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MOLT FREQUENCY AND SIZE-CLASS DISTRIBUTION IN THE CALIFORNIA SPINY LOBSTER (*PANULIRUS INTERRUPTUS*) AS INDICATED BY BEACH-CAST CARAPACES AT SAN NICOLAS ISLAND, CALIFORNIA

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Adult California spiny lobster (*Panulirus interruptus*) are described as molting once or more than once annually. We measured 815 beach-cast spiny lobster carapaces found along a 1.3-km section of San Nicolas Island, California, in 1988 and 1989. Of these, 759 (93%) were found during the months of August, September, and October, suggesting a single annual molt for adult animals. The average size of a beach-cast carapace was 79 mm carapace length (CL), compared with an average size of 92.1 mm CL for 1000 animals captured live in the same area.

INTRODUCTION

Growth in the Palinuridae occurs at ecdysis (Aiken 1980). The rate of growth is dependent on the molt frequency and the change in size per molt or growth increment. Previous methods to define molt frequency in spiny lobsters include observed changes in carapace condition over time (Mitchell et al. 1969), observations of molting in captive animals (Lindberg 1955, Chittleborough 1976, Nair et al. 1981), and changes in carapace lengths of marked and recaptured animals in the wild (McKoy 1985, Hunt and Lyons 1986). Estimates of the growth increment in spiny lobsters have generally been obtained from analyses of size distributions of captured animals (Mitchell et al. 1969, Chittleborough 1976) or observed changes in carapace lengths (CL) of marked individuals in the wild (Chittleborough 1976, Newman and Pollock 1974, McKoy 1985, Annala and Bycroft 1985, Ebert and Ford 1986) or captive animals (Lindberg 1955, Chittleborough 1976, Nair et al. 1981). Although considerable variation exists in documented molt-frequency in the Palinuridae (Aiken 1980), palinurid lobsters are recognized as following a common trend in decapod crustaceans of decreasing molt frequency with increasing age (Aiken 1980).

The California spiny lobster (*Panulirus interruptus*, Randall), occurs from Magdalena Bay, Baja California Sur, Mexico, northward to Point Conception, California (Shaw 1986, Holthuis 1991), and small isolated populations are reported

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as far north as the Monterey Peninsula, California (Schmitt 1921). Effective management of this recreational and commercially exploited resource requires accurate information on basic life history parameters (e.g., growth rates). Molt frequency for adult California spiny lobsters has been described as occurring once (Backus 1960, Mitchell et al. 1969) and twice annually (Lindberg 1955). These differences in molt frequency led to estimates of age at recruitment into the California fishery (83 mm CL) from 7 (Lindberg 1955) to 11 years (Mitchell et al. 1969).

The purpose of this study was to describe the temporal pattern of molting and the size structure of a population of California spiny lobsters as indicated by beach-cast carapaces along the shoreline of San Nicolas Island, California. The analysis of beach-cast carapaces is a new approach to examining growth processes in the California spiny lobster. To evaluate the technique, we compared the size class distributions of beach-cast carapaces with a sample of live lobsters captured offshore.

METHODS

The study area consisted of 1.3 km of shoreline along the northeast side of San Nicolas Island (Fig. 1). This section of shoreline was selected after several years of observations of the seasonal occurrence of lobster carapaces similar to the patterns described herein. Furthermore, offshore from this area were the sites used for the collection of live lobsters (Bodkin and Kenner 1988). From August 1988 through November 1989, we searched the study area at about two-week intervals during low tide. Each lobster carapace was measured dorsally from the anterior margin of the supra orbital groove to the posterior border of the cephalothorax, to the nearest mm in length (CL). Carapaces were crushed following examination to prevent resampling.

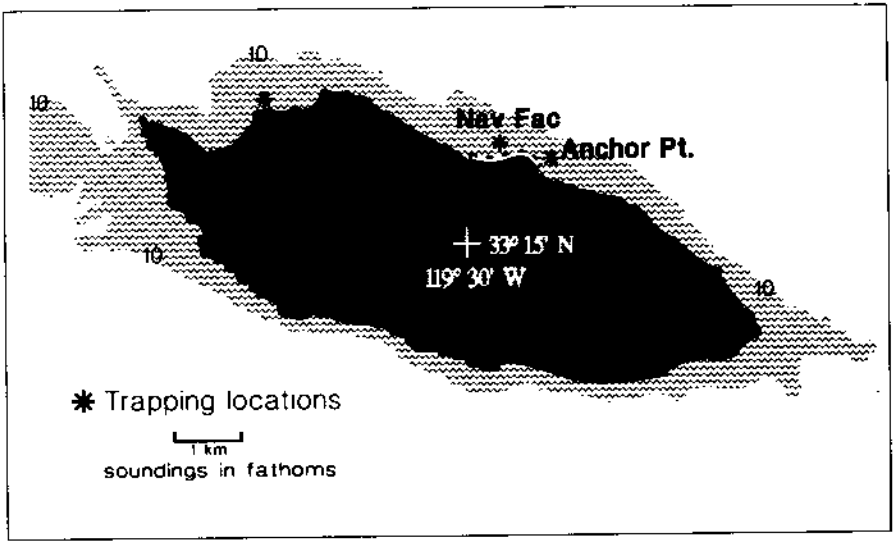

Figure 1. The study area at San Nicolas Island, illustrating coastal segment where carapaces were collected (---), and lobster capture sites (*).

Sex could not usually be determined because the exoskeletons were frequently disarticulated.

In 1988 and 1989, live lobsters were captured around San Nicolas Island either by hand or with traps similar to those used in the commercial fishery, except that no escape ports were provided for sub-legal lobsters. We collected live lobsters by hand, either free-diving or with the aid of SCUBA, during both day and night. Hand caught lobsters were collected from two depth-strata, the intertidal (< 3-m deep) and the subtidal (between 3- and 15-m deep). Lobster traps were set at water depths between 5 and 15 m in areas that contained apparently suitable lobster denning habitat as determined from visual observations while SCUBA diving. Traps were baited with 150-200 g of abalone trim (*Haliotis* sp.) or Pacific mackerel (*Scomber japonicus*). Traps were pulled daily and re-baited. Captured lobsters were sexed, measured (CL), marked and released. The reproductive status of each captured female was qualitatively assessed by the following categories; 1) recently deposited spermatophore present, female had mated; 2) berried, extruded eggs present; or 3) non-reproductive, eggs or recent spermatophore absent.

Comparisons of mean carapace lengths between beach-cast and live-caught lobsters and between live-caught lobsters by method of capture were made with a two-sample *t*-test. A significance level of 0.05 was established *a priori*.

RESULTS

We found and measured 815 beach-cast lobster carapaces during this study. Recovered carapaces ranged in size from 34 to 153 mm CL (Fig. 2), with a mean size of 79 mm. Mean carapace length did not differ between years (79 mm in 1988 and 80 mm in 1989). Carapaces were found during each month, except during March and May. Most (759 of 815, 93%) were found during August, September, and October (Fig. 3). Of the remaining 56 carapaces, 36 (64%) were found during November surveys of both years. Although more than twice as many carapaces were found in 1988 as in 1989 (582 compared to 233), the temporal pattern of carapace deposition was similar for both years (Fig. 3). In both years carapace recovery had ceased by late November.

The smallest carapaces were usually recovered during the early part of the molting period ($\bar{x}$ = 72 mm CL, SE = 1.43, 29 August 1988; $\bar{x}$ = 68 mm CL, SE = 1.82, 13 August 1989). The largest carapaces were found next ($\bar{x}$ = 90 mm CL, SE = 3.58, 26 September 1988; $\bar{x}$ = 88 mm CL, SE = 8.41, 27 August 1989). Following this period when the largest carapaces were recovered was an extended period when most carapaces were found (50% in 1988 and 78% in 1989). These carapaces averaged from 76 mm to 83 mm CL per collection period.

In 1988 and 1989, we captured 1,000 live lobsters (519 male:481 female) around San Nicolas Island (Bodkin and Kenner 1988), while 157 lobsters were caught by traps ($\bar{x}$ = 89.1 mm CL, SE = 1.14), 403 were captured by hand in the intertidal ($\bar{x}$ = 89.8 mm CL, SE = 1.33), and 440 were taken by hand in the subtidal ($\bar{x}$ = 96.1 mm CL, SE = 1.43). The general trend in female reproductive status throughout the year is

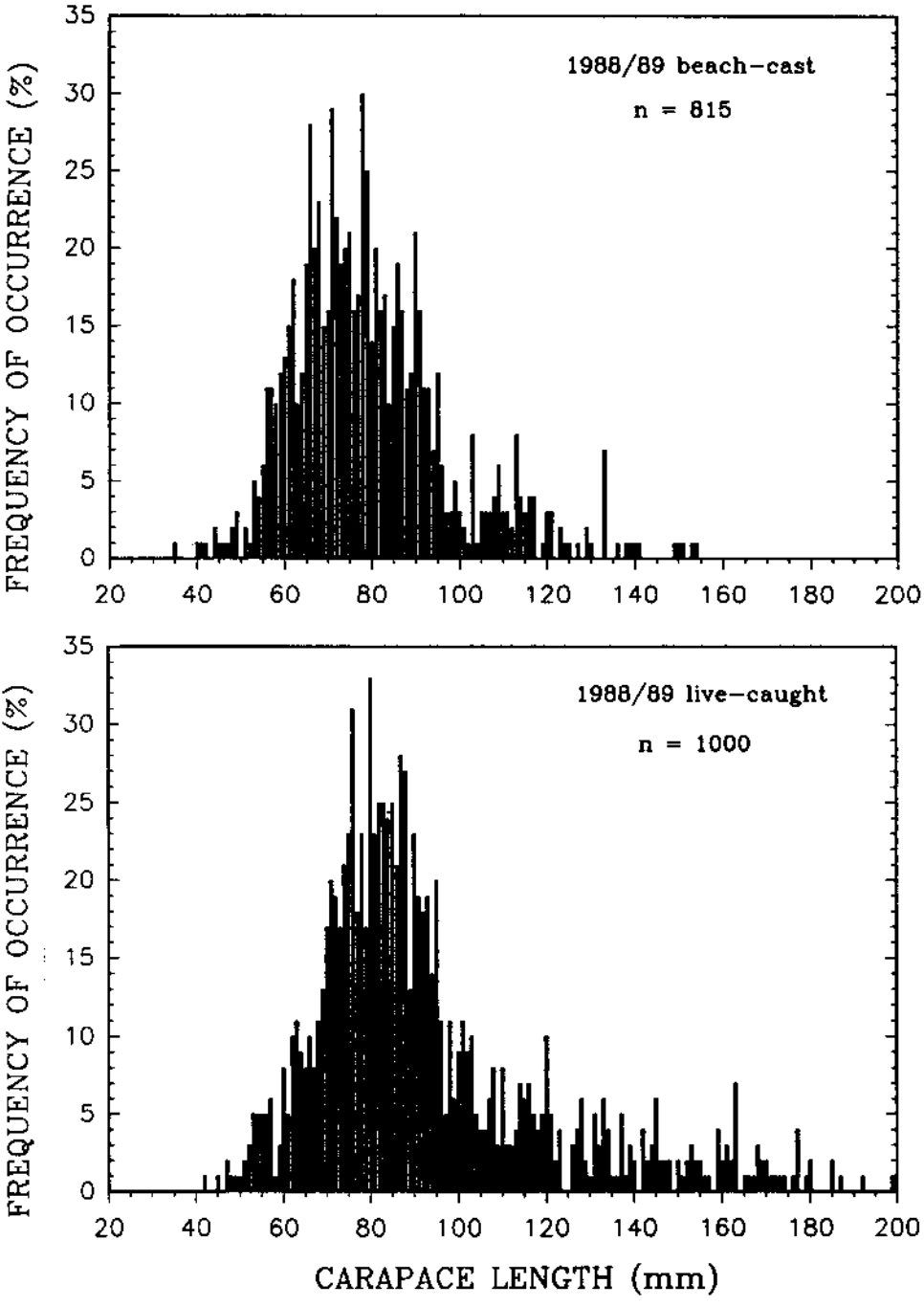

Figure 2. Size-class distribution of 815 beach-cast and 1000 live-caught spiny lobster carapaces at San Nicolas Island, CA, 1988-1989.

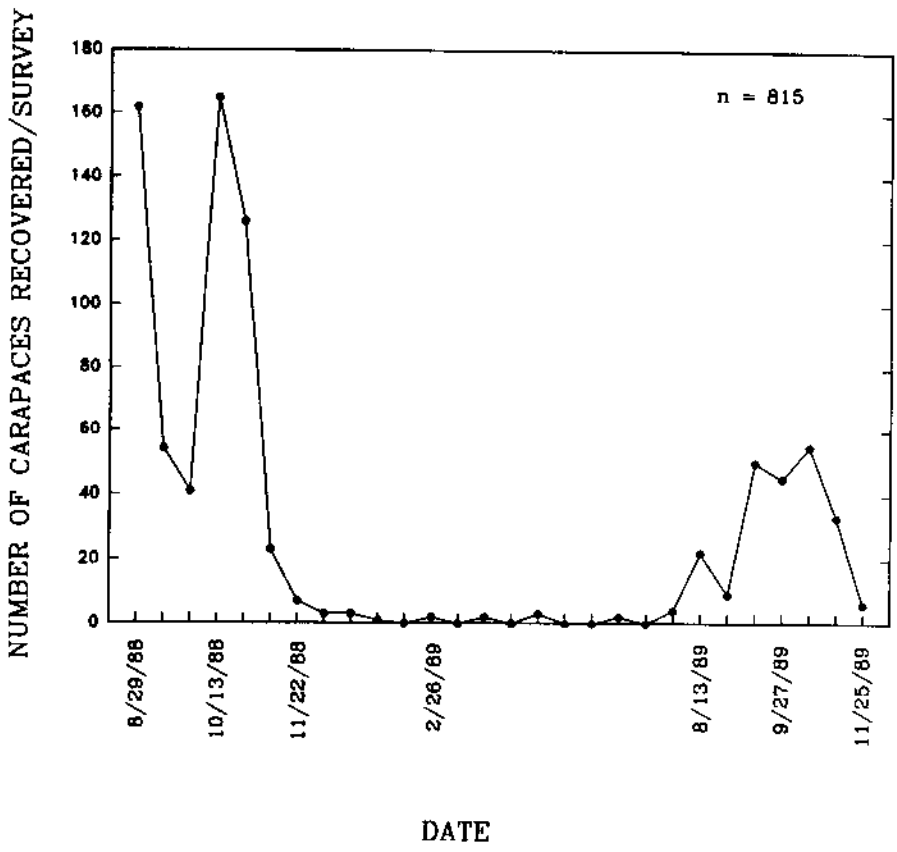

Figure 3. The temporal distribution of beach cast-spiny lobster carapaces at San Nicolas Island, CA, 1988-89.

presented in Fig. 4. During February and March, most females carried sperm packs, followed by the presence of eggs in June and July and finally by a non-reproductive period from August through November.

DISCUSSION

Inconsistent patterns of molt frequency are apparent in the Palinuridae. Annual molting was described for adult *Jasus tristani* (Pollock and Roscoe 1977) and adult female *J. lalandii* (Pollock 1986). Molting frequency was described as semi-annual (Smith 1948, 1951) and more than once per year for large *P. argus* (Hunt and Lyons 1986). Adult *J. edwardsii* molt once per year and more than once per year, dependent on location (McKoy 1985).

Molt frequency for adult California spiny lobsters, is described as occurring once (Backus 1960, Mitchell et al. 1969) and twice annually (Lindberg 1955). Our results suggest that within most size classes of *P. interruptus* carapaces encountered during

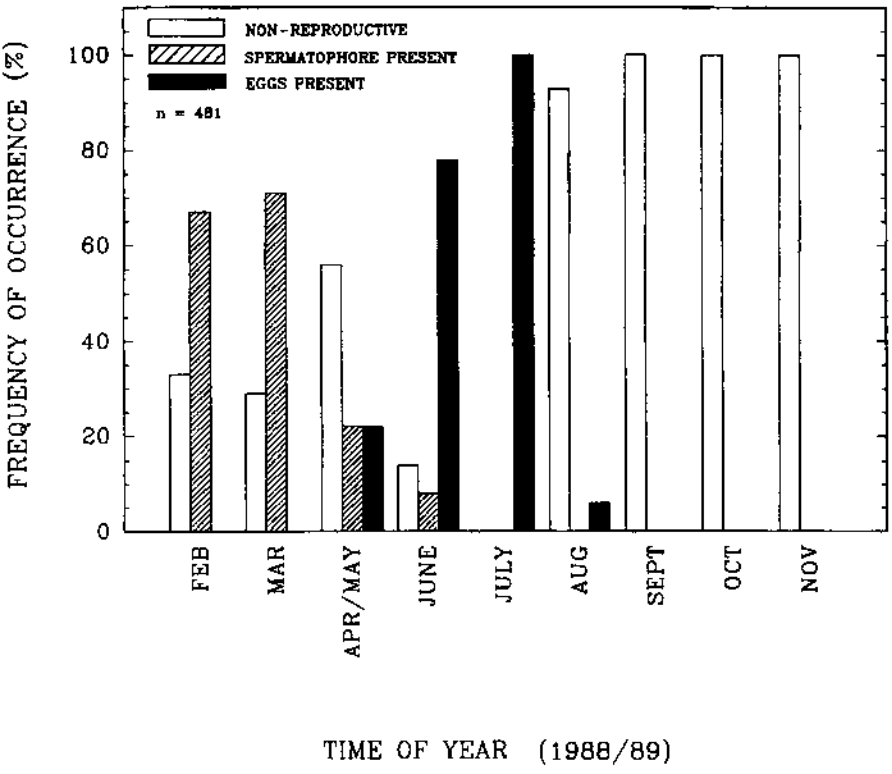

Figure 4. Annual reproductive cycle of female spiny lobster at San Nicolas Island, CA, as indicated by carapace condition.

this study (>50 mm), molting occurs once per year at San Nicolas Island during the months of August through October suggesting a large scale synchronous molt period. Although carapaces were found throughout most months of the year, their low frequency of occurrence may suggest they are not provided as part of the normal molt cycle. We expect that some proportion of the population dies of natural causes, e.g., predation (Lindberg 1955), and becomes beach-cast throughout the year and suggest that at least some of the carapaces we encountered were a result of mortality rather than molting.

Temporal patterns of lobster carapace deposition onshore could reflect the relative abundance of live lobsters offshore. However, observations of live lobsters directly offshore from our study site since 1986 (Bodkin and Kenner 1988) indicate that, although there are fluctuations, lobsters are relatively abundant throughout the year.

Mitchell et al. (1969) described a difference in the initiation and duration of molt period by sex; male lobsters begin to molt about two months prior to females but complete the cycle at about the same time, in late October. Lipcius (1986) described a general pattern in palinurid lobsters in which younger (smaller) lobsters of both sexes molted earlier than older animals. The patterns of carapace deposition we

observed are consistent with these models (Fig. 2).

By analyzing size-class modes, Mitchell et al. (1969) reported growth increments of 3.7 mm CL for males and 4.4 mm CL for females. Lindberg (1955) reported annual growth increments (two molts) of 2 cm in total length (about 6.5 mm CL/year). Engle (1979) reported that juvenile lobsters grow to 56 mm CL in two years. If we use an annual molt after two years (56 mm) and growth increments of 3.2 to 4.4 mm, we estimate age at entry into the fishery of 8-10 years (83 mm).

The mean size of beach-cast lobster carapaces was 79 mm CL, significantly smaller than the mean size of 93.1 mm CL from 843 live lobsters captured by hand around San Nicolas Island ($P < 0.01$) (Fig. 3). Reasons for this difference remain unclear. Within the sample of 843 hand-caught lobsters, we observed a significantly smaller mean size of 90.0 mm CL (SE = 1.26;) for animals captured in nearshore waters less than 3 meters deep, as compared with a mean size of 96.2 mm CL (SE = 1.35;) for animals captured in offshore waters greater than 8 m in depth ($P < 0$ .01). This difference suggests that lobsters may be spatially segregated by size during the molting period and that smaller animals occupy the nearshore in greater relative abundance. However, this difference explains only a small portion of the total difference between the beach-cast and live-caught samples. Additional explanations for this difference may include decreasing the adult molt frequency to less than once per year, after attaining some age or size, or more than one molt per season for smaller animals. Hydrodynamic sorting of nearshore materials may favor the deposition of smaller carapaces on shore, avian and/or terrestrial scavengers may select larger carapaces or live capture methods may be unintentionally biased towards larger animals.

Analysis of the reproductive condition of 481 live female lobsters captured in 1988 and 1989 indicates that reproductive behavior at San Nicolas begins in late winter and ends with the release of eggs late in the summer, followed by a molting period. This reproductive pattern, followed by the occurrence of large numbers of beach-cast carapaces, seems to support the conclusion of Mitchell et al. (1969) that ecdysis in mature California spiny lobsters occurs in late summer and fall after completion of the reproductive cycle.

Our results indicate a prolonged, single, annual molt cycle in California spiny lobsters, extending from August through October at San Nicolas Island. The smaller average size of the beach-cast carapaces compared to the live population offshore suggests lobsters may be segregated by size and depth during the molting period. Furthermore, a decreasing molt frequency in large lobsters may contribute to the observed patterns. Differences in the sizes between beach-cast and hand-captured samples needs further reconciliation before using beach-cast carapaces to describe the size-class structure of the live lobster population.

In conclusion, the presence of beach-cast lobster carapaces seems useful in describing temporal patterns of molting in the California spiny lobster. The U.S. Fish and Wildlife Service (1987) predicted the elimination of commercial and recreational lobster fisheries following the recent re-introduction of sea otters into the nearshore waters around San Nicolas. The methods we describe may be useful for monitoring

change in the size-class distribution and/or as an index to abundance of the lobster population at San Nicolas Island over time. Similar methods may be applied elsewhere, to facilitate the study of the population dynamics of this important crustacean.

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