85 mm CL) were concentrated in rocky dens and artificial shelters in marinas and under docks. The tidal "creeks" between the keys at Sands Cut, Caesar's Creek, and Broad Creek harbored the same size juveniles as were found in the eastern Bay. A comparison of the sizes of lobsters found in different areas of the Monument is presented in Table 1. A summary of seasonal variation in the sizes of lobsters, molting activity, frequency of injuries, and water temperature at the Elliott Key Marina is presented in Table 2. Young lobsters appeared to concentrate in rocky dens beginning in the winter as they reached sizes of 30-35 mm CL. There was a gradual increase in the mean size of lobsters in these areas through the summer, dropping sharply in November or December. There was also a gradual buildup in numbers of lobsters in these dens through the summer into the fall, with the fewest lobsters seen during the winter months (Table 3).

Mark and recapture estimates of the population in the Elliott Key Marina showed that simple visual counts underestimated the number of lobsters by 64 to 83 percent, increasing logarithmically as the population increased (Table 4). Within the range of the population levels sampled, a linear regression showed a significant relationship ($r = .99$, $n = 26$) between visual counts and population estimates made using tagged lobsters and modified Schnabel technique described in Ricker (1975, 3.17), defined as: $\log y = 2.2529 \log x - 3.2570$; where y = population estimate, and x = visual count. Over 4,000 female lobsters ranging from 34 to 101 mm CL were examined over a 24 month period in Biscayne Bay, and not one showed any sign of reproductive activity (bearing spermatophore or eggs).

Movement

At sizes of 30 to 40 mm CL, lobsters in the Bay abandoned their relatively scattered distribution in seagrass and sponge beds in the central Bay and concentrated in high densities in the rocky dens along the eastern shoreline of the Bay. Then, in a year or two, as they approached the minimum legal harvest size of

76.2 mm CL, they left the Bay and moved through the tidal creeks out to coral reefs 5 to 7 km east of Elliott Key (Fig. 3). The movements out of the Bay occurred in pulses at about eight week intervals regularly throughout the year. Small groups, including marked lobsters, were observed moving from the Elliott Key Marina and ghetto area north and south toward and through the tidal creeks every seven to nine weeks. Tag recoveries reported by recreational divers and commercial trap fishermen from the offshore reef also tended to be concentrated at approximately eight week intervals. Short queues of four to six lobsters were frequently observed moving across open areas in the Elliott Key Marina, and a single queue of 13 P. argus was seen at night in October, 1976, moving south from the Marina in the open Bay. Once the juvenile lobsters reached the coral reef zone, they turned north or south and continued moving along the reef tract at depths of 20 to 40 meters.

In 1976, all reported movement was to the south, with recaptures ranging from Pacific Reef and Carysfort Reef, in the upper Florida Keys, to Alligator Reef and Woman Key in the middle and lower Keys, respectively. Distances of up to 190 km were traversed in less than six months during these southerly movements. In the fall of 1977, there was a notable change in the offshore movements, with northerly movements of up to 135 km. Several marked lobsters released at the ghetto during the previous summer were recaptured to the north off Miami Beach, Fort Lauderdale, Boca Raton, and Lake Worth, Florida. During the winter and spring of 1978, recaptures were evenly distributed between the Florida Keys to the south and the Gold Coast area to the north. It is clear from these observations and those of Warner, et al., 1977, that juvenile lobsters from Biscayne Bay are recruited into virtually the entire Florida fishery. Figure 3 summarizes the net movement of lobsters tagged and released at the Elliot Key Marina/ghetto.

Fishery Impacts

There are two major user groups in the Florida lobster fishery--recreational divers and professional trappers. The relative harvests of these two groups from the offshore fishery has been the subject of considerable speculation for several years (Beardsley, et al., 1975). The significant impact of sport divers on a previously unfished lobster population was documented at Dry Tortugas, Florida (Davis 1977), but there are no data recording the total recreational lobster harvest in Florida, nor any indications of the relative proportions taken by amateur and professional fishermen. From our unmodified tag returns in 1977-78, it appeared that the recreational harvest was nearly equal to the professional harvest, since 33 of the 67 tags returned during that season were from recreational divers. Because of the sheer number of lobsters handled by individual professional fishermen, there is a higher probability that they would overlook or fail to report the capture of a tagged lobster than would a recreational diver. This bias was tested by "salting" commercial traps with tagged legal-sized lobsters and recording the return rate of these known "recaptures." A control on natural lobster escapes from the "salted" traps was provided by using unbuoyed, diver serviced traps deployed in the same area at the same time. This procedure is described in detail elsewhere (Dodrill, et al., in prep.). The results of this test showed that only 16.7% of the commercially caught tags were returned, meaning that the 34 returned tags actually represented 204 recaptured lobsters, or 86% of the total.

While both groups fished in Biscayne Bay, the majority of the activity in the Bay was by recreational divers (Tilmant and Forrester, 1978). The direct impact of fishing activity on the juvenile lobster population in Biscayne Bay was manifested in three ways: (1) reduced abundance, (2) reduced mean size, and (3) increased frequency of injuries. A special sportsman's season was held before the beginning of the regular lobster season on July 26, 1977 (FL. Stat. 370.14). The bag limit for the special season was six lobster per person per day, instead of the regular 24 per boat. Samples of lobsters were taken immediately before and after the two day season, on 19 and 26 July 1977, from Sands Cut between Elliott and Sands Keys. Before the season, 34% of the lobsters in the Cut were of legal harvest size ($\geq$76.2 mm CL). After the season, only 15% of the remaining lobsters were of legal size (Table 5). In addition to reducing the legal-size lobster population by over 50% in two days, the mean size of the remaining sub-legal size lobsters was significantly reduced ($t = 3.53$, $df = 123$, $P < 0.05$). Since there was not apparent grouping of lobsters in dens by size, thus suggests an illegal harvest of "shorts" (Table 5).

The number of lobsters observed in the Marina/ghetto area generally reached a peak in late July and early August at the beginning of the fishing season, and sharply declined during the first few months of the season (Fig. 4). How much of this decline was the result of fishing activity is difficult to assess, since it also coincided generally with declining water temperatures and the normal offshore fall migration. However, the declines in Biscayne Bay began with the opening of the season in August, and the major offshore movements of tagged lobsters did not start until late October or November, which corresponds with the normal movement pattern reported at Dry Tortugas (Davis, 1977) and in the Bahamas (Herrnkind et al., 1973).

More directly related to the fishing activity in the Bay was the seasonal variation in the incidence of injuries in the juvenile lobster population. By the end of the open season, about half of the lobsters in the Bay were missing legs and/or antennae prior to their capture for tagging. The frequency of injured lobsters dropped through the four month closed season to about 30%, as they all molted at least once without harrassment from fishermen (Table 2). Less than 25% of 963 juvenile lobsters examined from an unfished population at Dry Tortugas, Florida, displayed similar injuries, which were presumably due to encounters with natural predators, difficulties with molting, or other normal stresses (Davis, unpubl. data). The significance of these fishery-caused injuries will be discussed in the following section on growth rates.

<u>Population Limitations</u>

Chittleborough (1970) showed that limited food and shelter on inshore reefs effectively limited juvenile rock lobster populations in Western Australia, and Wolfferts (1974) suggested that artificial shelters should be tried in Florida to increase the number of lobsters for the fishery. Our observations in Biscayne Bay and the ghetto suggested that something other than shelter for juvenile lobsters limited recruitment to the fishery.

The first concrete block habitats comprising the ghetto were deployed in June, 1976, and adjustment and additions were completed in August, 1976. Extensive construction in the adjacent marina did not begin for over six months, yet the lobsters in the marina moved into the ghetto quickly (Fig. 3). By the end of October, over 1,400 lobsters were residing in the ghetto and the marina population fluctuated between 30 and 50. One year after completion, in August of 1977, an average of more than 2,800 P. argus resided in the ghetto.

During the first few months of its existence, the ghetto replaced the marina as the most popular shelter in the area, and remained so for the next 18 months, until it was dismantled and the habitats relocated in the new marina.

The ghetto showed the same seasonal fluctuation in population levels as the marina had in previous years, and there was a regular flow of juvenile lobsters through the area, with a mean residency in the ghetto of about 12 to 18 months. Lobsters first appeared in the ghetto at carapace lengths of 35 to 40 mm, and left as they approached the minimum legal harvest size of 76 mm CL. With regular recruitment from the adjacent grassbeds, the marina-ghetto population would have been greater than the marina alone if shelter were a significant limiting factor for the juvenile P. argus population in Biscayne Bay. There was no increase in the population, only a shift in distribution, and the marina stood essentially empty for nearly seven months before construction began to alter environmental conditions, such as turbidity and noise.

When construction was completed and the habitats from the ghetto relocated in the marina, the lobster population moved back into the habitats in the marina immediately, and in high numbers, so there was no apparent reason to believe that the marina had become unacceptable as lobster shelter while the ghetto existed. These observations strongly suggested that shelter was not a significant limiting factor for 35 to 85 mm CL P. argus in Biscayne Bay. In fact, it further suggested that factors affecting recruitment of smaller juveniles or post-larvae may be major limits to the subsequent population of larger juveniles.

From March, 1976 to March, 1978, 706 P. argus were caught and measured in 392 tows by shrimp trawlers in Biscayne Bay. The mean size of P. argus caught nightly by bait shrimp trawlers over the turtlegrass beds and hard open bottom of Biscayne Bay was 32.0 mm CL, ranging from 8.5 to 85.1 mm CL (Table 6). This population was recruited to the marina/ghetto population. The abundance of P. argus in the shrimp trawl catch showed considerable seasonal variation, part of which was undoubtedly a result of seasonal variation in the geographical distribution of the shrimpers as they followed the shrimp through the Bay. There was a major peak in the lobster catch rate in the late summer and early fall, and a minor peak in the spring. This seasonal variation was similar to that reported by Eldred, et al. (1972) for 1968 and 1969, however, the number of lobsters caught per tow in 1976-78 was dramatically lower (67%) than in 1968 and 1969 (Table 7). It seems reasonable to assume that the seasonal movements of the shrimping operations were about the same in each of the two year sampling periods, so the differences observed in catch rates probably reflected a real reduction in lobster abundance. A reduction in post-larval recruitment of this magnitude has serious connotations for the fishery, and should be investigated further.

In addition to the decrease in abundance, the mean and maximum sizes of lobsters caught in shrimp trawls in the Bay were apparently much larger in 1976-78 than in 1968-69. Of 1,464 lobsters caught during the 1968-69 sampling, only 0.4% were larger than 60 mm CL, and none had attained legal size (76 mm CL) (Eldred, et al., 1972). In the 1976-78 samples the mean size was 32 mm CL, 4 mm larger than 1968-69, and five percent were larger than 60 mm, with a maximum of 85.1 mm CL (Table 6).

The winter of 1976-77 set numerous records in Florida and elsewhere as the coldest in the past century (McGuirk, 1978). On the night of January 20, 1977, a cold front from the north moved rapidly across southern Florida dropping water temperatures overnight in shallow Biscayne Bay more than seven degrees, to below 11°C. In the ghetto, 49 of the 900 lobsters still in residence died that night. Over half of the dead individuals were undergoing ecdysis, and died in the "dump truck" stage of the molt (Figs. 6 and 7 in Travis, 1954). It appeared that the cold triggered an immediate flurry of molting activity, and synchronized molting in the population for the next six months (Table 2). Following the cold snap, 43% and 26% of the population molted in January and June, respectively, whereas the highest proportion of the population molting in any month during the previous year was only 14%. Mortality caused by these extreme weather conditions could not completely explain the observed decline in post larvae from 1968-69, nor could cold weather be considered a factor during 1976.

Growth Rates

Observations of growth were made for 844 time intervals, ranging from one to 82 weeks, on 534 individual lobsters in the wild, ranging in size from 38 to 83 mm CL. Carapace length measurements were replicated on the same day, independently on 153 lobsters during the 22 month tagging period to evaluate the precision of the carapace length measurements by various technicians. The mean error was 0.3 mm, with a range of -1.8 to +2.1 mm. Consequently, changes in carapace measurements greater than 2.0 mm were recorded as growth, others were considered measurement errors.

Two major factors appeared to affect growth rates: water temperature and the condition of individual lobsters. Neither sex nor size (within the range observed), significantly affected growth rates. The growth variables of mean intermolt period, growth increment, growth rate, and water temperature are summarized with respect to season and lobster condition in Table 8. Mean intermolt periods were estimated by doubling the time interval over which 50% of the lobsters observed had molted. This assumed that at the time of tagging the lobsters were randomly distributed throughout their molting cycle (Munro, 1974). This appeared reasonable since we observed molting activity throughout the year (Table 2), and direct observations of individual lobsters through periodic recaptures confirmed the mean values obtained for the population in this manner (Davis, 1978). For example, during the winter, the percentage of molted lobsters increased weekly from 12% after one week to 22, 31, 31, 32, 40, 44, and 58% after eight weeks indicating that 50% had molted after about 7.5 weeks, suggesting a mean intermolt of 15 weeks (Fig. 5). In contrast, the mean intermolt period during the summer months was reduced to eight weeks (Table 8). The mean intermolt period of injured lobsters was 15 weeks, and for uninjured lobsters it was 10 weeks (Table 8). The mean growth increments were estimated by examining frequency distributions of observed changes in carapace length (Fig. 6). The mean single molt growth increment in the summer was significantly larger tan in the winter and the mean uninjured increment was larger than the injured (Table 9).

Predictably, warmer summer (May-October) temperatures resulted in a greater summer growth rate (0.75 mm CL/week) than that observed during the winter months, November through April (0.31 mm CL/week). This 59% decrease in growth rate between summer and winter was apparently the result of an 8.0°C decrease in mean water temperature, from 29.1°C to 21.1°C, and the increased frequency of injuries incurred during the fall and winter fishing season. Both of these factors, reduced temperature and injuries, caused increased intermolt periods and reduced molt increments, which resulted in reduced growth rates (Table 8). Change in the length of the intermolt period was the major effect of both factors, but it was proportionately more important for the injury-caused reduction, whereas decreased molt increment was proportionately more important for the temperature-caused growth reduction.

The growth data presented here generally conform both in magnitude and character to that in the published literature for decapod crustaceans, but the precise effect of injuries in the wild and definition of their origin is apparently new information, particularly for P. argus. Estimated growth rates for juvenile P. argus in the Caribbean, Florida and Bermuda, range from 0.43 to 0.65 mm CL/week (Smith, 1951; Travis, 1954; Sutcliffe, 1957; Buesa M. 1965; Witham, et al., 1968; Sweat, 1968; Little, 1972; Eldred, et al., 1972; Ting, 1972; Munro, 1974; Peacock, 1974; and Olsen and Koblic, 1975). Our estimates for Biscayne Bay ranged from 0.31 to 0.75 mm CL/week, but the mean of 0.41 mm CL/week was the lowest reported. The 1977 winter in Biscayne Bay was the coldest in the previous century, and the Bay is already near the northern limit of P. argus distribution. That cold winter depressed the mean growth rate somewhat, but another significant factor was that the Biscayne Bay lobster population was the most heavily fished by sport divers of all of those for which growth rates were reported. The injuries resulting from diver activity also depressed the growth rate. A combination of cold weather and extremely high fishing activity caused the low growth rate reported in this study.

Variations in growth rates of lobsters have been attributed to several factors, the most common of which is temperature (Newman and Pollock, 1974; Phillips, Campbell and Rea, 1977; Travis, 1954; Chittleborough, 1974; Crawford and DeSmidt, 1922; Olsen and Kobic, 1975; (See Aiken, Dall, and Ford In Phillips and Cobb, 1977, for a review of lobster growth). Limited food (Chittleborough, 1970; Manviot and Castell, 1976; Sutcliffe, 1957; and Newman and Pollock, 1974), shelter (Chittleborough, 1970), salinity and light (Travis, 1954), and injuries (Chittleborough 1974; Aiken, 1977; and Ford, 1977) have also been cited as factors affecting lobster growth. The effects of these factors are translated into growth rate variations by changing either intermolt period, molt increment or both. Most commonly, intermolt is shortened by warm temperatures, darkness, or autotomy of appendages; and lengthened by age, cold, or low salinity. Under some conditions, as in this study, both changes in molt increment and intermolt occur (Aiken, 1977; Manviot and Castell, 1976; Pollock and Roscoe, 1977).

While autotomy stimulates molting, Chittleborough (1974) reported that repeated loss of two or three legs or a large number of appendages resulted in decreased molt increment, so the net result was a reduction in growth rate. The results of the current study in Biscayne Bay also clearly demonstrated the adverse impact of injuries on growth rates. However, our observations did not demonstrate any proportional relationship between the degree of injury and the degree of molt increment depression as demonstrated for shore crabs by Kuris and Mager (1975). The growth rate of the 15% most extensively injured P. argus was virtually identical to the growth rate of the remaining 85% that were missing fewer than five appendages. It appeared that even minor losses caused a significant shift in growth pattern.

CONCLUSIONS

At the mean growth rate of 0.51 mm CL/week observed for uninjured lobsters, it took over 51 weeks for a juvenile to reach the minimum legal size of 76.2 mm CL from a size of 50 mm CL at age 2 (Lewis, 1951; Sweat, 1968). At 50 mm CL they began to associate gregariously with the larger juveniles in the eastern Bay where they were subjected to fishery pressure. At the injury-depressed growth rate of 0.31 mm CL/week, it required 84.5 weeks to reach legal harvest size and enter the fishery, 33 weeks longer than uninjured lobsters. During the additional 33 weeks required to reach legal harvest size, natural mortality undoubtedly eliminated significant numbers of lobsters before they could enter the fishery. Olsen and Koblic (1975) estimated annual natural mortality of juvenile P. argus in Virgin Islands National Park at 34.8% per year. At that rate, about 22% (33 weeks/52 weeks x.348) of the injured lobsters in Biscayne Bay were lost to the fishery as a direct result of their injuries. Since about half of the injuries were due to fishing activity (the difference between the frequency of injuries observed at the end of the season and at the beginning of the season or in an unfished population), about 11% of the loss of lobsters from the fishery was directly attributable to fishing activity in the nursery area. The Biscayne National Monument portion of Biscayne Bay occupies about 100 km^2, and constitutes about eight percent of the shallow seagrass beds utilized by P. argus juveniles in Florida. Since the annual commercial harvest of P. argus in Florida has been about six million lobsters in recent seasons (NOAA/NMFS 1978), and recreational harvest appeared to be about 14% of the total, the annual Florida harvest was about seven million lobsters. The non-harvest loss of lobsters from the Biscayne National Monument portion of the nursery due to fishing activity was approximately 31,000 lobsters (% injured x % natural mortality due to injury x % of nursery affected x total harvest). This annual loss to the fishery could be stopped, and the impact of the fishery on the abundance, age structure, and distribution of juvenile lobsters could be eliminated by prohibiting the harvest of all lobsters in the Bay portion of the Monument, including the tidal creeks. The only costs incurred by this action would be associated with additional surveillance required of already existing law enforcement operations in the bay, and the lost opportunity to catch lobsters there. In return, a major disturbance to Bay biota would be eliminated, and fishery yield in adjacent areas increased.

RECOMMENDATIONS

Create a Lobster Sanctuary

It is the policy of the National Park Service to manage the natural resources entrusted to it in such a way as to leave them unimpaired for the use and enjoyment of future generations. Biscayne National Monument was created in 1968 with the express purpose of protecting intact the unique marine ecosystems of southern Biscayne Bay. The enabling legislation also stipulated that fishing activity would be permitted to continue, as long as that activity did not impair the natural resources of the Monument. The current fishing activity in the Monument is adversely altering the spiny lobster population in Biscayne Bay and is impairing the natural production of lobsters for fishery harvest in areas adjacent to the Monument.

The National Park Service should prohibit all harvest of spiny lobsters by any means in the bay portion of the Monument. To be an effective sanctuary, the tidal creeks between the Keys should be included. All lobster harvest should be prohibited in Sands Cut, Caesar's Creek, Broad Creek and their tributaries. The creation of this lobster sanctuary would yield two major benefits. First the spiny lobster population in the sanctuary would be unimpaired to fulfill its natural role in the bay ecosystem, thereby contributing to achievement of the paramount goal of the Monument. As the juvenile lobsters are allowed to reassume their natural distribution, large dense aggregations of lobsters in the shallow clear waters of the sanctuary would be available for viewing by Monument visitors, and would likely become a primary feature of the Monument's interpretive program. Second, the sanctuary would increase the number and amount of lobsters reaching the Florida fishery. Based on 1977-78 data, the potential increased production would have been in excess of 30,000 lobsters.

The State of Florida recently enacted legislation in recognition of the potential to restore the natural lobster productivity of southern Biscayne Bay and environs by restricting lobster harvest in the Bay. In establishing a lobster sanctuary in Biscayne Bay, the Florida law prohibits the taking of lobsters while swimming on or below the waters of the Bay, but does not prohibit bullynetting or trapping lobsters from boats. The new Florida law also excludes from the sanctuary the important tidal creeks in which juvenile lobsters concentrate during their last weeks and months in the nursery system, and through which virtually all of the juvenile lobsters in southern Biscayne Bay must pass to reach adult lobster habitat on nearby coral reefs.

Costs associated with the sanctuary appear to be negligible. Law enforcement costs should not appreciably change, since it would be easier to enforce a total ban on harvest than to continue the present practice of regulating times and methods of harvest, bag limits and a minimum harvest size. A potential negative impact of the sanctuary would be the concentration in adjacent areas of fishing activity that previously took place in the sanctuary. The potential of this increased fishing activity to adversely affect the lobster resource appears very low, since virtually every legal-sized lobster in Florida is already harvested each year with existing fishing effort. Further, since the specific impacts of current fishing and diving activities on systems adjacent to the sanctuary are presently unknown, it is virtually impossible to do anything but speculate about the potential impacts of increased activity that may result from establishment of the sanctuary. But, those potential adverse impacts do not appear to be significant, and the potential benefits greatly outweigh them.

Monitor Lobster Population

To evaluate the effectiveness of a lobster sanctuary in Biscayne Bay, it is desirable to monitor the two projected benefits. The in-sanctuary lobster population can be periodically (annually) assessed for relative abundance, distribution, condition, and size structure by diver conducted surveys along the western shore of Elliott Key, in Sands Cut and in Caesar's Creek. The results of these surveys can be compared with the data presented in this report to evaluate changes.

Evaluation of increased fishery production presents a much larger task, and one that is presently impossible for the National Park Service to address. Juvenile lobsters leaving the Biscayne Bay sanctuary enter the entire Florida and offshore fisheries from West Palm Beach to Key West. In order to detect increased production from the Bay, it would be necessary to have accurate estimates of the entire fishery, including recreational and commercial harvests, with sufficient precision to detect the projected 0.4% increase. No such fishery-wide monitoring system exists, and the costs of creating one would far outweigh the value of being able to test the sanctuary concept alone. Since the primary goal of the sanctuary is to restore the natural character of the juvenile lobster population in the bay, the impracticality of measuring increased fishery harvest should not be considered a major problem. The National Park Service should continue to monitor both the recreational and commercial fisheries in the Monument, and to cooperate with other agencies in developing accurate and precise measures of fishery harvest and fishing activity for the entire fishery.

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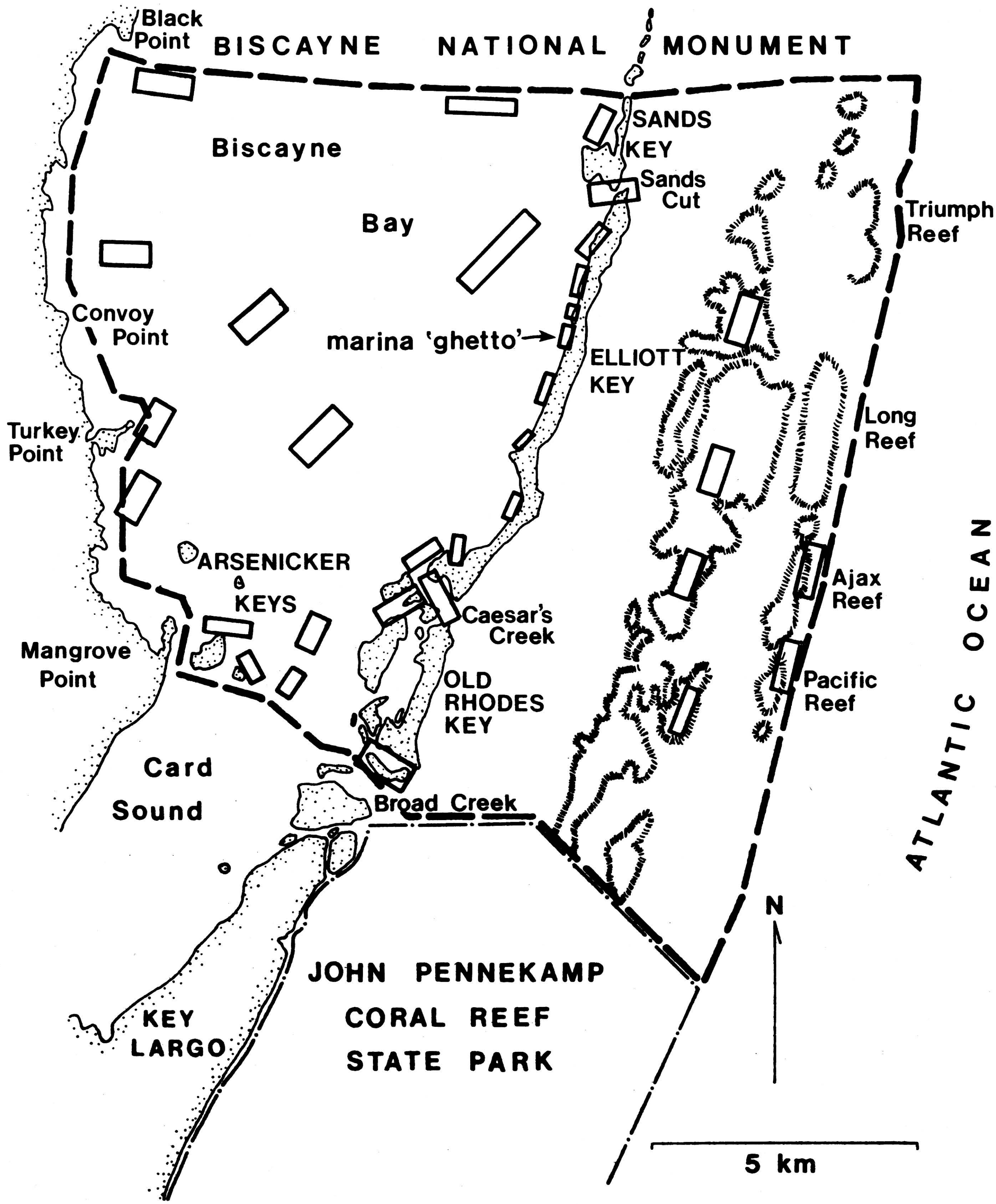
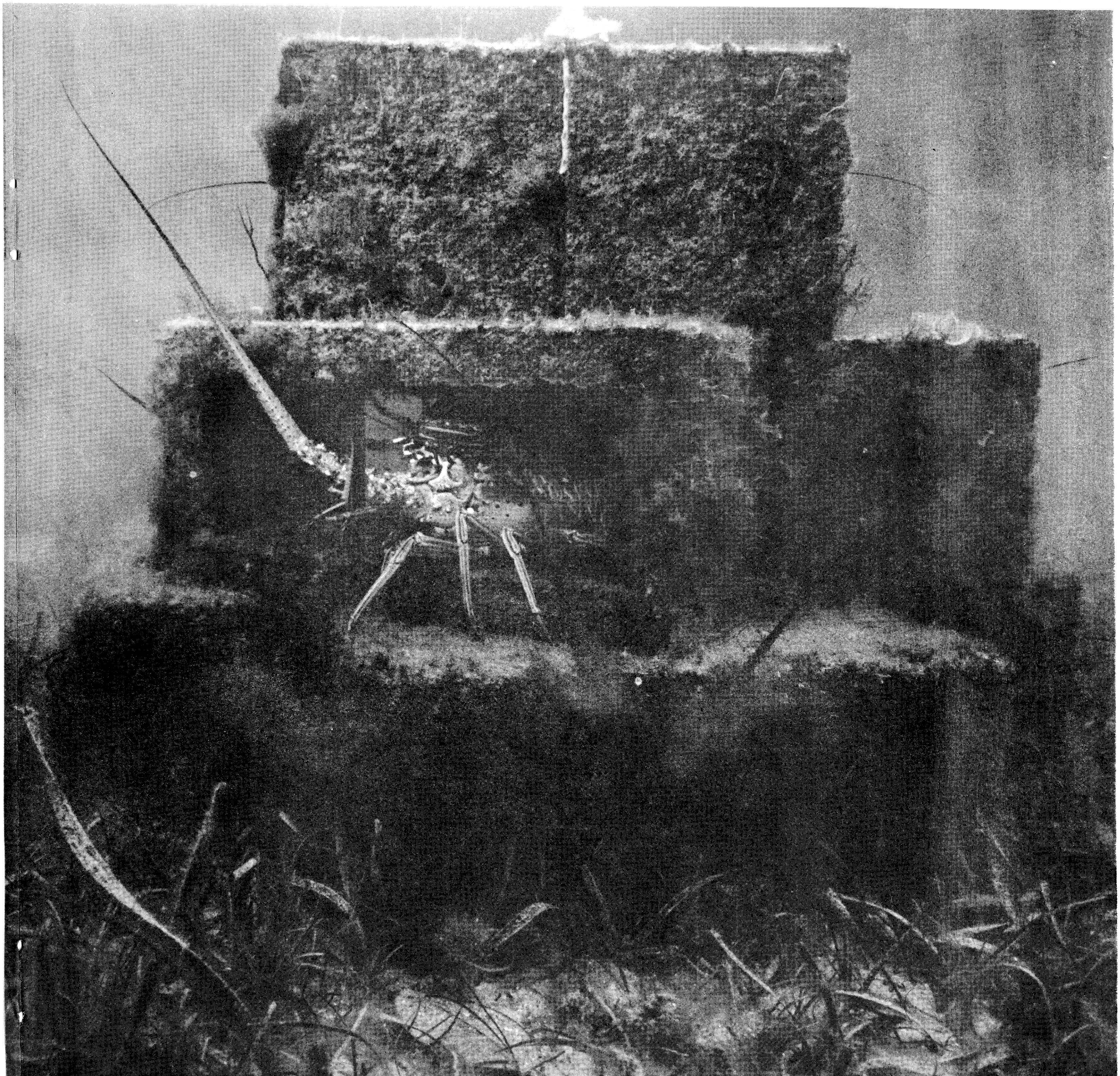


Figure 1. A map of Biscayne National Monument and vicinity showing lobster survey stations and bait shrimp sampling areas.



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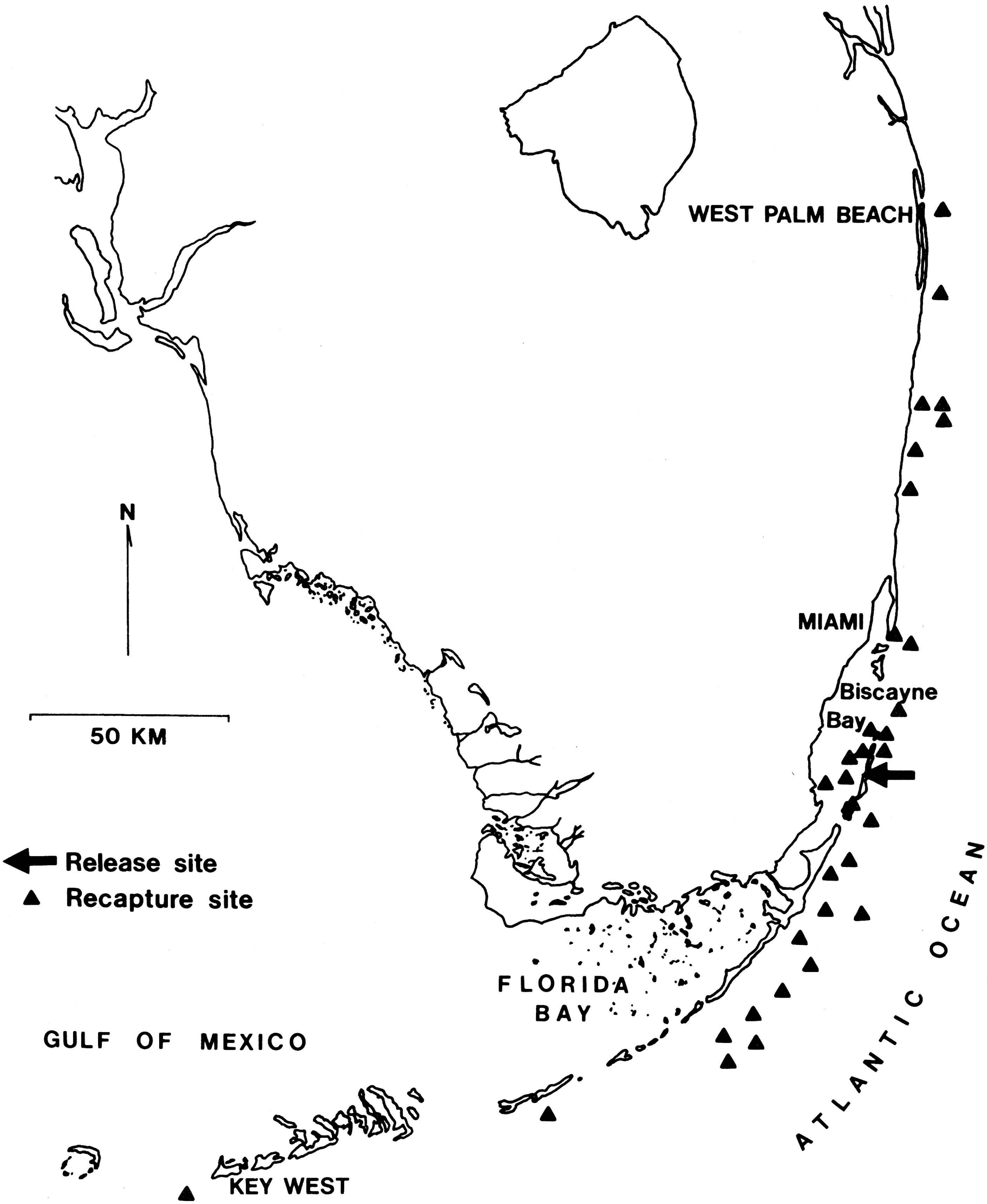

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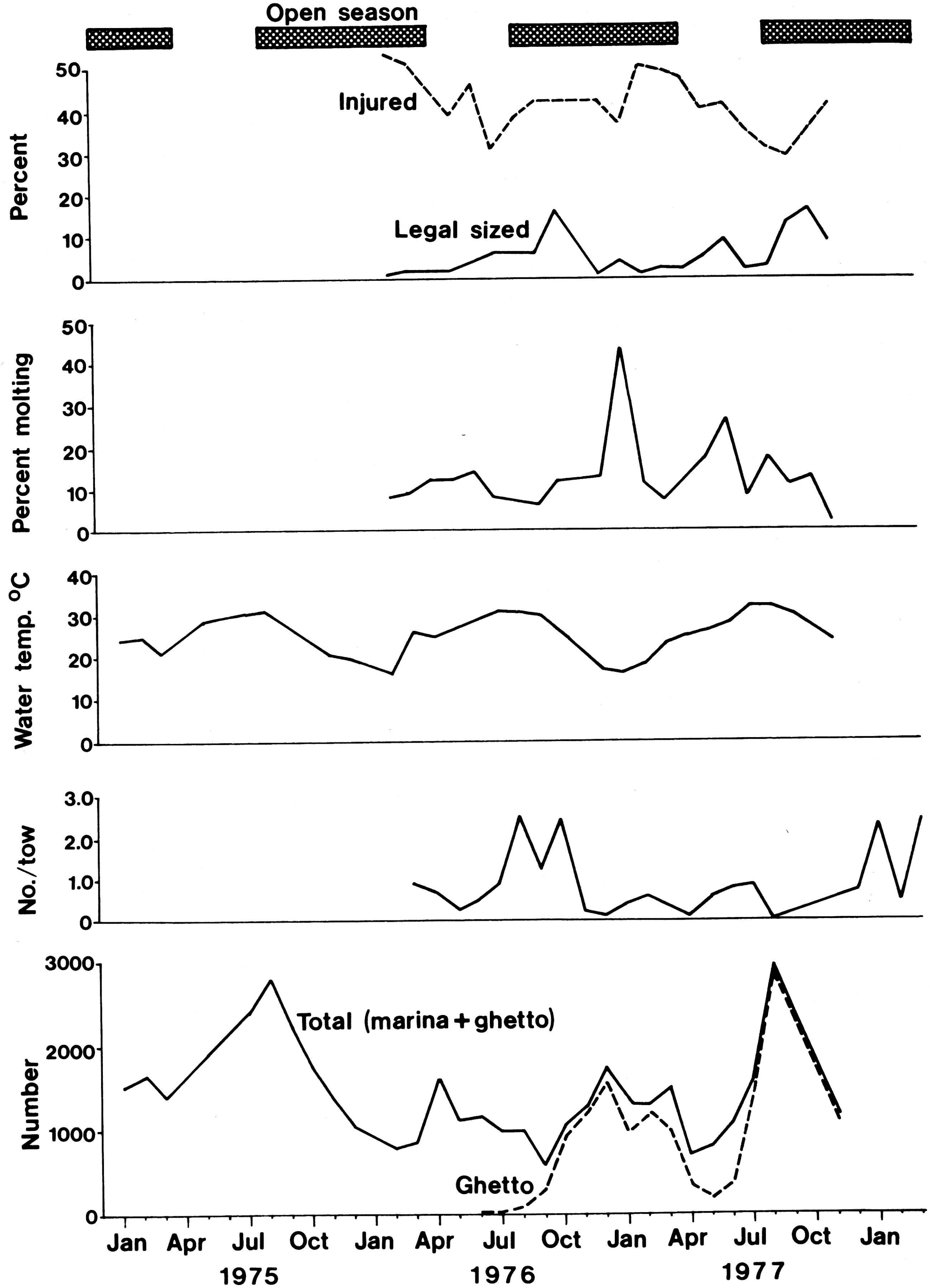

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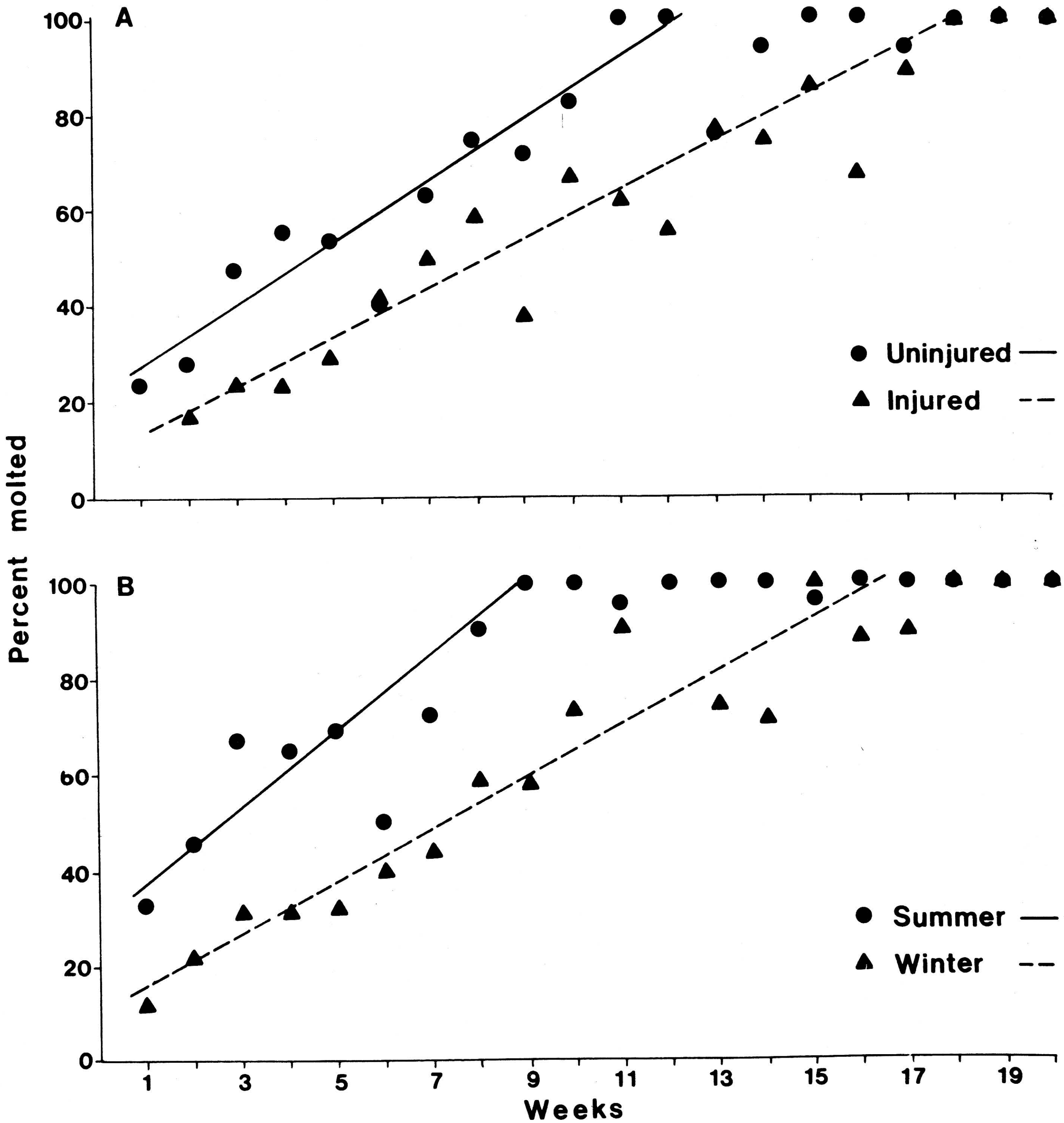

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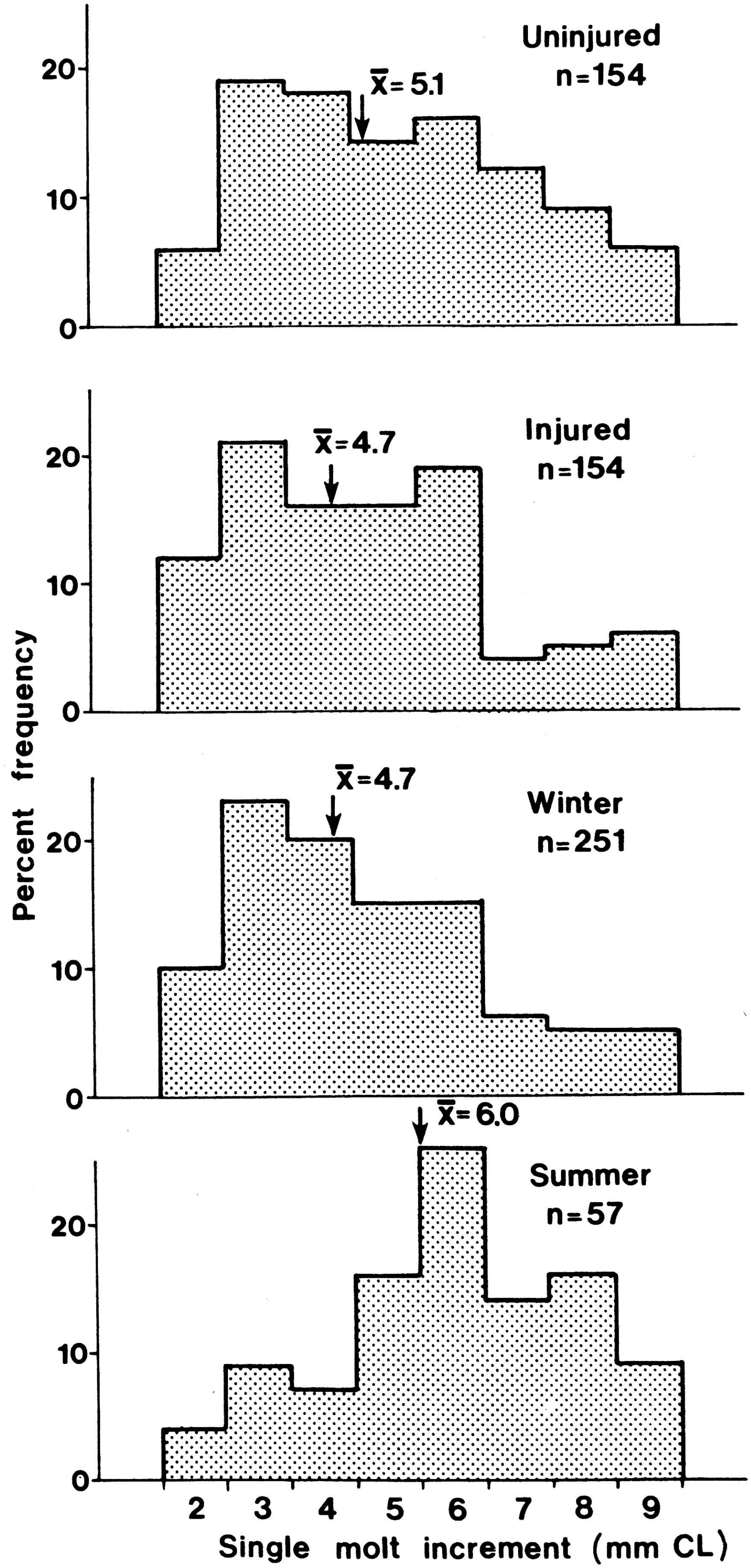

Figure 6. Length frequency distribution of single molt increments of uninjured and injured spiny lobsters, Panulirus argus, in summer and winter in Biscayne Bay, Florida.

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Table 1. Size distribution of spiny lobsters, *Panulirus argus*, in different areas of Biscayne National Monument 1976-77.

	Carapace Length (mm)				
Location	Mean	Min.	Max.	% legal	N
Biscayne Bay	60.3	31.2	101.3	3	1249
Tidal Creeks	64.2	32.7	99.2	17	264
Coral Reefs	74.4	50.3	125.1	61	231

Table 2. Monthly summary of size, molting activity, and condition of spiny lobsters, *Panulirus argus*, and water temperatures in eastern Biscayne Bay, Florida, 1976-77.

Month	Number of Lobsters Measured	Size (mm CL) Min.	Max.	Mean	Percent Molting	Injured	Legal	Mean Water Temp. °C
1976								
February	1247	34	84	56.1	8	53	1	16
March	353	33	83	56.4	9	51	2	26
April	464	38	86	60.0	12	45	2	25
May	362	34	79	59.4	12	39	2	27
June	340	43	87	63.2	14	46	4	29
July	414	15	85	61.6	8	31	6	31
August	398	37	83	63.5	7	38	6	31
September	217	40	96	63.1	6	42	6	30
October	25	35	89	64.6	12	24	16	26
December	139	38	85	54.7	13	42	1	17
1977								
January	86	33	85	57.7	43	37	4	16
February	619	30	81	55.5	11	50	1	18
March	387	31	88	57.3	7	49	2	23
April	272	39	80	59.2	12	47	2	25
May	220	39	101	61.8	17	40	5	26
June	268	27	85	63.6	26	41	9	28
July	322	35	86	62.1	8	35	2	32
August	414	30	84	63.6	17	31	3	32
September	454	30	97	66.9	11	29	13	30
October	335	32	99	65.3	13	35	16	27
November	307	32	92	60.1	2	41	9	24
Total/Mean	7,643/	33.6	87.4	60.7	12.8	40.3	5.3	25.7

Table 3. Summary of standard diver surveys at 11 stations in eastern Biscayne Bay, Florida, for spiny lobsters, *Panulirus argus*.

Number of Lobsters Observed

Month	Year 1976	1977
January		81
February	54	80
March	301	80
April	240	40
May	291	163
June	160	122
July	155	176
August	95	
September	82	
October	67	
November	66	
December	28	

Table 4. Comparison of visual counts of lobsters in the Elliott Key Marina and mark/recapture population estimates, after Schnabel (Ricker, 1975).

Date	Visual Count (± 2 S.E.)	Schnabel Estimate (± 95% Conf. Interv.)	Visual x 100 / Schnabel
February 1975	1661 ± 564	9767 ± 194	17
February 1976	914 ± 527	2535 ± 99	36
February 1977	1204 ± 462	5029 ± 139	24

Table 5. Comparison of the size (Carapace Length) of spiny lobsters (*P. argus*) in Sands Cut before and after the two day sport season, 20-21 July 1977.

	Number of *P. argus*								
					Carapace Length (mm)				
Date	Total				< 76.2			≥76.2 (legal)	
		CL (mm)							
	N	$\bar{X}$	SD	R	N	$\bar{X}$	SD	N	%
Before (19 July)	83	71.3	10.2	44.2-99.2	55	66.0	7.5	28	34
After (26 July)	80	64.1	10.3	42.0-87.0	69	61.1	8.0	12	15

Table 6. Sizes of spiny lobsters, Panulirus argus, caught at night by bait shrimp trawls in Biscayne Bay, Florida.

		Carapace Length (mm)				Mean	
Date	N	Mean	Min	Max	Mode(s)	Water Temp. (^{o}C)	Salinity (ppt)
1976							
March	14	30.6	12.5	53.7	27	-	-
April	16	24.3	11.1	43.9	17, 32, 42	-	-
May	15	22.7	11.1	58.3	12, 27, 37	29.4	35.9
June	20	22.1	14.8	32.5	15, 27	-	-
July	40	28.1	12.4	55.2	22, 42	-	-
August	129	32.8	15.2	85.1	27	30.7	19.0
September	58	36.0	8.5	70.1	38	30.2	22.5
October	150	30.1	11.6	56.2	38	27.6	34.0
November	9	-	-	-	15	24.5	27.6
December	1	40.5	40.5	40.5	-	20.3	27.6
1977							
January	19	43.9	16.4	56.0	15, 40, 55	-	-
February	27	37.7	14.6	68.1	17, 40, 65	-	-
March	10	41.0	33.0	56.2	45	-	-
April	4	36.4	28.2	46.2	30	-	-
May	17	37.6	18.1	72.0	15, 35, 45	25.5	28.2
June	16	37.3	15.5	61.6	20, 52, 61	30.7	33.9
July	66	24.7	11.3	76.2	18, 48	31.0	33.9
August	0	-	-	-	-	28.1	26.4
September	8	25.6	21.5	30.2	25	31.9	3.5
December	8	39.1	31.1	49.6	38	-	-
1978							
January	31	35.7	19.2	52.2	35	-	-
February	6	38.8	26.0	47.7	38	18.2	31.2
March	42	38.4	15.7	64.0	38	22.8	26.0
Total/Mean	706	32.0				27.0	26.1

Table 7. Comparison of mean number of juvenile spiny lobsters caught per tow by live bait shrimpers in Biscayne Bay, Florida, 1968-69 and 1976-78.

	Years			
	1968-69[a]		1976-78	
Month	No. Lobsters per Tow	N[b]	No. Lobsters per tow	N[b]
January	1.37	62	0.75	67
February	0.58	65	0.57	58
March	0.86	51	0.77	86
April	1.64	79	0.23	86
May	1.53	75	0.36	87
June	0.74	38	0.57	63
July	2.69	55	0.87	132
August	2.33	36	1.57	82
September	10.97	35	0.66	98
October	1.39	36	2.39	59
November	4.68	25	0.19	48
December	3.73	44	0.19	47
Grand Mean/Total	2.31	284	0.77	392

[a]From Eldred et al., 1972

[b]N = Number of tows;
1968-69 Tows seldom exceeded 20 minutes, and
1976-78 Tows averaged 21 minutes

Table 8. A comparison of growth factors determined from 1,604 observations on 534 tagged juvenile spiny lobsters, *Panulirus argus*, in Biscayne Bay, Florida in 1976 and 1977.

	Mean Growth Variables			
	Number of Growth Intervals Observed	Intermolt Period (weeks)	Growth Rate (mm CL/week)	Water Temperature (°C)
Season				
Winter	656	15	0.31	21.1
Summer	146	8	0.75	29.1
Condition				
Injured	465	15	0.31	n/a
Uninjured	379	10	0.51	n/a
All Observations	844	12	0.41	25.7

Table 9. A comparison of mean molt increments (mm change in carapace length) of juvenile spiny lobsters, Panulirus argus, in Biscayne Bay, Florida.

	Molt Increments			
	Summer	Winter	Injured	Uninjured
$\bar{x}$	6.0	4.7	4.7	5.2
$S_{\bar{x}}^2$	3.2	3.6	3.8	3.8
t, 306 d.f.	7.75**		2.25*	

*Significant at the 95% level

**Significant at the 99% level