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LOOE KEY NATIONAL MARINE SANCTUARY

JOHN H. HUNT, THOMAS R. MATTHEWS, DAVID FORCUCCI, BRENDA S. HEDIN,
AND RODNEY D. BERTELSEN

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NOAA TECHNICAL MEMORANDUM

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MANAGEMENT IMPLICATIONS OF TRENDS IN THE POPULATION DYNAMICS OF THE
CARIBBEAN SPINY LOBSTER, Panulirus argus, AT LOOE KEY NATIONAL
MARINE SANCTUARY

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A two year study designed to delineate trends in abundance and population dynamics of the spiny lobster, <i>Panulirus argus</i>, in Looe Key National Marine Sanctuary was conducted from April 1987 to April 1989. The goal was to evaluate existing management strategies, primarily the effectiveness of the non-consumptive core area, in providing protection for spiny lobsters. Abundance fluctuated within each year, but did not increase in any zone over the course of the study. Mean density on the Fore Reef was 64.9 lobsters/ha, less than half that recorded from the lobster sanctuary at Fort Jefferson National Monument (Dry Tortugas). During the open fishing season, abundance decreased in three of six zones while carapace length declined throughout the Sanctuary. The largest lobsters were found on the Fore Reef. There, sex ratio was heavily skewed toward females and nearly 100% were carrying external eggs or ripe ovaries. Multiple spawning was commonplace. In contrast, on the adjacent Reef Flat, lobster size was reduced, males more abundant, and reproductive activity reduced. Residency was greatest within the Core Area. Core Area lobsters foraged nocturnally in the rubble and mixed rubble/grass habitats on and surrounding the Reef Flat. Core Area lobsters were captured by fishermen in those regions. We conclude that the existing Core Area does not offer much additional protection to spiny lobsters. We recommend that its size be increased to include the entire foraging range and habitat of Reef Flat and Fore Reef lobsters plus a reasonable surrounding buffer.				
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ABSTRACT

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The largest lobsters were found on the Fore Reef. There, sex ratio was heavily skewed toward females and nearly 100% were carrying external eggs or ripe ovaries. Multiple spawning was commonplace. In contrast, on the adjacent Reef Flat, lobster size was reduced, males were more abundant, and reproductive activity was reduced. Residency was greatest within the Core Area. Core Area lobsters foraged nocturnally in the rubble and mixed rubble-grass habitats on and surrounding the Reef Flat. Core Area lobsters were captured by fishermen in those regions. We conclude that the existing Core Area does not offer much protection to spiny lobsters. We recommend that its size be increased to include the entire foraging range and habitat of Reef Flat and Fore Reef lobsters plus a reasonable surrounding buffer.

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PREFACE

Special thanks are due to B. Blonder, D. Heatwole, and C. Schultz for their considerable input into the design and tireless effort in the field. Also helping in the field were M. Butler, D. Gauld, M. Lusk, B. Herrnkind, and C. Sandusky. W.G. Lyons provided critical advice many times. We thank the Florida Park Service for use of boat dockage at Bahia Honda State Park. We especially thank the staff of Looe Key National Marine Sanctuary, B. Causey, B. Green, K. Hartsing, L. MacGlaughlin, and J. Tatgenhorst for their individual and collective support. The project was funded through support from the National Marine Sanctuary Program.

INTRODUCTION

Looe Key National Marine Sanctuary is located about 9 km south of Big Pine Key, Florida. The 18.2 km² Sanctuary is composed of a spur-and-groove bank reef (Jaap 1984, Wheaton and Jaap 1988) and surrounding environments (Figure 1). The Sanctuary is divided into seven management units that roughly correspond to physiographic zones (Dobbins 1983). These units are the Deep Ridge, the Deep Reef, the Intermediate Reef, the Fore Reef, the Reef Flat, the Sand Plain, and the Back Reef.

The Deep Ridge has been described as a patchy, low-relief, hard-bottom ridge offering limited habitat structure (Antonius et al. 1978). Within LKNMS, it has been reported to occur in depths of 40-46 meters depth. However, seismic profiling conducted by the U.S. Geological Survey failed to find the ridge (Lidz et al. 1985, Wheaton 1987). Searches conducted during the course of a deep-water P. argus project supported by the NOAA National Underseas Research Center at the University of North Carolina at Wilmington in September 1987 using the *Johnson Sea Link Submersible* and fathometer transects from the *R/V Edwin Link* were also unable to find the deep ridge inside LKNMS (W. G. Lyons and J.H. Hunt pers. obs.).

The Deep Reef and the Intermediate Reef are intertwined. Both environments are characterized by low-relief (2-3 meters), partially filled spur-and-groove formations (Dobbins 1983). The primary shelters for spiny lobster are massive coral heads that

have been eroded on their undersides. These reefs are most developed in the western section of LKNMS. The Intermediate Reef extends from about 9 meter to 23 meter depths. At about 23 meters the gradual sloping topography steepens signifying the beginning of the Deep Reef which then plunges precipitously to a sand bottom in about 30 meters.

The Fore Reef is characterized by high-relief coral spurs that are separated by sandy channels called grooves (Dobbins 1983). Spurs may be as much as 7 meters high. Water depths range from 2 to 9 meters. Lobster habitat consists of caves and spur overhangs near the bottom; behind the plate coral, Agaricia agaricites, on spur sides; and under massive star corals and brain corals and in large holes on the upper surface of the spurs.

Lobster habitat on the Reef Flat is of two distinct types, isolated patches of coral heads and grass-bed blowouts. The coral heads, irregularly shaped mounds consisting mainly of Montastrea spp. and Acropora palmata, provide permanent lobster habitat. Blowouts are large sand structures formed by erosion in seagrass beds (Patrignin 1975). Wave action erodes blowouts through a cliff face, undercut, collapse, cliff face cycle. It is the undercuts that provide an ephemeral habitat for spiny lobster. The Reef Flat is surrounded by extensive areas of rubble, most of which is too compacted to provide shelter for lobster.

The Sand Plain is located to the east and to the west of the Core Area and consists of large expanses of unconsolidated substrate intermixed with small patches of mostly sparse seagrass.

Lobster habitat there is widely spaced and is composed primarily of small isolated corals.

The Back Reef is located in the northern section of the Sanctuary, and consists of an expansive area of seagrass beds and a line of patch reefs along the nearshore boundary (Figure 1) where water depth is about 8 meters. These patch reefs provide most of the spiny lobster shelter habitat in the Back Reef. The patch reefs in the eastern portion of the Sanctuary are dome shaped (3 meter relief), whereas those in the western part are typically low-relief hardbottom. In the eastern region, lobster shelter is concentrated under numerous star corals and brain corals. In the western region, shelter is more sparse, consisting of widely spaced corals and solution holes. Solution holes were formed during periods of sub-aerial exposure in the limestone bedrock.

A central goal of the National Marine Sanctuary Program is to enhance protection of important marine habitats while simultaneously providing opportunity for compatible consumptive activities, such as fishing, to take place. The seven management units of Looe Key National Marine Sanctuary (LKNMS) are divided into two primary management areas, the overall Sanctuary (Figure 1) and the 0.5 km² Core Area, comprising 3% of the total area of the Sanctuary (Figure 2). The Core Area contains portions of the Fore Reef and portions of the Reef Flat where more extensive management regulations are in effect. Regulations for the Core Area are designed to protect the Sanctuary's primary feature, the spur-and-groove coral reef. Activities that may damage the reef, such as

anchoring, touching or standing on corals, are prohibited there. Recreational lobster harvest by divers is permitted within the Core Area, but commercial lobster trapping is prohibited. However, trapping is allowed throughout the remainder of the Sanctuary. Previous attempts to further limit lobster harvest within the Core Area through enforcement of the prohibition against touching coral (B. Causey, LKNMS manager, pers. comm.) have met with only partial success. Results obtained during the course of this study and presented previously (Blonder et al. in press), indicate that harvest by recreational divers still exerts considerable influence on lobster abundance on the Reef Flat.

The Caribbean spiny lobster, Panulirus argus, constitutes the major commercial and recreational fishery in the Florida Keys. Average annual commercial harvest is about 2500 tonnes and has ranged from about 1800 tonnes to 3600 tonnes for the past fifteen years (Powers and Sutherland 1989). Recreational harvest has been estimated at 10% of commercial harvest (Zuboy 1980). During the special two-day sport-diver season, as many as ten thousand boat trips in search of spiny lobster may occur (Austin 1986). P. argus is abundant in the offshore reef environment; lobster density at protected offshore reefs has been estimated as high as 328.5 ha⁻² (Davis 1974). Lobsters dwell in dens on reefs during the day, and move to surrounding habitats at dusk to feed (Herrnkind et al 1975). In addition to its fishery importance, P. argus is, because of its abundance and habits, a key component affecting the structure of offshore reef and associated communities (Davis 1975, 1977a,

1977b).

Panulirus argus larvae inhabit oceanic waters where they pass through 11 stages (Lewis 1951, Baisre 1964) during a period estimated to be more than six months (Sims and Ingle 1967) before they metamorphose to a transitional swimming stage termed a puerulus (Lyons 1980). Panulirus argus pueruli arrive along the southeastern Florida coast during every month of the year (Little 1977, Little and Milano 1980, Menzies 1981, Marx 1986) by swimming at night (Calinski and Lyons 1983) during dark lunar phases (Witham et al. 1968, Little and Milano 1980). Pueruli transit channels between the Florida Keys (Sweat 1968) to enter nursery areas in Florida Bay, where they preferentially settle into clumps of the red alga, Laurencia (Herrnkind and Butler 1986, Butler and Herrnkind 1991). Here the pueruli metamorphose into juveniles in seven to nine days (Butler and Herrnkind 1991).

Juveniles take up solitary residence in these algal clumps (Marx and Herrnkind 1985a, 1985b), where they remain for two to three months. Upon attaining 15-16 mm carapace length (CL), they enter holes and crevices in rocks, corals, and sponges (Davis 1978, Andree 1981, 1982, Marx and Herrnkind 1985a). At approximately 25-35 mm CL, lobsters abandon solitary residence to congregate in rocky dens (Davis 1978). Most of their remaining juvenile life is spent foraging and seeking shelter appropriate for their increasing size. Juveniles reside in nurseries for 15 months (Calinski 1985) to 2 years (Davis 1978). Biscayne Bay, Florida Bay, and oceanside shallows (< 3 meter depths) of the Florida Keys are the principal

Florida nurseries supporting juveniles (Eldred et al. 1972, Warner et al. 1977, Davis 1978, Lyons et al. 1981) in residence or in transit toward adult habitat.

Older juveniles migrate from inshore nurseries and begin adult life after arrival at seaward reefs (Davis 1978, Lyons et al. 1981). Migratory routes from bays to reefs have been demonstrated through tagging studies (Little 1972, Warner et al. 1977, Davis and Dodrill 1980,) and by population size-frequency progressions (Warner et al. 1977, Lyons et al. 1981). Average size in undisturbed adult populations is near 100 mm CL (Davis 1974), and resident adults exhibit only limited seasonal movements related to reproduction (Davis 1977a). Reproductive activity, as indicated by females with spermatophores or eggs, is entirely an oceanside activity; most mature lobsters occur near offshore reefs (Warner et al. 1977, Lyons et al. 1981, Gregory et al. 1982). Spawning occurs at those offshore reefs, and larvae enter oceanic waters at or near those sites.

The goal of this study was to examine the effectiveness of the LKNMS management strategy, as it pertains to P. argus, in meeting the goals of the Sanctuary program. To this end, we conducted extensive sampling throughout the Sanctuary. Data on trends in P. argus abundance, plus aspects of the population structure that depict the usage pattern of LKNMS by P. argus, are presented. We utilize a synthesis of these data to evaluate and suggest adjustments to the LKNMS management strategy.

METHODS

Site Selection and Establishment

Sampling sites were established in the Deep Ridge (OR), Deep Reef (DR), Intermediate Reef (IR), Fore Reef (FR), Reef Flat (RF), and Back Reef management units of Looe Key National Marine Sanctuary to examine trends in spiny lobster abundance and population dynamics (Figure 1). In this report, we utilize the term "zone" to denote a management unit. The Deep Ridge was coded as OR (offshore ridge) to distinguish it from the Deep Reef. The RF was further subdivided into two subzones, the reef-crest coral heads (RC) and the seagrass blowouts (RB) farther from the FR (Figure 2). All Back Reef sampling was conducted at the patch reefs. Consequently, the Back Reef is renamed Patch Reef (PR) in this report. The Sand Plain was not surveyed. Sampling was conducted in deep water (OR and DR) using traps and in shallow water (IR, FR, RF, and PR) using SCUBA.

Thirty wire lobster traps with wooden-slat tops were deployed in two trot lines in 40-46 m depths in the OR. Fifteen standard wooden-slat lobster traps were placed in 33 m depth in the DR. Traps were pulled in the OR from April 1987 through July 1988 and in the DR from April 1987 through March 1989. Because OR traps were in a southbound shipping lane, trap loss was severe. The interval between trap pulls (i. e. soak period) ranged from 8 to 36 days, depending upon weather conditions and our ability to relocate trap lines. Most soak periods (73%) were 12-16 days. Catch per

unit effort was calculated as catch per trap adjusted to a one week soak period (Heatwole et al. 1988, Lyons and Hunt in press).

In shallower waters, 23 permanent sites were established and sampled using SCUBA from April 1987 until April 1989 (Table 1). Sites were sampled biweekly during year 1 and once every four weeks during year 2. Of a possible 897 scheduled samples, 835 (93%) were completed. Most missed samples occurred during Fall 1987 soon after the passage of Hurricane Floyd. Twenty-nine missed samples occurred in the PR; the remainder were spread evenly among the other zones. Following the end of the two year study period, some sites were sampled aperiodically through June 1989. Data from these samples were used to examine size-structure, sex ratio, and reproductive seasonality. They also provided recaptures for residency analysis.

Sites were selected in all zones using a stratified random design. Each zone was divided into eastern and western regions to prevent possible biases caused by changes in the habitats that occur along an east-west gradient at LKNMS (B. Causey, pers. comm). Sites were selected randomly within regions. With the exception of the IR, key habitat features (e.g. sand channels in the forereef) were used to establish the total possible sites from which the study sites were selected. Different habitat features were utilized in each zone. IR sites were established at the bases of randomly selected mooring buoys. Use of mooring buoys enabled each site to be quickly found in a zone where diver bottom time was limited. Sand channels were used to locate sites in the FR. All

sand channels were numbered using an aerial photograph, and sites were randomly selected from the numbered list. The RF and PR were surveyed by towing divers who dropped numbered buoys on or near all coral heads, blowouts and individual patch reefs. Sites were then selected randomly from the total of all possible sites in each zone. Some coral heads in the shallowest portions of the reef crest were excluded because of concerns that we might impact the habitat there during rough weather.

Habitats suitable for spiny lobster shelter varied among the different zones of LKNMS. Consequently, site configuration was different in each zone. Each IR site consisted of a 100-m belt transect. A swath 5-m wide was sampled on each side of the transect resulting in a 1,000-m² site. In the FR, each site consisted of the vertical sides and tops of two reef spurs on either side of a central sand channel. Site areas were dictated by the sizes and shapes of each spur and ranged from 909-1863 m² (Table 1). Three RC sites consisted of single Acropora palmata mounds isolated from other potential lobster shelters by 5-20 m of rubble. The remaining RC site was a 551 m² area of mostly Montastrea heads. In blowouts, lobster shelter occurs in undercuts along the linear cliff face; small coral rocks sometimes provide shelter in the sand away from the cliff face. Patch reefs at the eastern end of the Sanctuary were all mounds surrounded by sand; these were sampled in their entirety. Two PR sites (5 and 6) in the western part of LKNMS were located in a continuous expanse of hard-bottom. These sites were arbitrarily demarcated by using natural features and

buoys that floated about 2 m above the bottom along the site boundaries.

Sampling Design

All 23 sites were searched completely for spiny lobsters. At 14 sites, lobsters were counted but were otherwise left undisturbed (Table 1). Lobsters were counted and captured at the remaining 9 sites. At all PR sites, at RF4, and at four of six FR sites, den locations were marked permanently by nailing a numbered tag into the rock adjacent to each den. A den was initially located by the presence of one or more lobsters. Each marked den was refound and searched for lobsters during every survey after its initial discovery. The number of lobsters was recorded for every marked den; zero was recorded for vacant dens. The number of lobsters per site was calculated as the sum of the lobsters in marked dens. At sites where dens were not permanently marked, the total number of lobsters observed was recorded. Other species in the families Palinuridae, Scyllaridae, and Synaxidae were also counted when they were encountered.

We are confident that all sites were searched completely regardless of environmental conditions. Diver bottom time was unlimited in all areas except the IR. The large number of dens on every site where dens were permanently marked (Table 1), combined with their being spread throughout each site and our protocol for censusing every marked den, ensured that those sites were searched thoroughly. Comparisons between permanent den sites containing

marked dens and other sites on the FR revealed no differences in abundance. IR sites were searched on both the outgoing and the return swim along the belt transect; divers exchanged sides on the return trip. Additional lobsters were found on the return swim in only three cases.

The location within a den (floor, wall, ceiling) was recorded for every lobster, their sizes were estimated, and an attempt was made to determine their sex and the presence of external eggs. However, size, sex and reproductive condition were difficult to ascertain in dens that contained more than three lobsters.

The number of lobsters was summed for each site, then adjusted to a density (lobster/ha) estimate. Density was used to remove variability in the number of lobsters observed per site caused by the wide range of site areas (Table 1) and conditions across all zones. Because of the known clumped distribution and gregarious behavior of P. argus (Berrill 1975, Herrnkind et al. 1975, Herrnkind and Lipcius 1989, Zimmer-Faust and Spanier 1987) large sites were sampled to ensure that an accurate estimate of lobster abundance would be generated. Densities in the IR, FR, and PR were calculated by dividing total lobster count by site area. In the RC and RB, the proportion that study sites represented of the total area was determined using an aerial photograph taken during the NOAA photogrammetry survey in 1985. Density was then calculated using the equation:

$$\text{Density} = \text{Lobsters per site} / P \times (\text{Total area of region});$$

where P is the proportion that each site represented of the total available shelter. In the RC, $P = 1$ of 87 coral heads 2 m in diameter or greater, or 0.0115. In the RB, P fluctuated in direct relation to blowout length (Table 1). Total areas of the RC and RB were 6.5 ha and 16.8 ha, respectively (R. Rodkey, NOAA, pers. comm).

Although numerous factors other than density can affect catch rates, traps do provide a gross index of animal abundance (Miller 1989). The correlation between catch per trap and density was good ($r^2 = 0.74$) during a study examining population dynamics of Panulirus cygnus in western Australia (Morgan, 1974). Miller (1989) compared diver estimates of rock crab, Cancer irroratus, density in Nova Scotia to catch rates in traps and found them to be in fair agreement. Given the possible confounding factors affecting trap catch, no attempt was made to convert catch rates in traps to density in this study, but they are used to represent the relative changes in abundance for lobsters in the DR and OR.

All captured lobsters were brought to the research vessel and double-tagged with a sphyron or t-bar tag inserted into the dorsolateral extensor muscle between the cephalothorax and abdomen (Davis 1978, Herrnkind et al. 1975) and with a plastic bird band around the base of the antenna. The antenna tags were color-coded to indicate zone of initial capture. Data recorded for each lobster were zone, site, date, den number, carapace length (CL) to nearest mm, sex, presence and condition of spermatophores and eggs, presence of ripe ovaries, molt stage, and number of leg and antenna

injuries. Molt staging was accomplished by clipping one pleopod from each lobster and examining it under a microscope to determine the extent of epidermal separation (Aiken 1973, Lyle and MacDonald 1983). Previously tagged lobsters were coded as recaptures. All lobsters were returned to the den from which they were captured.

Data Analysis

Estimates of abundance were calculated using different techniques in different zones. Abundance was expressed as weekly catch/trap in the OR and DR. Elsewhere, density (lobsters/ha) was estimated using methodologies dictated by the unique sampling requirements of each zone. These differing methodologies result in adjustments to the raw counts that, while biologically meaningful, cause variance to vary non-linearly with the mean (Bliss 1971, Sokal and Rohlf 1981, Ewing et al. 1988).

Recognizing and understanding the scope of long-term and short-term trends in lobster abundance and lobster size are critical for the development of a management plan concerning lobsters and lobster habitat in Looe Key National Marine Sanctuary. A trend is a consistent increase or decrease of a measured parameter over time or distance. Evaluation of the relative importance of natural processes or fishery impacts is aided by knowledge concerning the timing, duration and direction of these trends. We employed the Mann-Kendall sign tests to detect trends within zones and seasons. We also used the Mann-Kendall sign tests to determine homogeneity of trends between zones, years and

seasons. We used the Sen estimator of slope to quantify and confirm the Mann-Kendall results. The Mann-Kendall sign tests and Sen estimator of slope contain algorithms for determining significance levels. The Mann-Kendall sign tests produce χ^2 test statistics for homogeneity and a Z statistic for individual signs. The Sen estimator of slope produces a Z statistic. Gilbert (1987) and van Belle and Hughes (1984) explain and review these methodologies in detail. Parametric methods such as linear regression and covariance models have historically been used to evaluate trends. However, much of the biological data collected in field studies creates difficulty in meeting the assumptions of parametric methods (in particular, the assumptions of normality and independence). These problems, plus additional nonlinear abnormalities such as missing data, outliers, and seasonality occurred in this study and further complicate parametric analysis. These nonparametric methods are more flexible and can handle these characteristics of our data.

Data collected to examine other aspects of population dynamics do not present the analytical problems and biases found in the abundance data. These data constitute observations of characteristics for individual lobsters. Where appropriate, comparisons were made using analysis of variance (ANOVA), preceded by an F-max test for homogeneity of variance (Sokal and Rohlf 1981). Sex ratios were transformed using an arc-sine transformation prior to testing for the assumptions of ANOVA. Post-hoc comparisons of means utilized the GT-2 test. Type I error

in GT-2 tests is controlled experimentwise, resulting in greater confidence when finding significant differences (Day and Quinn 1989).

Tag-Recapture

Recaptures were used solely to investigate residency within LKNMS. Every lobster record was summed across its entire recapture history to create residency times and movement patterns. A resident lobster was defined as one whose initial capture and all subsequent recaptures were made within one zone and residency time was defined as the number of days between the initial capture and last recapture. The tag-recapture program was advertised through word of mouth directly to recreational and commercial fishermen that utilized the Sanctuary. No media advertising was conducted, nor were rewards for returned tags offered. The recapture data set is also limited by the sampling constraints of this study. The extensive sampling regime limited searching for tagged lobsters from established sites. For example, if a lobster moved away from an FR site to an adjacent spur, it would no longer be detected. Thus, recapture rates and residency times must be considered to be minimum values.

Additional Sampling

Transects were sampled quantitatively on the Reef Flat and adjacent rubble areas on five occasions during the night in order to determine the foraging patterns of lobsters dwelling in the Core

Area. A grid consisting of one 200 m tape crossed perpendicularly by five 100-m belt transects was placed on the seabottom at the randomly selected forage sites. Each transect was sampled by two divers using underwater lanterns. Each diver searched one half of a belt transect, counted, and captured, the lobsters. All lobsters were brought to the research vessel, measured, tagged and released. We estimate that total belt transect width ranged between six and eight meters (3-4 m per diver), depending on water visibility. For the purpose of estimating density, we have conservatively chosen an eight-meter width; thus, total area per transect was 800 m². The origin and direction of the 200-m central transects were selected by first, randomly selecting one of twelve approximately two hectare areas delineated on a chart of the reef flat and second, by randomly selecting one of eight 45 degree compass directions (e.g., 0, 45, 90, etc.). These sites were sampled from one to three consecutive nights depending upon weather conditions.

Transects were strategically placed on and adjacent to the reef crest, west rubble ridge, and the northwest and northeast portions of the rubble ridge surrounding the Reef Flat on 19 July, 1989 to examine further the foraging habitat preference of P. argus. Three, roughly parallel, 100-m transects were placed at each site; one transect was placed entirely on rubble, and the others were placed in adjacent grass, sand and mixed rubble-grass areas. Each site was sampled simultaneously by four teams of divers twice during the night. The first dive started at 2130 hrs; the second at 2300 hrs. Lobsters were counted during the

first dive, but otherwise left undisturbed. They were captured during the second dive.

Additional haphazardly selected areas within the forereef and reef flat were searched in their entirety, and lobsters captured, tagged, and released. The purpose of these efforts was to increase the sample size of lobsters for use when examining lobster size, sex ratio, reproductive status, and other population parameters. As long as all lobsters were captured during these dives, then the data derived from them were considered to represent the conditions in those zones at the time of sampling. Only if lobsters were captured according to a selection criteria such as, capture only large previously tagged lobsters, would these data be biased.

RESULTS

Abundance

During the entire study, 4446 P. argus were observed by divers at five zones. An additional 1396 lobsters were captured in traps deployed at the Deep reef and Offshore ridge. In addition, 1907 Panulirus guttatus, 76 Scyllarides aequinoctialis (Scyllaridae), 15 Scyllarides nodifer (Scyllaridae), 4 Parribacus antarcticus (Scyllaridae), and 3 Palinurellus gundlachi (Synaxidae) were observed. Most P. guttatus were observed on the Forereef. One S. aequinoctialis was repeatedly observed on the ceiling of the same den of PR 6 during 20 of the 23 times that den was sampled (October 1987 - April 1989).

Density fluctuated from ten- to thirty-fold between times of low abundance to times of high abundance (Table 2). Density was highest in the PR. The maximum observed density occurred in the PR during August 1988 (Figure 3), when 60 lobsters were counted on PR 3. Density in the IR was lower than density in the FR.

Abundance (density or weekly catch/trap), when examined at all zones pooled across the entire study, exhibited no trend (Table 3). One zone (RB) experienced a significant decline ($p < 0.001$). However, abundance fluctuated widely in all zones within each year (Figure 3). These fluctuations were particularly apparent in the FR (Figure 3) where density declined from a high of about 90/ha in May to about 30/ha in September, and then rebounded to highs in December and January during both years. Trend analysis revealed that both the declines ($p < 0.001$) and the increases ($p < 0.001$) were statistically significant and homogeneous across all FR sites. Similar fall-winter increases in abundance have been observed at other offshore Keys reefs in 1978-79 (Lyons et al. 1981). Mann-Kendall sign tests were conducted for the other zones using the cycle delineated at the FR to examine the differences in abundance trends throughout the Sanctuary (Table 3). In general, within year trends at the FR were different than those observed at other zones (Figure 3, Table 3). Lobster abundance in the IR fluctuated similarly, but no significant trends were detected due in part to a high proportion of lobster counts equalling zero there. A very weak positive trend ($p = 0.08$) did occur on the deep reef during the late fall (Table 3). Density declined significantly ($p =$

0.024) in the RB throughout the summer of 1987 to lows in September (Figure 3), but did not increase during the Fall. The decrease at the RB was sharpest during August, the first month of the open lobster season.

The impact of lobster fishing on the lobsters dwelling within LKNMS was examined, in part, by analyzing the trends in abundance during the closed season and during the open season using non-parametric trend analysis. Abundance increased significantly during the closed fishing season in the PR ($p = 0.015$) and RC ($p = 0.014$) during both years (Table 3). Weekly catch/trap in the DR increased from <0.05 lobsters/trap during April to >1 lobster/trap at the beginning of the season; this trend was not significant. Simultaneously, the FR experienced a significant ($p = 0.011$) negative trend (Figure 3). Lobster abundance decreased during the open fishing season in the PR ($p < 0.001$) and DR ($p = 0.012$) during both years and during the first year in the RB ($p = 0.006$) and exhibited no increasing or decreasing trends in the remaining zones.

Hurricane Floyd passed over the Florida Keys with minimal hurricane force winds on October 12, 1987. Blowout undercuts that had previously been used for shelter by lobsters were eroded by hurricane-induced waves at three of the four survey sites. These undercuts did not redevelop during the remainder of the study, and no lobsters were found at those sites during 10 of the 24 periods (42%) following Hurricane Floyd. Undercuts were not eroded at the remaining site (RF7). Lobsters continued to inhabit that site.

Mean density in the RB remained low in this zone for the duration of this study. RB density estimates should be treated with caution. Blowout undercuts may have developed elsewhere in this zone and attracted lobsters from our sites. Future monitoring in this dynamic environment will require sampling a greater number of sites.

Overall mean density throughout the Sanctuary, excluding the DR and OR, was 43.3 lobsters / ha and ranged from 11 to 132 lobsters / ha (Table 4). Lobster densities were converted to lobsters/zone to provide an estimate of the number of lobsters that might reside inside LKNMS. These projections, limited to the zones we sampled, indicate that as few as 2500 lobsters may have resided in LKNMS at times of low abundance and as many as 30,000 lobsters during times of peak abundance (Table 4). However, the maximum number of lobsters within the Core Area probably did not exceed 2,000.

Population Dynamics

A total of 3029 lobsters (including those from traps) were captured and measured by researchers within LKNMS. Of these captured lobsters, 2639 were initial captures where lobsters were tagged and 390 were recapture events. Some lobsters were recaptured repeatedly. Capture success rate was lowest in the FR (Table 5), probably because lobster habitat there was spatially complex and working conditions were often difficult. All divers had similar capture success rates.

Overall, lobster size was 79.0 mm CL (SE = 0.21) and ranged from 71.7 mm CL (SE = 0.79) in the PR to 81.8 mm CL (SE = 0.43) in the FR. Mean lobster size declined significantly (all zones pooled; $p < 0.001$) during this study (Figure 4, Table 6). Carapace length decreased with significant (all $p < 0.01$) negative slopes during the open fishing season of both years in the PR, FR, and DR. Those decreases, combined with non-significant negative trends elsewhere, produced the overall significant decrease in carapace length during the open season (Table 6). Mean carapace length had decreased to less than minimum legal size (76 mm CL) in all zones by the end of the fishing season (March) during at least one year (Figure 4), indicating that lobster fishing impacted all zones in the Sanctuary.

Size structure of the lobster population differed throughout the Sanctuary (Figure 5). More than 50% of the lobsters captured in the PR and in the RB were smaller than the minimum legal size in Florida (76 mm CL). Legally harvestable lobsters (≥ 76 mm CL) comprised $\geq 50\%$ of the captured lobsters at the remaining zones. Legal-sized male lobsters were captured in greater proportions than females in the DR, FR, RC, and RB (Figure 6).

Within the Core Area, lobster size structure shifted dramatically from the FR to the RB (Figure 5). Linear distance between the FR and RB is less than 500 meters (Figure 2). In the FR, 13% of all lobsters were ≥ 96 mm CL (Figure 5), and nearly 12% of the male lobsters were ≥ 106 mm CL on the FR (Figure 6). Fewer than 5 % of the males were ≥ 106 mm CL at the RC and these large

males were nearly absent from the RB. Male lobsters ≤ 65 mm CL were rare at the FR and at the RC, but common at the RB. Males ≥ 106 mm CL were nearly absent outside the Core Area. A similar trend of larger lobsters being captured at the FR occurred with females, too. Female modal size class shifted from 76-80 mm CL in the FR and RC to 71-75 mm CL in the RB (Figure 6), and larger (≥ 86 mm CL) females were more abundant in the FR than RC.

A three-way ANOVA on CL revealed a complex relationship between zone, sex, and reproductive season (Table 7). The three-way interaction term was significant ($p \leq .01$), as were all main effects ($p \leq .01$). Reproductive season was defined as the time between the appearance and the disappearance of egg-bearing females on the FR (Figure 7). Male lobsters on the FR during the reproductive season were significantly larger than any other group, and males dominated the largest groups overall (Table 7). RB and PR lobsters during the nonreproductive season were significantly smaller than those of other locations or times and, in general, were smaller than lobsters in other zones at all times.

The reproductive season extended from March through September (Figures 7 and 8). Mating was observed on the FR as early as February both years. Most reproductive activity occurred on the FR. Across the FR-RB gradient, the proportion of females with eggs decreased markedly from 72% at the FR, to 39% and 19% in the RC and RB, respectively (Figure 7). Fewer females contained ripe ovaries (all years) in the RB (16%) than either the FR (29%) or the RC (38%). Multiple spawning was commonplace on the FR. During May

and June in 1987 and much of the reproductive season in 1988, nearly 80% of females were carrying external eggs; simultaneously, more than 30% had ripe ovaries on the FR. Many females were observed with external eggs, ripe ovaries and a fresh spermatophore laid over an eroded spermatophore.

Incidence of spawning away from the FR was reduced and nearly non-existent in the RB, OR, and PR (Figures 7 and 8). Where reproductive activity was low, the reproductive season was compressed.

Sex ratio was heavily skewed toward females on both the FR and the IR (Table 8). However, IR lobsters were significantly smaller than FR lobsters during the reproductive season and IR males were significantly smaller than FR males during the nonreproductive season (Figure 5, Table 7). Across the FR-RB gradient F:M sex ratio changed markedly from 3.6:1 to 1.1:1; two-way ANOVA (arc sine transformed) revealed these differences in sex ratio to be significant ($p \leq 0.01$). Sex ratio overall, changed little at the end of the reproductive season ($p \geq 0.5$) and no zone-season interaction was detected ($p \geq 0.2$). Sex-ratio shifted toward a slightly greater proportion of males during the nonreproductive season at the FR and toward a greater proportion of females at the adjacent RC (Table 8).

Occupancy rate in marked dens throughout the Sanctuary was 13.8%. The 734 marked dens (Table 1) were searched a total of 11,704 times; on 1,625 occasions one or more lobsters were observed in a marked den. Occupancy rate in the zones that contained marked

dens was 13.4%, 13.5% and 17.1 % in the PR, FR, and RF, respectively.

An overall average of 1.42 (SE = 0.02) lobsters resided in dens occupied by 1 or more lobsters (Table 9). The extremely low number of lobsters/den that occurred during all seasons in the IR (Figure 9) was related to low density observed there throughout the study (Table 4). A two-way ANOVA revealed a significant interaction ($p \leq 0.01$) between zone and reproductive season. The mean number of lobsters/den on the FR increased dramatically during the nonreproductive season (Figure 9). During 1988, that increase began in September when density was at its lowest (Figure 3), suggesting density itself was not a factor. In contrast, multiple occupancy was highest during the reproductive season in zones where few lobsters were spawning (PR and RB).

The greatest number of lobsters residing in one den (20; Table 9) occurred on PR3 during August 1988 when 60 lobsters were counted on that site. The low maximum occupancy in the RB reflects the limited size and ephemeral nature of the undercuts in the blowouts. P. argus has a strong affinity for the floor of dens. Ninety-four percent were observed on the floor, and the remaining 6% were equally partitioned between the wall and ceiling. In dens with ≥ 6 lobsters, especially on the PR, we observed that small (≤ 65 mm CL) lobsters were more likely to be found on the ceiling.

Zones where lobsters were smaller and reproductive activity was low (RB and PR) contained a much higher proportion of molting lobsters than did other zones (Table 10). Molting nearly ceased on

the FR during the spawning season but it increased there nearly tenfold after the spawning season. A shift from 2.5% to 19.8% in the proportion of lobsters molting is indicative of a major seasonal shift in the utilization of internal energy resources. The proportion of molting lobsters caught in traps was low (Table 10); similar results have been obtained in other trap studies (Lyons et al. 1981). Traps may be a biased sampling tool relative to molting.

Two isolated coral rocks discovered near blowouts after the study began afforded an opportunity to examine the hypothesis that lobsters may molt in isolation from their companions when possible. Upon their discovery, both rocks were surveyed in concert with the adjacent blowouts and molting frequencies compared between lobsters dwelling in the coral rocks and the adjacent blowout undercuts. At one of the rocks, lobsters were three times more likely to be molting than in the nearby blowout; at the other, there was no difference (Table 11). The only difference we observed between the sites was that two lobsters were often dwelling in the rock at RF 10; whereas the rock at RF 9 was typically occupied by one lobster. Molting is a precarious time for lobsters, because they are at greater risk of predation or molestation by conspecifics. In captive conditions, lobsters will move away from conspecifics and molt (W. Lellis, Harbor Branch Foundation, pers. comm.). These observations present the first field evidence that lobsters move away from conspecifics to molt when isolated den habitat is available.

Nocturnal Foraging

Density of lobsters during their nocturnal foraging period on the Reef Flat was calculated using the area of each belt transect. The randomly selected transects (6/88-1/89) crossed all Reef Flat habitat types and thus should be relatively unbiased. Mean density values obtained during those surveys were consistently higher than the mean density of lobsters dwelling, as calculated from our daytime abundance surveys, in the RF (Table 12, Figure 3), indicating that lobsters from other areas were moving to the Reef Flat to forage. Lobsters tagged on the RF and the FR were recaptured on the Reef Flat foraging grounds (Table 12). Mean size of the 73 males captured while foraging at night was 80.9 mm CL (SE = 1.86) and mean size of the 142 females was 78.6 mm CL (SE = 1.23); these sizes and sex ratios are intermediate between the sizes and sex ratios calculated from lobsters captured in their daytime shelters on the FR, RC, and RB (Table 7 and 8). Density averaged 75 lobsters / ha and was consistent between dives on the twelve transects sampled during July 1989.

During the July, 1989, nocturnal survey, most lobsters were observed foraging in rubble and in rubble mixed with the seagrass, Thalassia testudinum (Table 13). Very few lobsters were observed foraging in the sand or grass and nearly 12% of the lobsters were still in their daytime shelters during these dives. If lobsters do not exhibit a foraging habitat preference at Looe Key, then the expected percent distribution of foraging lobsters should correspond closely with the distribution of habitat. Chi square

analysis (lobsters in dens excluded) revealed that the lobsters were not distributed randomly across foraging habitat on the reef flat ($\chi^2 = 62.3$, $df = 5$, $p < 0.001$). A survey of potential prey items in the rubble on 9 August, 1989 revealed that densities of the small, rubble-dwelling gastropods, Cerithium litteratum and C. guinaicum, approached 75 m^{-2} (J. H. Hunt and W. G. Lyons unpub. data). Three species of small hermit crabs, Clibanarius tricolor, Calcinus tibicen and Paguristes invertisacculus, found in C. litteratum shells, were also common, as was the chiton, Ischnochiton erythronotus. C. litteratum, Ischnochiton sp., and hermit crab fragments have been found in lobster gut contents at other Florida reefs (G. E. Davis, Channel Islands National Park, pers. obs.). The distribution and abundance of these taxa may influence patterns of nocturnal foraging by P. argus at LKNMS.

Residency

Of the 557 lobsters tagged and released on the FR, eighty-six (15.4%) were recaptured exclusively within that zone (Table 14). Similar within zone recapture rates occurred in the RF, IR, and PR. Residency rates were lowest in the DR and the OR. Lobsters tagged in the PR were not recaptured in other zones. Most interzone interactions occurred between the FR and RF; where 3.4% (N=28) of the lobsters that were tagged and released on the RF were recaptured on the FR, and 2.2% (N=13) of the lobsters initially tagged on the FR were recaptured on the RF. Several lobsters moved repeatedly between the FR and RF. One female lobster had a

particularly interesting recapture history. She was tagged on the west rubble ridge of the RF on 22 September, 1988 during a night dive, recaptured on the RF in November 1988, and then moved to the FR (Site 1) during the winter, where she resided at least until August 1989. During that time, she grew from 78 to 89 mm CL and spawned twice. Of the seven tagged lobsters that were recaptured inshore of the sanctuary, five were recaptured during the early fall. One was recaptured during July and one was recaptured during November.

A few tagged lobsters were recaptured from outside the Sanctuary (Table 14), most from along the reef west of the Sanctuary. Tags were returned by fishermen from as far west as the Sand Key area, approximately 36 km from the Sanctuary. With the exception of two females, no lobsters were returned further east than Big Pine Shoal (16 km). One female lobster initially captured in the OR migrated about 165 km northeastward during the summer to Carysfort Reef in two months, and the other, initially captured in the PR during March 1989, remained there until September 1989, and was ultimately recaptured near Key Biscayne, about 220 km northeastward during August 1990. Both lobsters were 75-mm CL when initially captured.

Most resident lobsters (i.e. those lobsters whose final recapture zone was the same as that of their initial and all intervening captures) were recaptured within three months (Table 15). Mean time from first to final capture was similar for the FR, RF, and PR (Table 16), but the proportion of recaptures during the

first three months was higher in the PR (Table 15). Mean time out for lobsters that left their initial capture zone was highly variable. Low return rates of these lobsters is the likely cause of this variability. Long-term residency (time out ≥ 9 months) occurred only in the FR and RF, none occurred in the PR. Five (4%) lobsters were at large for nine to twelve months and four (3%) remained at large for more than one year within the FR and RF. Although the sample size is low, these lobsters indicate that the potential for development of a residential population may exist. Two lobsters, a 110-mm CL male and a 102-mm CL female, were recaptured repeatedly on one FR site from April through December 1987.

Twenty-four lobsters were recaptured by commercial and recreational fishermen fishing in or near the rubble zone region surrounding the RF and an additional three were captured just offshore from the FR. Two tag histories illustrate this phenomenon. A 77-mm-CL female initially captured on the FR was recaptured just offshore from the FR six months later and an 82-mm-CL male initially captured on the FR on June 30, 1989 was recaptured from the area surrounding the RF five months later.

DISCUSSION

Behavior associated with reproduction is the controlling biological factor affecting population structure in the Fore Reef/Reef Flat complex. Population characteristics observed at the

Fore Reef during the reproductive seasons sampled in this study were the high incidence of large males (≥ 96 mm) relative to smaller males, the heavily skewed female-to-male ratio, the preponderance of single-occupancy dens, and the general decrease in abundance. In contrast, on the immediately adjacent Reef Flat, males were smaller, females and males were found in near-equal proportions, total lobster abundance increased significantly, and multiple occupancy of dens was substantially more prevalent, especially during 1988 (Figure 9). We infer that this population structure is the result of male behavior and that male behavior controls the distribution and abundance of lobsters throughout the FR-RF complex. These observations are consistent with the hypothesis that polygynous males establish and defend mating territories on the Fore Reef. Numerous observations of large males roaming through our sites and visiting several dens, each occupied by a different female during the daytime on the Fore Reef further support this theory. In one instance, two males were observed exhibiting this behavior simultaneously on different sections of one Fore Reef site. Courtship behavior (Lipcius et al. 1983) was also observed. Herrnkind and Lipcius (1989) reported a sex-related size structure similar to that observed on the Fore Reef (Figure 6) among P. argus on offshore reefs at Lee Stocking Island, Bahamas, although lobster size was generally much larger there. They attributed the size structure of that population to sex-specific differentiation in growth rates upon maturation. Although their conclusion provides a clear explanation for the general pattern of

size structure in offshore populations, it does not provide an adequate explanation for the markedly changing size structure that we documented within Fore Reef-Reef Flat complex. Our observations delineate a marked shift in size structure over a spatial scale of a few hundred meters. Such a shift is related to behavioral interactions, not to a broad, population-based phenomenon.

We hypothesize that aggressive male-to-male interactions, either within a defended territory or perhaps in portions of the nocturnal foraging area, induce smaller males to move to less favorable reproductive habitat on the reef flat. Although we observed no male-to-male interactions, some of these interactions likely occur at night, perhaps at the end of the nocturnal foraging period. High densities, especially on rubble, make it likely that lobsters routinely come into contact with each other while foraging. That, coupled with recaptures of Fore-Reef and Reef-Flat lobsters from their nocturnal foraging grounds indicate that they routinely intermingle at that time.

As soon as the reproductive season ends, incidence of multiple occupancy in dens on the Fore Reef increases. This shift occurred during September 1988 even while the population density was declining, clearly signalling a major change in the behavior of the population. The end of the spawning season eliminates the necessity for males to defend mating territory. All incidences of den occupancy by more than five lobsters on the Fore Reef occurred during fall months following the reproductive season. These multiple-occupancy dens contained mixtures of a wide range of sizes

and both sexes. Consistent with theory that defense of mating territory by males during the reproductive season strongly influences population structure is the prediction that after the reproduction season is over, sex ratio should shift toward unity. Although a slight shift occurred, sex ratio remained skewed toward many more females than males on the Fore Reef. Perhaps some external factors reduce the abundance of male lobsters at this time. A small proportion of the population likely emigrates at this time. We observed a small inshore migration from the Sanctuary that began at the end of the reproductive season. Such an offshore-inshore migration has been observed at other locations in the Florida Keys (Gregory and Labisky 1986).

Superimposed on those biological factors are impacts imposed by fishing pressure. No zone within the Sanctuary was immune from the effects of fishing, but zones outside the Core Area were most obviously affected. Our analyses indicate that significant negative trends in abundance and size during the open fishing season were more prevalent in zones where both trap and recreational diver fishing was allowed, but Fore-Reef and Reef-Flat lobsters were also affected. Lobster size decreased on the Fore Reef and Reef Flat during the fishing season indicating that larger lobsters were removed by fishing pressure. Mean sizes of lobsters there dropped below minimum legal size by the end of the open fishing season.

Transects conducted at night on nocturnal feeding grounds revealed a strong tendency for Fore-Reef and Reef-Flat lobsters to

forage on the rubble areas on and surrounding the reef flat. Much of that rubble is outside the boundaries of the Core Area (Figures 1 and 2); tag returns indicate that Fore-Reef and Reef-Flat lobsters were harvested there. Removal of these lobsters by fishermen increased the rate of population turnover on the Fore Reef and Reef Flat beyond that which would be experienced in a natural setting.

The lack of a decrease in abundance at the FR during the open season is not evidence for a lack of fishery impact nor is the observation that lobster abundance increased there during the fall and early winter. A fall-winter offshore migration has been well-documented, both in this study and elsewhere (Davis 1978, Lyons et al. 1981). This migration is sufficiently strong to result in increasing lobster abundance even on offshore reefs where intensive fishing pressure occurs (Lyons et al. 1981). At the Fore Reef, larger legal-sized lobsters captured during their nightly foraging on the rubble surrounding the Core Area were replaced by smaller newly-matured lobsters migrating to offshore reefs. As a result, mean size decreases while abundance remains stable. Some of the loss of large lobsters is likely related to emigration, however, only two of the seven inshore migrants were initially captured in the Core Area. In contrast, fourteen of the twenty-seven lobsters captured on foraging grounds surrounding the Core Area were initially tagged in the Core Area. The maintenance of a strongly skewed female-to-male sex ratio through the winter may be related to fishing pressure, as well. Large (legal-sized) males were,

relative to sublegal-sized lobsters, more abundant than legal-sized females. Fishing may, therefore, impact males proportionally more than females.

Tag-recapture efforts to examine residency were limited by problems with tag-loss early during the study, by the large scope of the sampling regime necessary to examine the entire Sanctuary and possibly by the limited advertising. The tag was replaced with a new tag that reduced tag-loss and we believe that advertisement through word of mouth alerted a substantial portion of fishermen fishing within the Sanctuary to our tagging research effort. The large scope of the project dictated repeated sampling of the same sites with its concomitant limitations to tag-recapture surveys. However, this sampling regime enabled a data set on many aspects of the population dynamics of Panulirus argus throughout the Sanctuary to be developed.

Tag-return rate of residential lobsters in this study was similar to that observed in the Tortugas in a study with similar goals (Davis 1977a). The obvious incidence of a few long-term residents within the Core Area indicates that the potential exists to develop a population of residential lobsters in the Core Area if the influence of fishing on resident lobsters is eliminated there. Lobsters have remained in a localized area within the lobster sanctuary at Fort Jefferson National Monument for at least two years (Davis 1977a).

Most evidence for the phenomenon of multiple spawning by individual females in a single season has been conjectural (Creaser

1950, Lipcius 1986), principally because of the difficulties in following single lobsters in the field. However, this study provided many opportunities to make such observations and we found that multiple spawning on the Fore Reef was commonplace. As the spawning season progressed, fresh spermatophores were frequently observed on eroded spermatophores, and females carrying external eggs routinely had ripe ovaries as well. These observations are consistent with our observation of only 2% molting among lobsters on the Fore Reef during the reproductive season. Molting frequency increased to 20% during the nonreproductive season. Molt frequency was high throughout the year in zones where reproduction was uncommon. These data support the model proposed by Lipcius (1986), wherein large mature females are predicted to molt only during the winter and spawn repeatedly during the summer.

Densities of P. argus that we observed in Looe Key National Marine Sanctuary (Table 2) are compared to densities that have been reported at various locations throughout the Caribbean Region (Table 18). Densities observed at Looe Key National Marine Sanctuary are similar to those from fished areas of Cuba (Cruz et al. 1986), and portions of Little Bahama Bank (Waugh 1981). Cuba and Little Bahama Bank have extensive nursery habitat, as does Florida. These nurseries provide the environmental setting for supporting high densities (Waugh 1981) if left unfished and serve as the source for lobsters that recruit to fisheries (Peacock 1974, Davis 1978, Waugh 1981, Lyons 1986). Lobster density is much lower at most other Caribbean islands (Table 18). These islands slope

steeply into deep water. Consequently, they are bereft of large, shallow bays that support spiny lobster nursery habitat. The extent and quality of nursery habitat may regulate abundance of lobsters on a Caribbean-wide scale.

SANCTUARY MANAGEMENT RECOMMENDATIONS

Our major conclusion is that the Core Area of LKNMS does not serve as a sanctuary for P. argus. On the FR and RC, abundance was cyclic during each year but showed no increasing trend overall during the two year study. Mean size decreased inside the Core Area during the open fishing season. Lobsters that dwell on the FR and RF leave their daytime shelters and preferentially forage on the extensive rubble areas that surround the Core Area (Tables 12, 13). We conclude that, in addition to the behavioral causes for abundance and population fluctuations, legal recreational fishing inside the Core Area, especially on the reef flat (Blonder et al. in press), plus trap and diver fishing in the foraging areas surrounding the Core Area significantly impact the dynamics of P. argus within the Core Area. In particular, fishing pressure in those areas may result in harvest of lobsters that are core-area residents, not those that are migrating from the region.

We propose a two-fold management strategy for the Core Area; 1) prohibit harvest of P. argus inside the Core Area, and 2) expand the Core Area to include the entire rubble foraging area on and surrounding the reef flat plus an appropriately sized buffer around

that foraging area. The buffer zone in front of the FR should be extended as well. Knowledge of the foraging range of spiny lobsters can provide some insight for consideration of a minimum buffer width. Panulirus argus have been known to forage at least 300 meters from their dens (Herrnkind et al. 1975, Herrnkind and Redig 1975), and Panulirus cygnus, a similarly sized species from western Australia, has a nightly foraging range of 500 meters (Jernakoff et al. 1987).

The impact of this management strategy on the fishing community will be minimal. At most, we estimate that 2000 lobsters reside in the Core Area (Table 4). Further, this strategy will not protect spiny lobsters that emigrate from the area. Emigrating lobsters will enter the fishery upon leaving the buffer zone. This management strategy should, however, protect spiny lobsters residing on the FR and RF during all phases of their diel cycle.

We predict that the Core Area lobster population will slowly increase in response to this suggested management strategy. Average size of those lobsters should also increase. Slowly, a residential population of lobsters may develop. Already, lobsters on the FR are larger and exhibit a greater tendency toward residency than do lobsters in other parts of the Sanctuary. Large, mature P. argus develop a tendency toward longer residency at one site (Herrnkind et al. 1975, Davis 1977a). In the Dry Tortugas sanctuary, lobster density is 3 to 5 times higher (Table 18) and mean size are approximately 20 mm CL longer (Davis 1977a) than those measured at the Fore Reef, the equivalent habitat, in this

study at Looe Key. Further, the extremely low occupancy rate of known dens indicates that lobsters have not approached crowded conditions. A brief survey that we conducted at Dry Tortugas during the summer of 1989 reconfirmed Davis' (1977a,b) observations. Even though the Dry Tortugas is an endpoint for migrating lobsters (Gregory and Labisky 1986), the size structure is likely related to the fact that Fort Jefferson National Monument has been an effective sanctuary for many years. Lobster sizes in the commercially fished area adjacent to the Dry Tortugas sanctuary are considerably less than those in the sanctuary (Davis 1974), and, in fact, those lobster sizes are very similar to sizes of lobster captured on offshore reefs in the middle and upper Florida Keys (Lyons et al. 1981).

If this management strategy is adopted at Looe Key National Marine Sanctuary, long-term monitoring of lobster abundance inside the Core Area, using methods similar to those in this study would be sufficient to test our predictions, if samples are timed to separate within-year fluctuations from annual trends. However, the design should attempt to minimize lobster disturbance by carefully selecting tags (Trendall 1988) and by limiting lobster captures (Herrnkind et al. 1975).

We propose no regulatory changes for the remainder of the Sanctuary. Although, abundance and size patterns are consistent with other offshore areas that experience fishing pressure (Lyons et al. 1981), lobsters in the Patch Reef and Deep Reef zones do not appear to be inextricably linked to lobsters in the Core Area. Few

lobsters from either zone were recaptured in the Core Area. Even though lobster density was low in the Intermediate Reef, the absolute number of lobsters was fairly high when pulses of lobsters appeared there due to its large areal extent. On three separate occasions, traps were deployed by fishermen on our Intermediate Reef sites. In all three instances, scrape marks and broken soft corals clearly caused by the trap were observed. Perhaps the location of trap placement (e.g. away from reefs) should be incorporated into the Sanctuary education program.

Our recommended management strategy is designed to meet the overall goals of the Looe Key National Marine Sanctuary as they pertain to Panulirus argus. Core Area lobsters would become less impacted by fishing, a resident population of large lobsters may develop, and protection of the important Reef Flat-Fore Reef habitat complex will be enhanced. Further, because the management recommendations are limited to the Core Area, lobster fishing will still be permitted in the remainder of the Sanctuary.

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Figure 1. Schematic map of Looe Key National Marine Sanctuary. The Deep Reef is located immediately south of the Intermediate Reef. The Deep Ridge (Offshore Ridge) is located along the southern boundary. Core boundary buoy locations are approximate. An ancient drowned spur and groove reef is located southeast of the Fore Reef outside the Core Area.

81°23'
24°34'

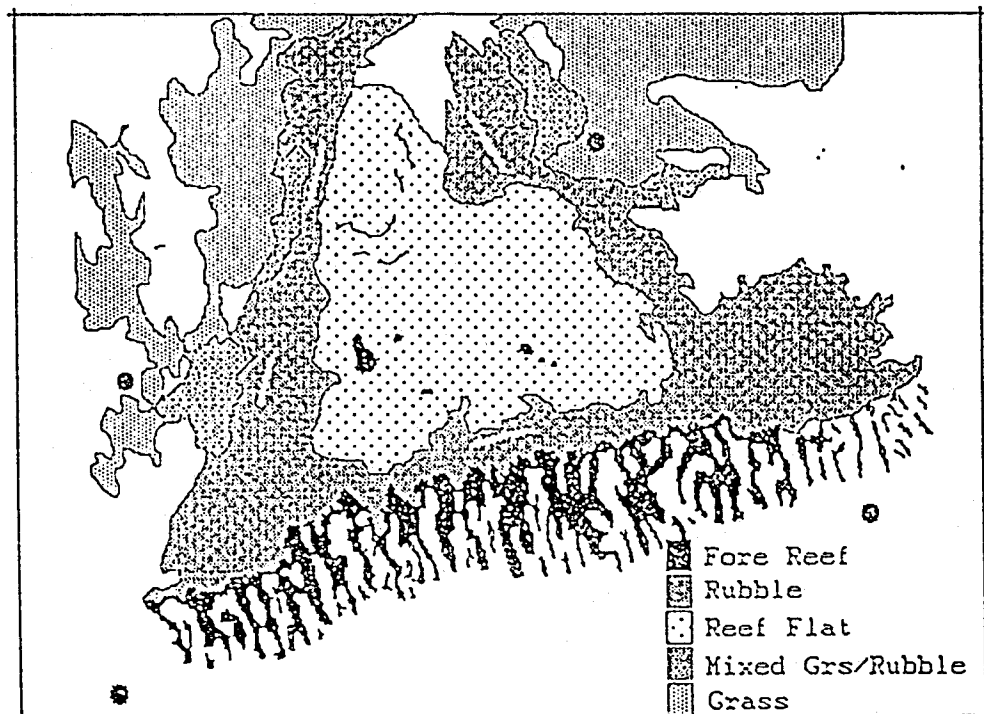
N
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24°32'
81°26'

- Intermediate Reef
- Fore Reef
- Rubble
- Reef Flat
- Patch Reef
- Core Boundary Buoy

Figure 2. Schematic map of the Fore Reef/Reef Flat complex. Within the Reef Flat, blowout sites are delineated by irregular lines. Coral Head sites are delineated by filled shapes. Within the rubble area, white lines mark the locations of night transects. Core boundary buoy locations are approximate.

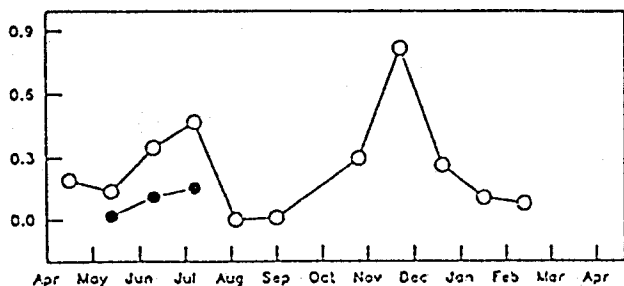
81°24'00"
24°33'07"



24°32'36"
81°24'46"

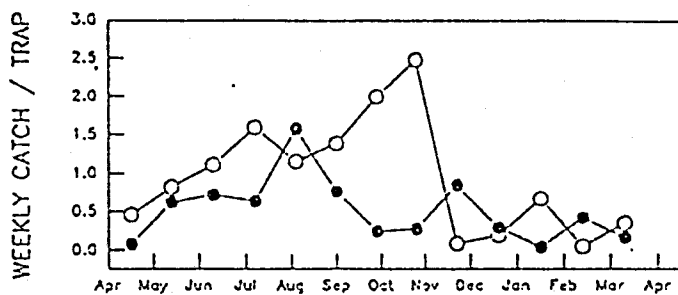
Figure 3. Between-year comparisons of fluctuations in lobster abundance in all zones. Deep Reef and Offshore Ridge abundances are expressed as weekly catch/trap. Other zones are density/ha. During year 1, the mean density of two consecutive sampling periods (1 period = 2 weeks) is plotted in order to better observe the comparison with year 2.

Offshore Ridge



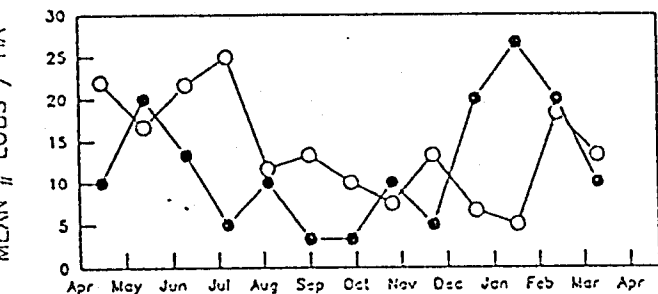
MONTH

Deep Reef



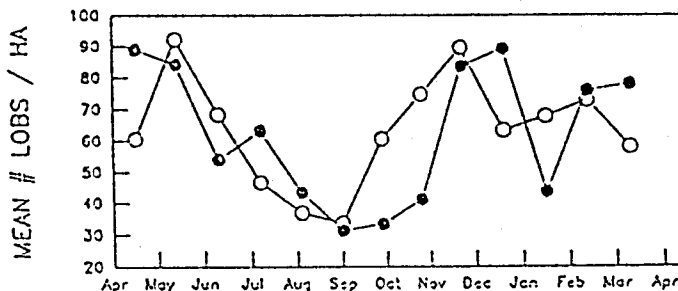
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Intermediate Reef



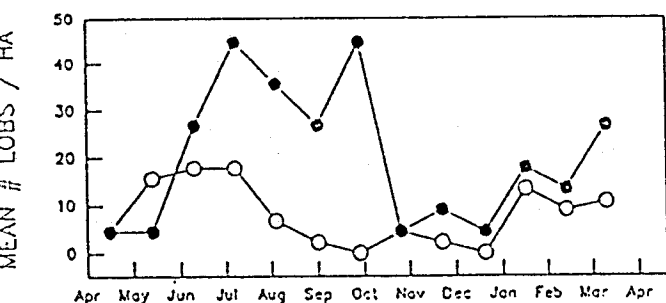
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Fore Reef



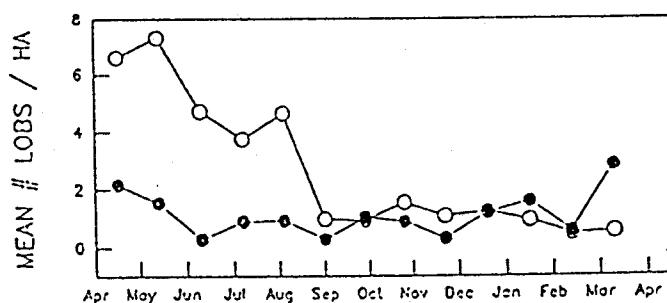
MONTH

Reef Flat Coral Heads



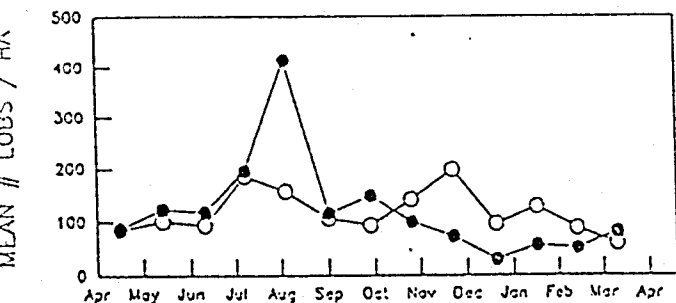
MONTH

Reef Flat Blowouts



MONTH

Patch Reef

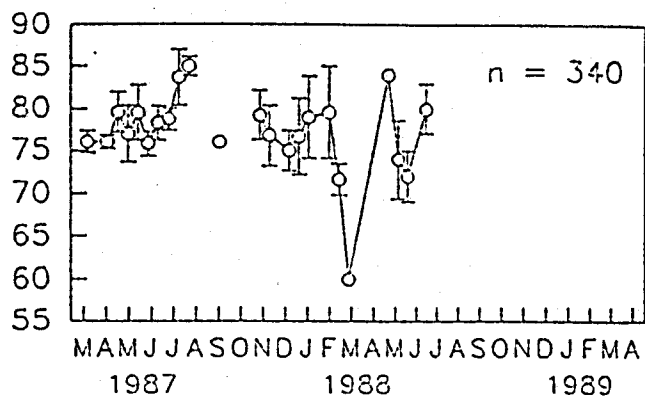


MONTH

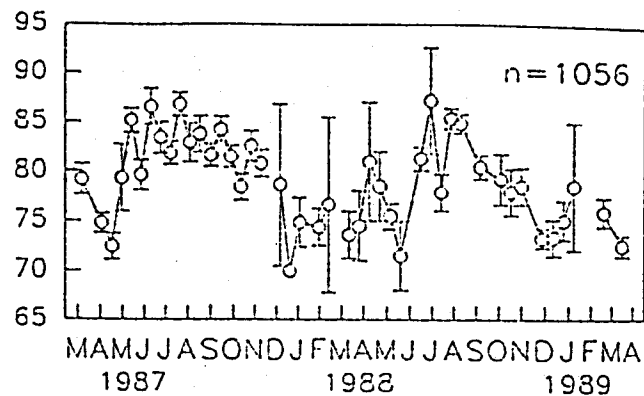
○ = 1st year
● = 2nd year

Figure 4. Fluctuations in mean carapace length (± 1 SE) for the entire study period in all zones. No error bar indicates that only one lobster was captured. Spaces in the Offshore Ridge and Deep Reef plots indicate that no lobsters were captured at those times.

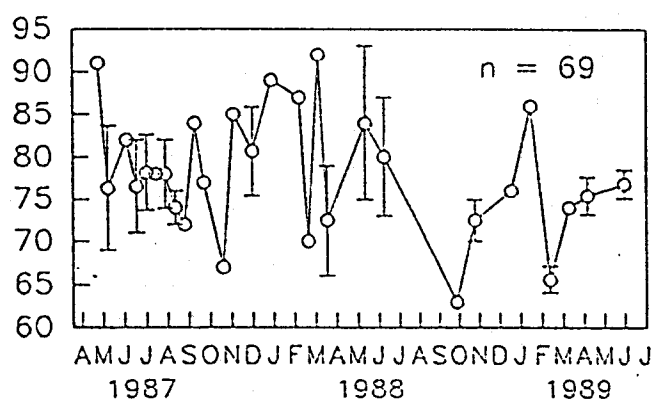
Offshore Ridge



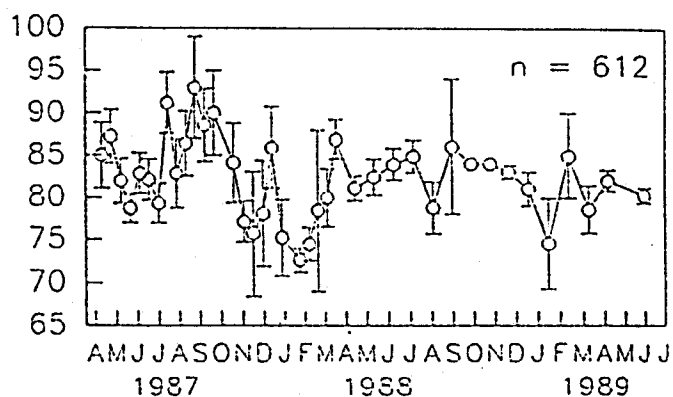
Deep Reef



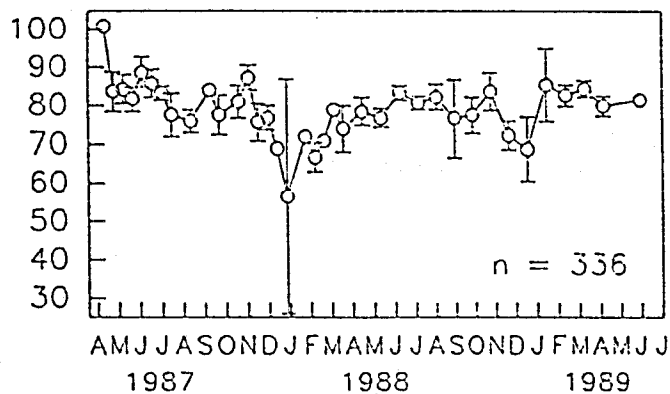
Intermediate Reef



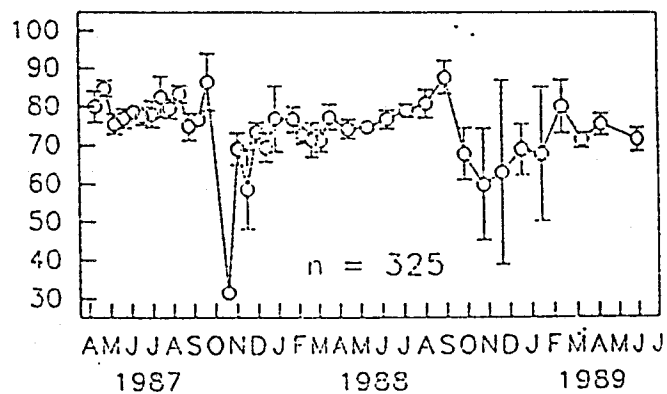
Fore Reef



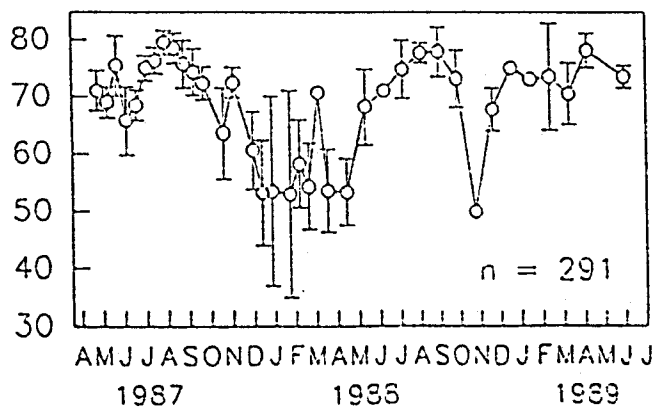
Reef Flat Coral Heads



Reef Flat Blowouts



Patch Reef



MEAN CARAPACE LENGTH

Figure 5. Size structure of all lobsters measured in each zone throughout the entire study.

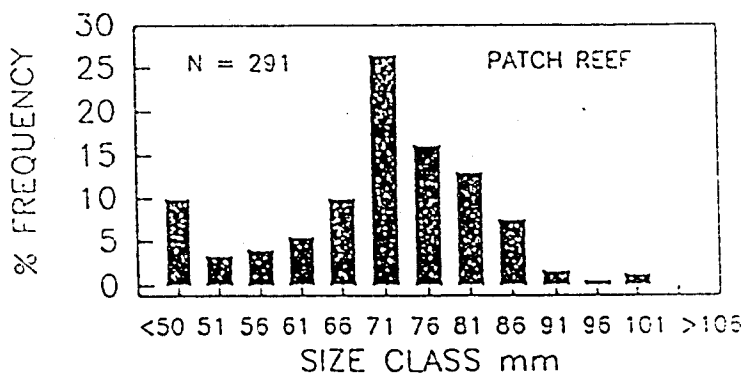
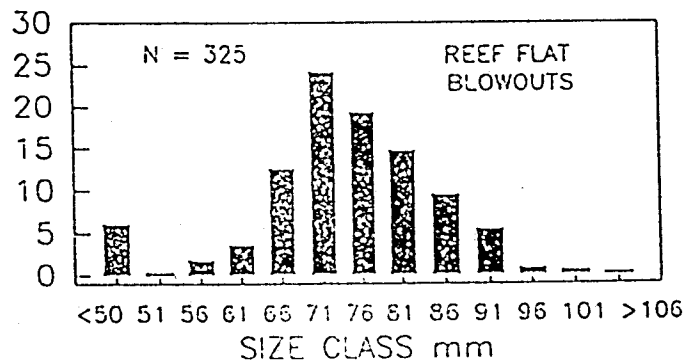
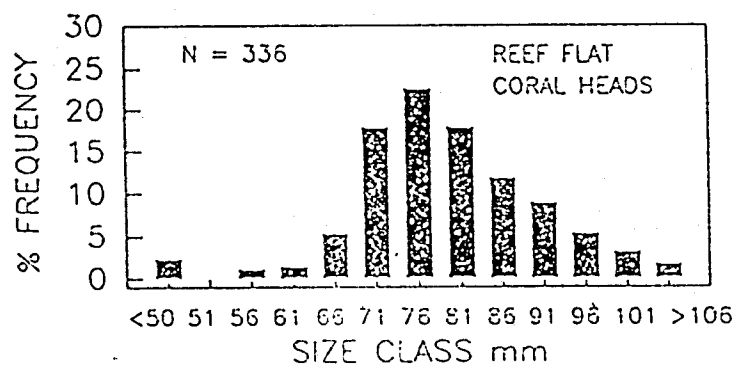
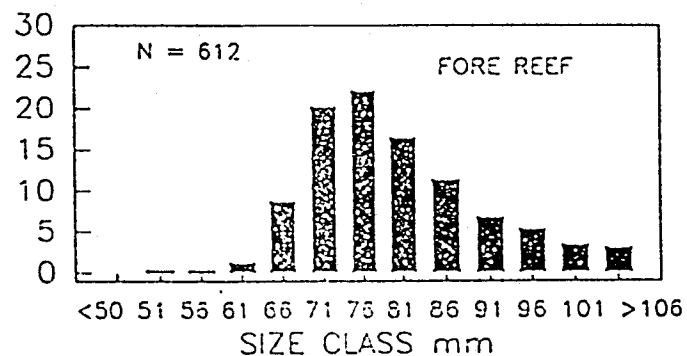
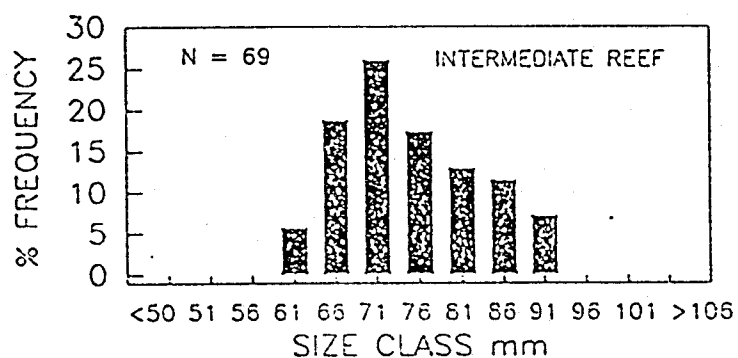
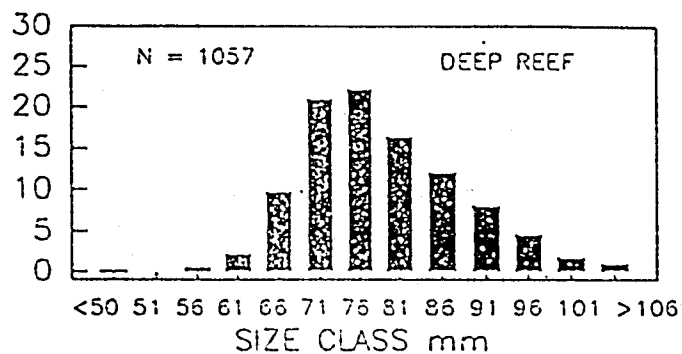
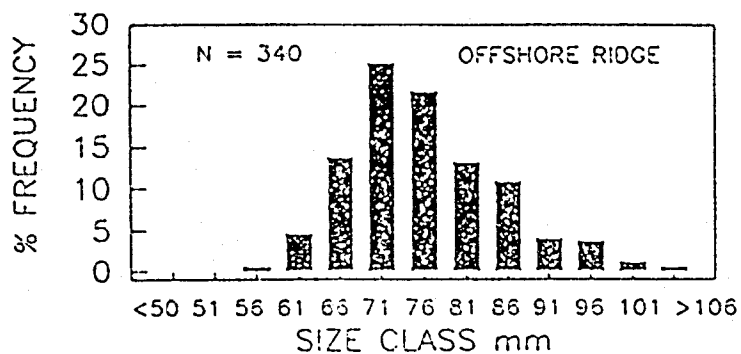
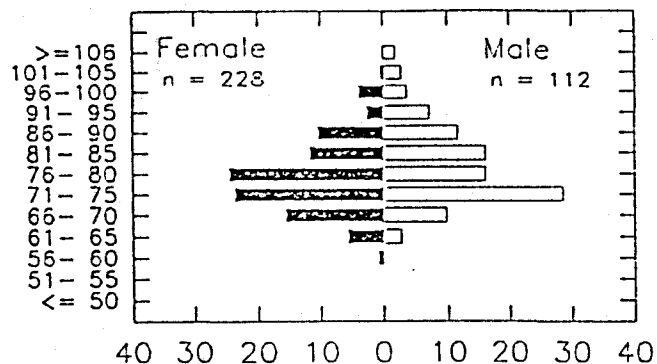


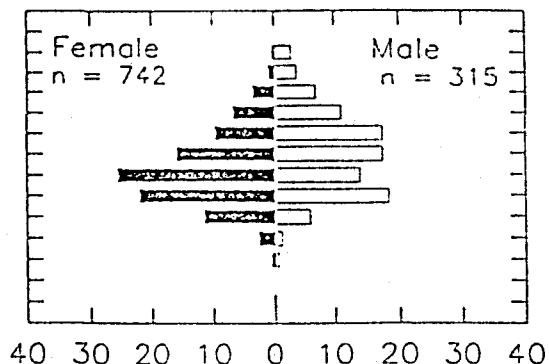
Figure 6. Size structure of male and female lobsters measured in each zone throughout the study.



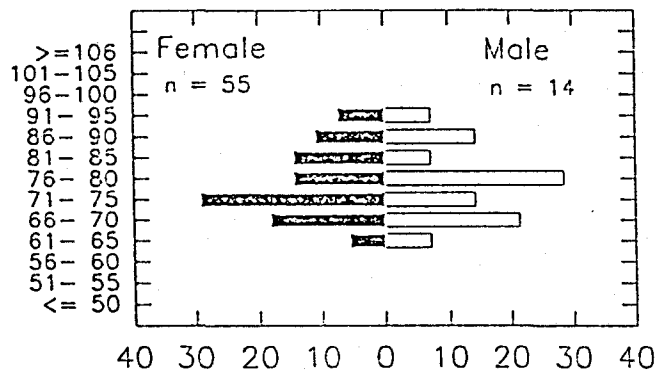
Offshore Ridge



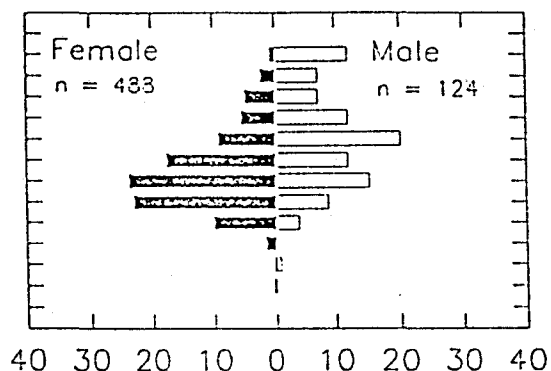
Deep Reef



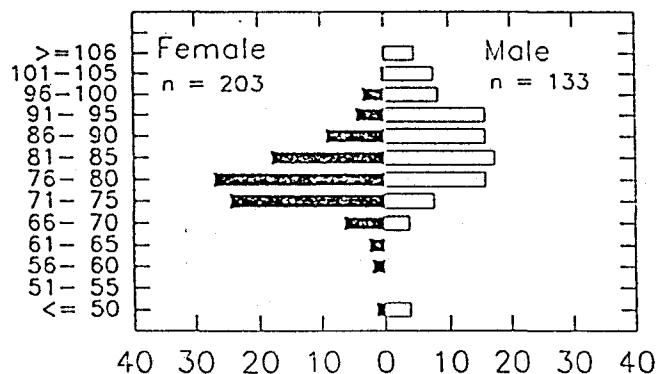
Intermediate Reef



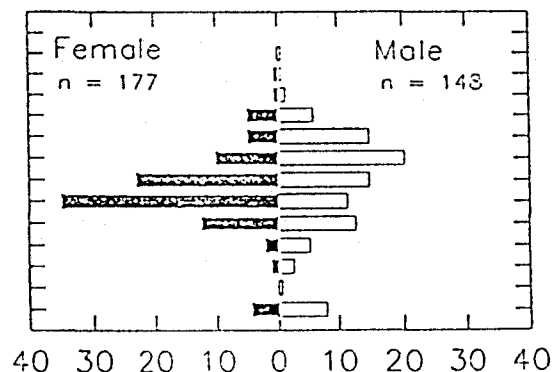
Fore Reef



Reef Flat Coral Heads



Reef Flat Blowouts



Patch Reef

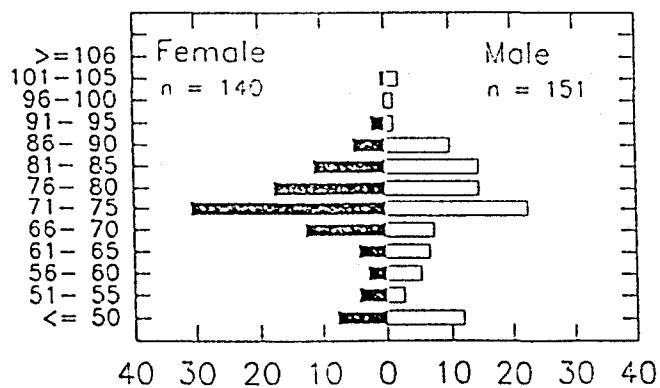


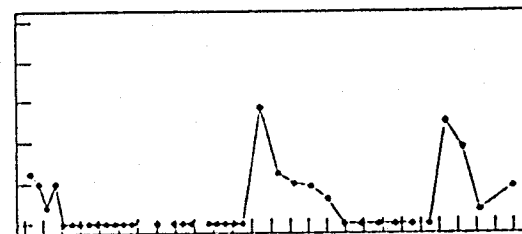
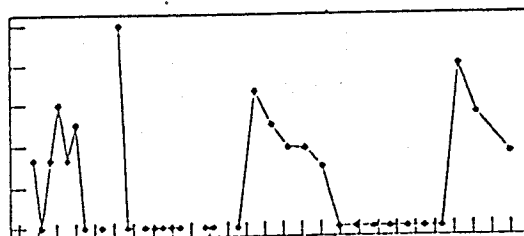
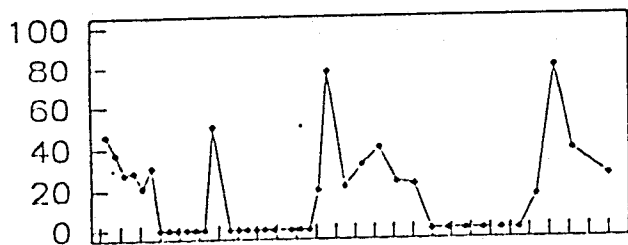
Figure 7. Female P. argus reproductive seasonality and extent at the Fore Reef, Reef Flat Coral Heads, and Reef Flat Blowouts, 1987-1989.

Fore Reef

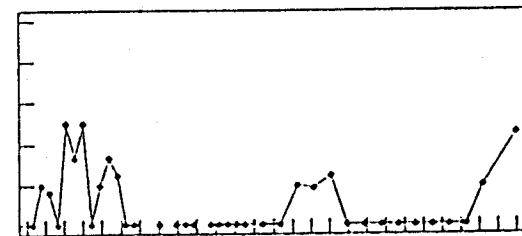
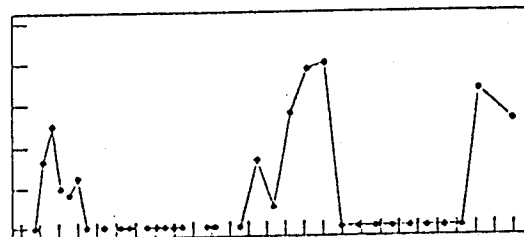
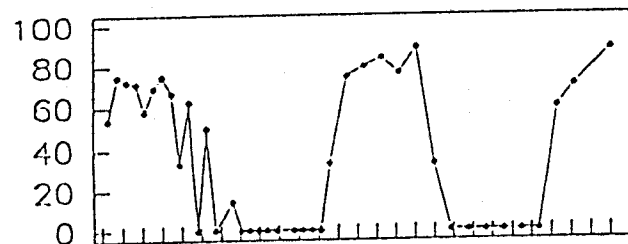
Reef Flat Coral Heads

Reef Flat Blowouts

% W/ Ripe Ovaries



% W/ Eggs



% W/ Spermatophore

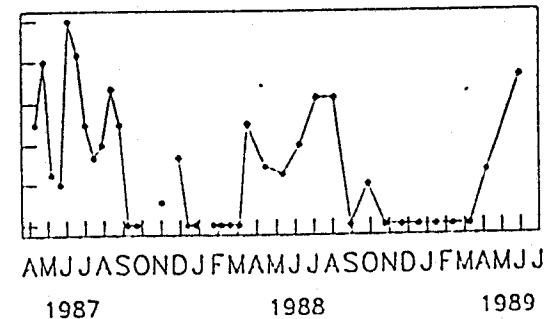
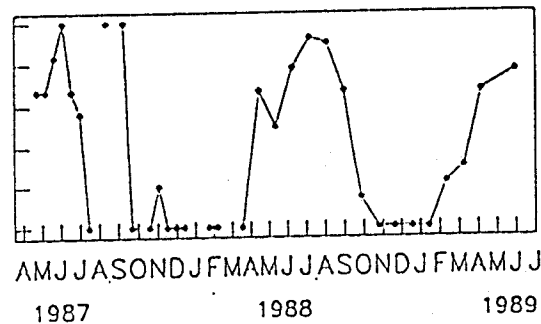
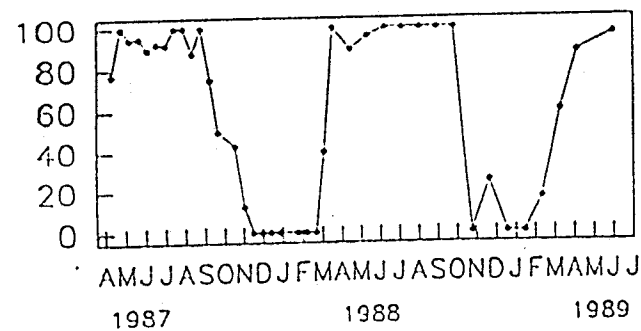
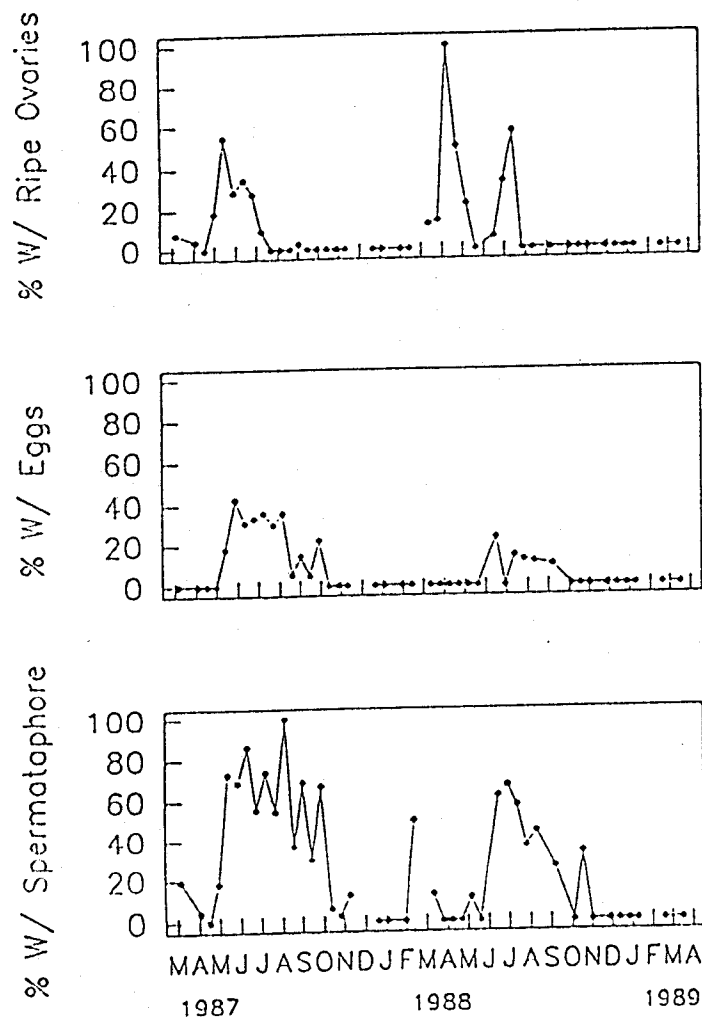
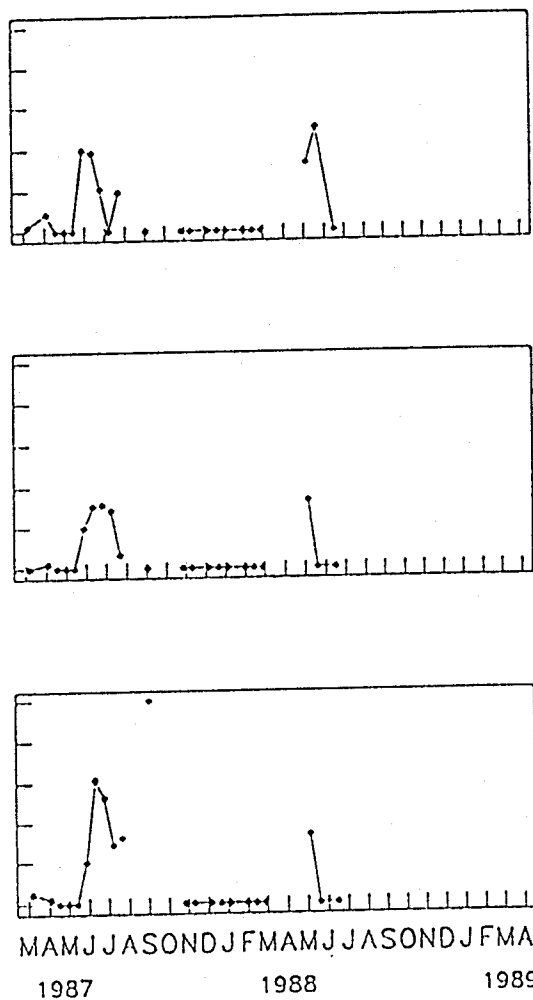


Figure 8. Female P. argus reproductive seasonality and extent at the Deep Reef, Offshore Ridge, and Patch Reef. The low number of captured females (N=55) at the Intermediate Reef prevented inclusion.

Deep Reef



Offshore Ridge



Patch Reef

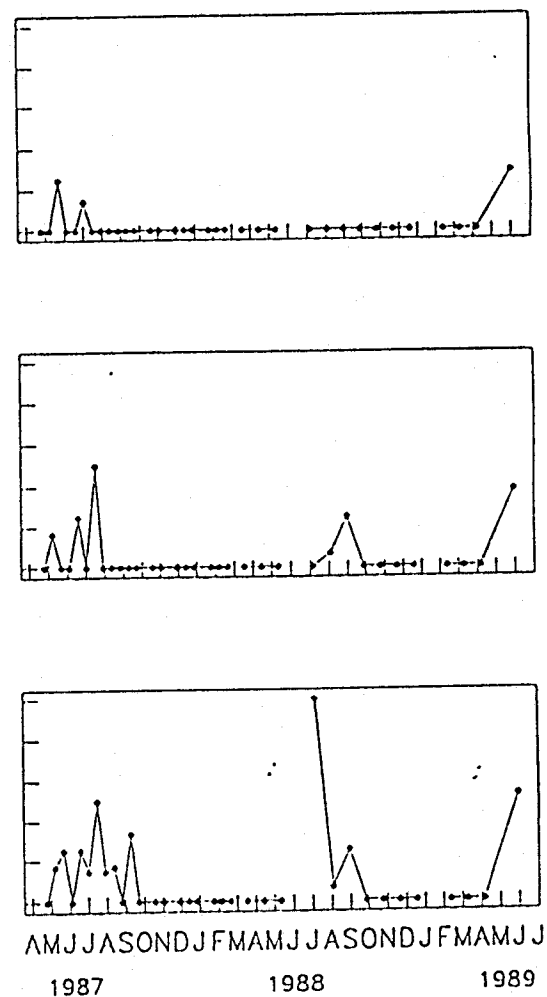
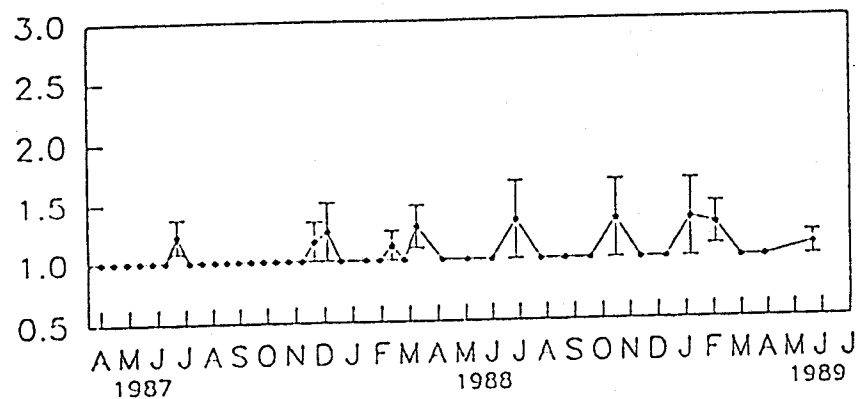
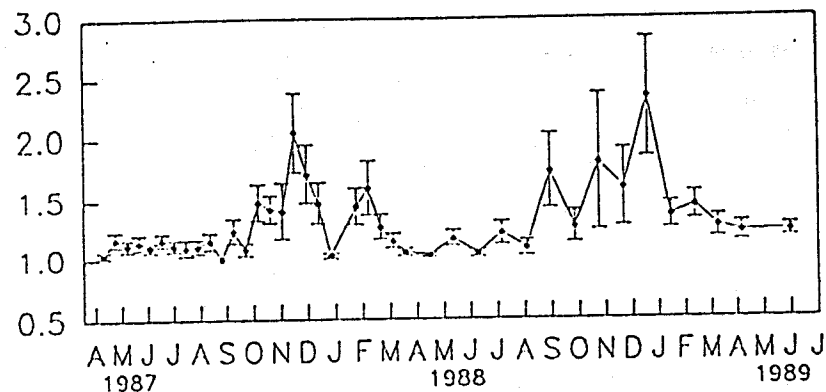


Figure 9. Fluctuations in mean number of lobsters in occupied dens for all zones where dens were identified.

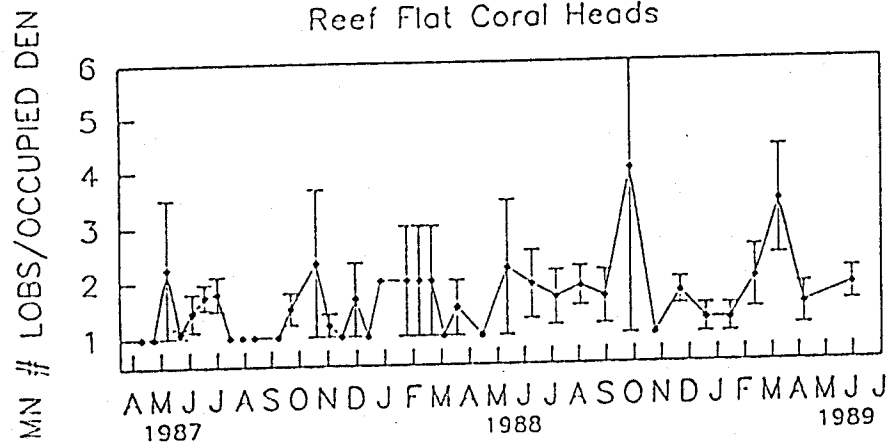
Intermediate Reef



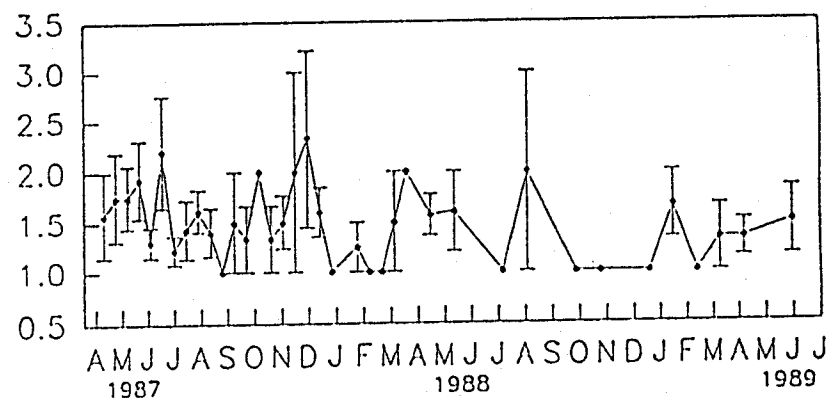
Fore Reef



Reef Flat Coral Heads



Reef Flat Blowouts



Patch Reef

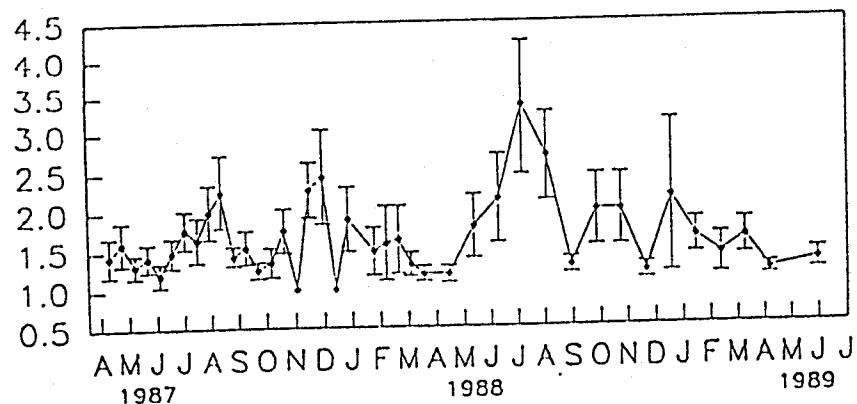


Table 1. Distribution of sites used to assess abundance and population structure trends at LKNMS. Only sites where sampling was conducted by divers are included. Except at the Reef Flat, sites are ordered from east to west within each zone.

Zone ¹	Site	Type ²	Area ³	Dens ⁴
IR	1	A	1,000	n
IR	2	C	1,000	n
IR	3	A	1,000	n
FR	1	C	1,645	97
FR	2	A	909	69
FR	3	A	1,842	n
FR	4	C	1,863	80
FR	5	A	1,533	n
FR	6	A	1,163	102
RF	1	C	⁵	1
RF	2	A	⁵	1
RF	3	A	⁵	1
RF	4	C	551	37
RF	5	C	38 ⁶	n
RF	6	A	51 ⁶	n
RF	7	C	82 ⁶	n
RF	8	A	15 ⁶	n
PR	1	A	662	105
PR	2	C	377	38
PR	3	A	344	68
PR	4	C	1,014	48
PR	5	A	1,019	56
PR	6	A	1,243	31

¹ IR=Intermediate Reef, FR=Fore Reef, RF=Reef Flat, PR=Patch Reef.

² A=abundance only, lobsters not captured; C=lobsters captured.

³ Area in m².

⁴ Total number of dens per site; n=dens not permanently identified.

⁵ RF 1-3 were isolated coral heads surrounded by rubble.

⁶ RF 5-8 were grassbed blowouts; measurements were linear meters along the edge of the blowout.

Table 2. Average density of P. argus per zone during the entire two-year period in LKNMS. Data presented as lobsters/hectare.

Zone	Mean	Minimum	Maximum
FR	64.9	29.1	115.7
RC	12.0	0	44.6
RB	2.2	0.3	8.8
PR	115.8	28.1	415.7
IR	18.2	3.3	36.7

Table 3. Comparison of trends in lobster abundance using the Mann-Kendall test for homogeneity. Where two comparisons are presented, they indicate different trends in year one and year two. Comparisons could not be made using the OR because sampling there was discontinued prior to the end of the study. 0 = no trend; + = positive trend; - = negative trend. Significance level set at $\alpha \leq 0.05$ for comparisons with zones polled; $\alpha \leq 0.01$ otherwise.

Zone	Entire Study	<u>Between Two Years</u>			<u>With Fore Reef Cycle</u>	
		Apr-Apr	Fishing Closed	Season Open	May - Sep	Sep - Jan
All	0	0	0	0	0	0
PR	0 ¹	0 ³	+	-	+	0
RC	0	0	+	0	0/+	0
RB	-	-	0	-/0	-	0
FR	0 ²	0	-	0	-	+
IR	0	0	0	0	0	0
DR	0	0	0	-	0	0 ⁴

¹ PR2 had a negative trend, PR1,3,4,5,6 = no trend.

² FR1 had a negative trend, FR3 had a positive trend, all other FR = no trend.

³ weak negative trend.

⁴ weak positive trend.

Table 4. Average numbers of spiny lobsters residing in zones sampled by divers in LKNMS. Area = ha. Mean density = lobsters/hectare. Overall mean density and density range are weighted means to account for the different areas of the zones. Mean number and range of abundance = area x mean density or maximum and minimum values for density range.

Zone	Area ¹	Mean Density	Density Range	Mean Number	Range Of Abundance
IR	136.6	18.2	3 - 37	2486	455 - 5015
FR	14.7	64.9	29 - 115	954	425 - 1700
RF	23.3	5.5	1 - 13	128	23 - 312
PR	56.9	116.8	28 - 415	6475	1600 - 23614
Overall	231.5	43.3	11 - 132	10043	2503 - 30641

¹ Areas courtesy of R. Rodkey, NOAA Photogrammetry section

Table 5. Spiny lobster capture success rates (percent of total) in all zones and for divers who captured more than 50 lobsters.

Zone	Success Rate	Diver	Success Rate
FR	83.5	BB	86.7
RE	93.6	BH	85.7
PR	90.3	CS	93.0
IR	94.8	DF	87.9
		DH	87.0
		JH	88.8

Table 6. Comparisons of trends in lobster carapace length using the Mann-Kendall test for homogeneity of slope. 0 = no trend; + = positive trend; - = negative trend. Significance level set at $\alpha \leq 0.05$.

<u>Zone</u>	<u>Entire Study</u> ¹	<u>Between Two Years</u>	
		<u>Fishing Season</u>	
		Closed	Open
All	-	0	-
PR	na	0	-
RB	na	0	0
RQ	na	0	0
FR	na	0	-
IR	na	0	0
DR	na	0	-

¹ Homogeneity cannot be tested for locations with one slope. Thus entire study individual zones were tested using a Mann-Kendall sign test. All showed a negative slope. Only two were significant.

Table 7. Differences in carapace length related to zone, site, and reproductive season. Means with overlapping vertical bars are not significantly different ($\alpha \leq .05$).

Zone	Sex ¹	Repro ²	Mean CL $\pm$ SE
PR	M	N	62.7 $\pm$ 3.6
PR	F	N	63.6 $\pm$ 3.4
RB	M	N	65.3 $\pm$ 3.6
RB	F	N	70.7 $\pm$ 2.8
PR	M	Y	72.7 $\pm$ 1.3
PR	F	Y	73.6 $\pm$ 1.1
IR	M	Y	74.0 $\pm$ 3.5
OR	F	N	74.6 $\pm$ 1.3
RB	F	Y	75.7 $\pm$ 0.9
DR	F	N	75.9 $\pm$ 0.6
IR	F	Y	77.0 $\pm$ 1.7
IR	F	N	77.0 $\pm$ 2.7
RC	F	N	77.1 $\pm$ 2.0
FR	F	N	77.5 $\pm$ 1.1
RC	M	N	77.9 $\pm$ 4.4
RC	F	Y	78.6 $\pm$ 0.8
RB	M	Y	79.1 $\pm$ 1.1
OR	F	Y	79.7 $\pm$ 0.8
DR	F	Y	81.0 $\pm$ 0.4
FR	F	Y	81.4 $\pm$ 0.6
OR	M	N	81.8 $\pm$ 2.8
DR	M	N	82.2 $\pm$ 1.1
OR	M	Y	82.4 $\pm$ 1.3
IR	M	N	84.7 $\pm$ 4.3
FR	M	N	85.0 $\pm$ 3.3
DR	M	Y	85.5 $\pm$ 0.7
RC	M	Y	85.8 $\pm$ 1.5
FR	M	Y	90.4 $\pm$ 1.6

¹ M = male; F = female.

² Y = reproductive season (March-September);
N = nonreproductive season (October-February).

Table 8. Sex ratio (Female : Male) within each zone during the entire two-year study period.

Zone	Overall	Reproductive	Nonreproductive
FR	3.6 : 1	4.0 : 1	3.2 : 1
RC	2.0 : 1	1.5 : 1	2.6 : 1
RB	1.1 : 1	1.1 : 1	1.2 : 1
IR	3.3 : 1	3.8 : 1	2.8 : 1
DR	2.3 : 1	2.8 : 1	1.7 : 1
OR	2.0 : 1	2.2 : 1	1.9 : 1
PR	1.3 : 1	0.8 : 1	1.8 : 1

Table 9. Mean number of lobsters per den that contained one or more lobster throughout LKNMS.

Zone	N ¹	Mean $\pm$ SE	Maximum Occupancy
FR	1344	1.28 $\pm$ 0.02	15
RC	114	1.59 $\pm$ 0.09	10
RB	150	1.51 $\pm$ 0.06	8
IR	192	1.07 $\pm$ 0.02	3
PR	536	1.68 $\pm$ 0.06	20
Overall	2293	1.42 $\pm$ 0.02	20

¹ Number of observations of dens containing one or more lobsters over the entire two-year study.

Table 10. Percentage of lobsters molting (molt stage AB, D₀, D₁, D₂, D₃ or E) per zone during reproductive and nonreproductive seasons.

Zone	<u>Percent Molting</u>		
	Overall	Reproductive Season	Nonreproductive
FR	5.4	2.5	19.8
RC	4.8	4.7	5.0
RB	20.3	19.3	24.2
PR	11.0	11.9	6.4
OR*	2.4	2.5	1.7
DR*	5.7	6.8	3.1
IR	4.4	5.3	0.0

* Trap collections.

Table 11. Percentage of lobsters molting (molt stage AB, D₀, D₁, D₂, D₃, or E) in two Reef-Flat blowout sites and in nearby coral rocks located in the center of each blowout.

Type	Site	Percent Molting
Blowout	5	20.0
Rock	9	73.9
Blowout	7	21.0
Rock	10	25.8

Table 12. Density (lobsters/ha) and number of recaptures by source zone of spiny lobsters on nocturnal foraging grounds on and near the Reef Flat. Mean daytime densities from equivalent four-week period abundance samples are presented for comparison. Blank spaces mean no data for that period.

Date	Lobster Number	<u>Foraging</u>			<u>Daytime Density</u>		<u>Recaptures</u>	
		Mean Density	±	SE	RF	FR	RF	FR
6/27-29/88 ¹	40	33.3	±	3.5	8.0	54.1	4	0
7/25-27/88 ¹	15	18.8	±	3.0	13.4	63.1	1	0
8/17-18/88 ²	9	11.3	±	1.0	11.2	43.1	1	0
10/10-12/88 ²	22	55.5	±	5.7	13.3	33.5	9	1
1/9/89 ³	47	117.5	±	9.9	6.2	89.0	0	5
7/19/89 ⁴	58	69.8	±	7.2				
7/19/89 ⁵	66	80.6	±	9.8			6	3

¹ Total transects = 15

² Total transects = 10

³ Total transects = 5

⁴ Simultaneous dive on 12 transects; 2130 hrs; lobsters not captured

⁵ Simultaneous dive on 12 transects; 2300 hrs; lobsters captured

Table 14. Distribution of recaptured lobsters captured in each zone. The zone of recapture reflects the final recapture event for each lobster. Some lobsters were recaptured repeatedly. Lobsters whose recapture locations were unknown are omitted.

Capture Zone	Initial Captures	FR	RF	IR	Distribution of Recaptures (%)				W ²	E ³	I ⁴
					DR	OR	PR	LK ¹			
FR	557	<u>15.4</u>	2.2	0.0	0.2	0.0	0.4	1.3	0.4	0.0	0.4
RF	834	3.4	<u>16.1</u>	0.0	0.1	0.0	0.0	1.4	0.4	0.1	0.1
IR	56	1.8	0.0	<u>17.9</u>	0.0	0.0	0.0	1.8	0.0	0.0	0.0
DR	1031	0.5	0.1	0.4	<u>2.0</u>	0.1	0.0	1.5	0.4	0.1	0.1
OR	353	0.0	0.0	0.0	0.3	<u>0.3</u>	0.3	1.4	1.4	0.1	0.0
PR	245	0.0	0.0	0.0	0.0	0.0	<u>19.2</u>	2.0	0.4	0.4	0.4

¹ LK = Inside LKNMS

² W = West of LKNMS

³ E = East of LKNMS

⁴ I = Inshore

Table 15. Percentage of resident lobsters recaptured within zones over time. A resident lobster is one whose initial capture and all recaptures are from one zone.

Time Out Months	RF	FR	PR
0-3	77	78	90
3-6	15	17	6
6-9	3	4	4
9-12	3	1	0
>12	2	1	0
Total	100	101	100

Table 16. Number of recaptures and mean (± 1 SE) number of days between initial capture and final recapture. All tags returned without information on location were assumed to have been captured outside the Sanctuary. LK = inside LKNMS; out = outside LKNMS.

Initial Capture	Final Recapture	N	Time Out
FR	FR	86	62 $\pm$ 7
FR	RF	12	53 $\pm$ 11
FR	LK	11	95 $\pm$ 18
FR	OUT	4	87 $\pm$ 40
Total		113	
RF	RF	133	52 $\pm$ 5
RF	FR	28	93 $\pm$ 14
RF	LK	14	160 $\pm$ 51
RF	OUT	8	67 $\pm$ 13
Total		183	
PR	PR	47	54 $\pm$ 7
PR	LK	5	34 $\pm$ 13
PR	OUT	4	257 $\pm$ 143
Total		56	
IR	IR	10	142 $\pm$ 62
IR	LK	2	70 $\pm$ 7
IR	OUT	0	
Total		12	
DR	DR	21	30 $\pm$ 6
DR	OR	1	1
DR	LK	25	56 $\pm$ 16
DR	OUT	7	50 $\pm$ 25
Total		54	
OR	OR	1	33
OR	LK	7	52 $\pm$ 23
OR	OUT	6	48 $\pm$ 32
Total		14	

Table 18. Estimates of *P. arcus* density from the Caribbean. Most estimates were determined for larger (>70mm carapace length) spiny lobsters and were often obtained from fishery data. Data presented as weight of the fishable population are restated as the number of 80-mm-CL lobsters using the morphometric relationship: total weight(g) = [0.002185 * carapace length(mm)]^{2.78138} (FMRI, unpub. data). Density estimates were not examined critically.

Location	Density	Method	Duration	Source
Dry Tortugas Florida	180-328.5 lobsters/ha	Diver transects Traps	April 1971- August 1973	Davis, 1974
Dry Tortugas Florida	58.3 kg/ha (136 lobsters/ha)	Diver transects Traps	April 1971- July 1977	Davis, 1977a
U.S. Virgin Islands	4.8-15 lobsters/ha	Diver survey	April 1970- Sept. 1970	Herrnkind et al. 1975
Little Bahama Bank	4.2 kg/ha (9.8 lobsters/ha)	Diver transects	June 1983- June 1984	Smith and van Nierop, 1986
Great Bahama Bank	2.87 kg/ha (6.7 lobsters/ha)	Diver transects	June 1983- June 1984	Smith and van Nierop, 1986
Little Bahama Bank	84-1230 lobsters/ha	Tag-Recapture	1976-1978	Waugh, 1981
Cuba	35-61 lobsters/ha	Tag-Recapture	1981-1985	Cruz et al. 1986
Bermuda	3.7-7.8 lobsters/ha	Tag-Recapture Divers	May 1987- Dec. 1987	Evans, 1988
Antigua and Barbuda	16.1-30.6 lobsters/ha	Tag-Recapture Divers	April 1973- July 1973	Peacock, 1974
Curacao	1.54 kg/ha (3.6 lobsters/ha)	Diver surveys		Sybesma et al. 1986
Los Roques Venezuela	0.8 kg/ha (1.9 lobsters/ha)	Sustainable Yield Estimate	Oct. 1969- April 1970	Cobo de Barany et al. 1972
Guajira Pen. Colombia	4.45 kg/ha (10.3 lobsters/ha)	Sustainable Yield Estimate	1971	Squires and Riveros, 1978
Jamaica	1.59 kg/ha (3.7 lobsters/ha)	Traps		Vidaeus, 1970
Looe Key NMS Florida	64.9 lobsters/ha (Forereef)	Diver surveys	April 1987- June 1989	This study



UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SERVICE
OFFICE OF OCEAN AND COASTAL RESOURCE MANAGEMENT
Washington, D.C. 20235
Sanctuaries and Reserves Division

JUL 22 1991

Dr. John Hunt
Biological Administrator II
Florida Marine Research Institute
Marathon Field Lab
13365 Overseas Hwy., Suite 103
Marathon, Florida 33050

Dear Dr. Hunt,

This letter is in regard to the in-house review of the draft final report for Contract #50 DGNC 600093, Modification #0004, entitled "Management Implications of Trends in Abundance and Population Dynamics of the Caribbean Spiny Lobster, Panulirus argus, at the Looe Key National Marine Sanctuary". Enclosed you will find two copies of this report with recommended changes submitted by Dr. Michael Crosby, SRD Research Coordinator, and myself. Please review these suggestions and make the necessary modifications.

The revised document should be submitted to this office by August 12, 1991. Upon receipt of the final revised report a determination will be made regarding the publication of this study as a NOAA Technical Memorandum.

Please call myself (202-606-4122) or Michael Crosby, (202-606-4126), if you need further clarification or guidance.

Sincerely,

Pamala L. James
Program Specialist

Enc.



August 11, 1991

Ms. Pamala James
Program Specialist
Sanctuaries and Reserves Division
NOAA/NOS/OCRM
1825 Connecticut Avenue, N.W.
Suite 714
Washington, DC 20235

Dear Ms. James:

Enclosed is the revised version of the final report for Contract #50 DGNC 600093, Modification #0004, now entitled "Management implications of trends in the population dynamics of the Caribbean spiny lobster, Panulirus argus, at Looe Key National Marine Sanctuary.

I have endeavored to address all of your and Dr. Crosby's review comments. The introduction was reorganized and I have attempted to clarify the methods and results section throughout each. Also, I have added a paragraph where I attempt to tie in fishery impacts into a more cohesive discussion prior to making the management recommendations. I hope you find this to be an improved report.

Because of the time constraints, I am unable to provide more detail concerning my response to individual suggestions. Consequently, I am returning most of Dr. Crosby's review with my notes. Pertinent sections of your review are attached, as well. By the way, one of the authors cited is Dan Dauer (Ewing et al.).

Please inform me of your intentions concerning the future disposition of this paper. If you plan to publish it in the Technical Memorandum series, I would like one last opportunity to revise it under less constrained conditions.

On a separate note, my staff and I are conducting a mail survey of recreational lobster fishermen. The sport season mail out is today and yes it has been wild here. We will mail out the regular season survey in a few weeks. I think the results will be of interest to the Sanctuaries and Reserves Division. For your information, I have enclosed a copy of each survey questionnaire.

Thank you for your efforts in my behalf.

Sincerely yours,

John H. Hunt
Research Administrator II

BUOY POSITIONS

45	13975	43532.5	24-33.553	81-24.776		PATCH
46	13974.8	43532.8	24-33.520	81-24.813		PATCH
47						
48						
49						
50	13973.7	43532.2	24-32.563	81-24.637	38	
51	13973.3	43532.6	24-32.549	81-24.760	42	
52	13973.3	43532.8	24-32.542	81-24.832	42	
53	13973	43533.2	24-32.590	81-24.917	45	
54	13972.9	43533.4	24-32.501	81-24.978	45	
55	13972.7	43533.8	GONE		45	
56	13972.9	43533.1	24-32.451	81-24.892	68	
57	13971	43537.4	NONE TAKEN		50	
58	13970.9	43537.6	24-32.280	81-25.778	50	
59	13970.8	43537.7	24-32.282	81-25.840	50	
60	13970.7	43538	GONE		50	
61	13970.7	43538.2	NONE TAKEN		50	
OUTER NE	13979.4	43523.9	24-34.172	81-22.993	28	
OUTER SE	13977.3	43523.9	24-32.966	81-23.008	41	
OUTER NW	13972.8	43538.6	24-33.597	81-25.980	35	
OUTER SW	13970.7	43538.6	24-32.334	81-26.003	42	
CORE NE	13975.2	43530.1	24-33.087	81-24.250	12	
CORE SE	13975	43529	24-32.760	81-24.055	23	
CORE NW	13974	43532	24-32.828	81-24.623	18	
CORE SW	13973.7	43532	24-32.633	81-24.629	28	