

AN INTENSIVE FISHING EXPERIMENT FOR THE CARIDEAN SHRIMP, *HETEROCARPUS LAEVIGATUS*, AT ALAMAGAN ISLAND IN THE MARIANA ARCHIPELAGO

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ABSTRACT

During January 1984 an intensive fishing experiment for the deepwater caridean shrimp, *Heterocarpus laevigatus*, was conducted near Alamagan Island in the Mariana Archipelago. Twenty standard shrimp traps were set daily, producing a significant decline in the average catch rate from 3.33 to 1.82 kg/trap-night over a 16-day period. This drop was associated with a removal of 776 kg of shrimp from the study site. Resampling the area 4 months later showed that the catch rate remained depressed. Length-frequency data demonstrate that the decrease in catch per unit effort was due to a decline in the number of shrimp caught. An initial population size of 1.714 kg from 312 ha habitat is estimated, corresponding to one exploitable shrimp per 51 m². The estimate of q , catchability (0.001945 trap-night⁻¹) indicates that *H. laevigatus* may be easily overfished by trapping.

Intensive fishing experiments can provide the ideal complement to resource surveys using catch per unit effort (CPUE) to estimate the relative abundance of exploitable stock. Whereas values of CPUE are usually adequate for studying spatial and temporal variation in resource abundance, often an absolute estimate of exploitable biomass is required. This is particularly true of yield assessments. Due to the relative nature of CPUE statistics, a conversion factor is necessary to translate catch rates into absolute units of biomass. This proportionality is termed catchability, typically a constant parameter (but see Schnute 1983; Polovina 1986) which can be estimated from the results of intensive fishing experiments (Ricker 1975).

The advantages of intensive fishing over alternative methods of estimating the catchability coefficient (q) are several. Foremost is that no history of either catch or effort data is needed. This characteristic makes methods of fishing success (Ricker 1975) or survey-removal (Schnute 1983) particularly attractive for use in assessments involving exploratory survey data, as well as for studying emerging new fisheries. A second advantage is that results can be obtained rapidly. Because fishing is, by definition, conducted intensively over a short time period and the necessary computations are quite simple, an estimate of q is quickly realized.

Although these advantages recommend the approach, two restrictive assumptions must be made in analyzing the data. One must assume, in the absence of information to the contrary, that the population fished is closed, or equivalently, that additions exactly balance removals other than those due to fishing. The basis of this assumption can be strengthened if the intensive fishing site is located in a naturally isolated area. For example, Polovina (1986) performed an intensive fishing experiment on a small pinnacle 5.5 km in circumference which was isolated by 75 km of deep water from the nearest similar habitat. A second assumption is that fishing removals account for all changes in stock biomass, i.e., natural mortality, growth, and recruitment are negligible during the period of fishing. For this reason, removals are carried out intensively over as short a time interval as possible. If both assumptions hold then q can be estimated directly by the slope of the linear regression of either CPUE on cumulative catch (Leslie and Davis 1939) or $\log\{CPUE\}$ on $\log\{\text{cumulative effort}\}$ (DeLury 1947).

Refinements to these two basic methods have been proposed by Braaten (1969), Crittenden (1983), Schnute (1983), and Polovina (1986) among others. Generally, estimators have been found to be most sensitive to a departure from the assumption of constant catchability. A variety of adjustments have been used to correct this and other statistical problems which often occur with real data.

The work reported here is an application of the intensive fishing method to estimate the catchabil-

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ity and population density of a deepwater caridean shrimp, *Heterocarpus laevigatus*. This circumglobal species is found in depths of 400-950 m in subtropical and tropical latitudes (King 1984). Experimental trapping surveys have shown it to be abundant at widespread localities in the central and western Pacific (King 1983), and a developing commercial fishery for this species has emerged in the Hawaiian Islands (Gooding 1984). Interest by Pacific island nations in promoting the harvest of this shrimp is great (King 1981), providing the impetus for an assessment of the *Heterocarpus* resource in the Mariana Archipelago. Additional results of this research program are reported elsewhere (Moffitt and Polovina²).

MATERIALS AND METHODS

Intensive fishing for *Heterocarpus laevigatus* was conducted in an area 3.5 km off the north end of Alamagan Island in the western Pacific (lat. 17°39'N, long. 145°50'E). Alamagan is part of the Commonwealth of the Northern Mariana Islands, lying 450 km north of Guam (Fig. 1). It is small, uninhabited, and of recent volcanic origin. While the ocean bottom slopes steeply away from the island at an angle of 25° to the east, south, and west, a broad shelf, approximately 6.5 km² in area and lying 600-800 m deep, extends well off the north end of the island. This shelf was selected as a study site because 1) good catches of *H. laevigatus* were previously obtained in the area, 2) 700 m is an ideal target depth for trapping this species (Moffitt and Polovina fn. 2), 3) the relatively uniform bottom topography would facilitate setting and retrieving fishing gear, and 4) the area had no known history of prior exploitation.

Fishing was conducted over a 16-d period, 9-24 January 1984, from the NOAA ship *Townsend Cromwell*. Shrimp traps of standard Honolulu Laboratory design were set daily in four strings of five traps each. All traps were half round in shape (91 × 66 × 46 cm), with a frame constructed of 1.27 cm reinforcing steel, covered with 1.27 × 2.54 cm mesh hardware cloth (illustrated in figure 3 of Gooding 1984). Individual traps within a set were spaced 40 m apart and were baited with three chopped Pacific mackerel, *Scomber japonicus*. All traps were set between 1100 and 1300 h in 600-800

m and were retrieved the following day between 0800 and 1100 h. In addition, a large (150 × 150 × 150 cm) pyramidal commercial shrimp trap was sometimes deployed alone.

When fishing gear was recovered, the traps were individually emptied and the contents sorted, counted, and weighed to the nearest 0.01 kg by species lot. On three occasions a random length-frequency sample of trap-caught *H. laevigatus* was saved for later study. All shrimp in these samples were measured to the nearest 0.1 mm CL (carapace length) with dial calipers.

To accurately delimit the bottom topography of the study area, an unregistered reconnaissance hydrographic survey was conducted over the site on 9 February 1984, with the *Townsend Cromwell*. Depth soundings from a Raytheon³ fathometer were recorded every 3 min over an 8.5-h period as the vessel ran a predefined cruise track which covered the entire study area. The position of the vessel was recorded to the nearest 0.01 min at each sounding.

The *Townsend Cromwell* returned to the study site again from 12 to 16 May 1984, to assess the recovery of the *H. laevigatus* population in the study area and to determine the effect of different baiting practices on CPUE. Four sets of six traps each were set overnight on each of four occasions. Half these traps contained three chopped Pacific mackerel whereas the other half (i.e., every other one) contained two whole Pacific mackerel. The catch was sorted and treated as discussed previously.

RESULTS

Hydrographic Survey

A total of 164 depth soundings were obtained over the study site. The data were contoured using the GCONTOUR procedure of SAS/GRAPH (SAS 1981) and the resulting chart is presented in Figure 2. Solid lines represent isobath contours spaced at 200 m depth intervals. Note that the shrimp study site is a saddle point; concave upwards along the north-south axis and concave downwards from east-west. The hydrographic survey revealed a small but steep pinnacle and a deep canyon immediately adjacent to the study area.

In the figure the locations of each string of five standard traps are shown as open circles ($n = 60$) whereas single sets of the large pyramid trap are given as closed circles ($n = 8$). Fishing effort was

²Moffitt, R. B., and J. J. Polovina. In prep. Distribution and yield of the deepwater shrimp resource in the Marianas. Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, 2570 Dole Street, Honolulu, HI 96822-2396.

³Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

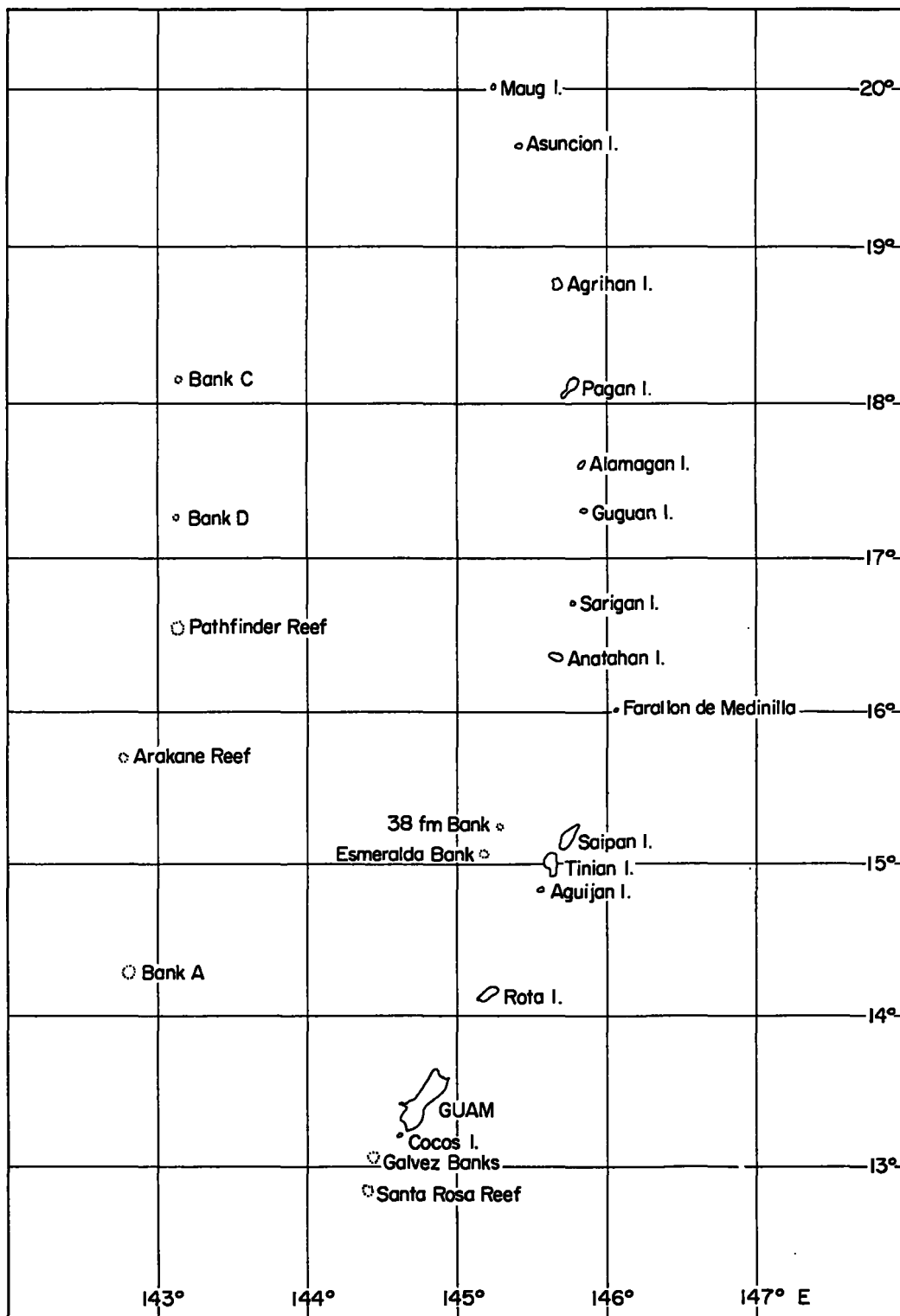


FIGURE 1.—Map of the Mariana Archipelago.

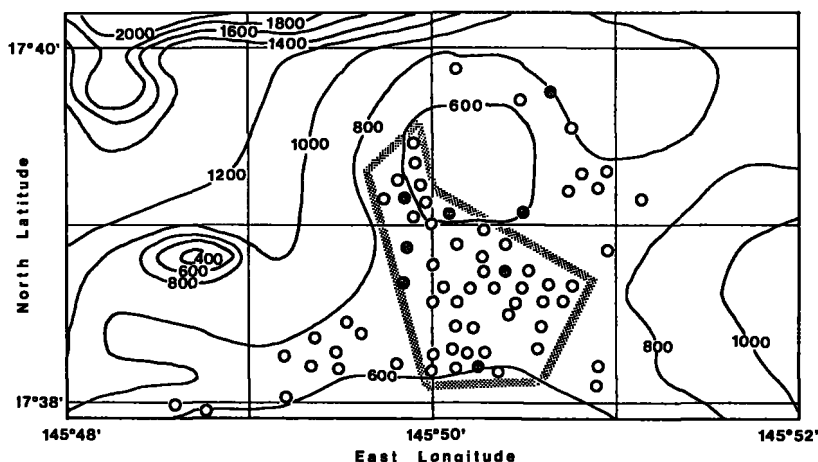


FIGURE 2.—Contour map of the Alamagan study site. Isobaths given in meters. Open circles represent set locations of standard traps (one set is composed of five traps); closed circles show sets of the pyramid trap. The stipple border encloses the area of greatest fishing intensity. One minute latitude = 1.85 km.

concentrated in the area enclosed by stipple borders, where 65% of all sets (44 of 68) occurred. This area represents 312 horizontal ha of shrimp habitat.

Intensive Fishing Experiment

Although 20 standard shrimp traps were set daily for 15 consecutive days, 29 traps were lost due to entanglement on the bottom. This resulted in 271 effective trap-nights of standard fishing effort and a gear loss rate of 9.7% (Table 1). The loss of shrimp traps is not believed to have affected the outcome of the intensive fishing experiment for two reasons: First, the Pacific mackerel bait was rapidly exhausted in the traps, as evidenced by its condition after a single night's soak; second, large holes were usually evident in traps if the fishing gear was successfully retrieved after being fouled on the bottom.

The catch of *H. laevigatus* was quite pure; only trace amounts of *H. longirostris*, *H. ensifer*, and the eel *Synaphobranchus affinis* co-occurred in the traps. The latter species was observed to consume individual *H. laevigatus* on occasion, but this had a negligible impact on overall catch rates of the shrimp.

A total catch of 663.36 kg of *H. laevigatus* was landed from standard traps, yielding an overall CPUE of 2.45 kg/trap-night (Table 1). In addition, another 112.77 kg were taken in eight sets of the pyramid trap for an overall CPUE of 14.10 kg/trap-night (Table 1). The larger commercial trap outperformed individual standard Honolulu Laboratory

TABLE 1.—Summary of catch and effort statistics of the intensive fishing experiment for *Heterocarpus laevigatus* at Alamagan Island, 9-24 January 1984. All catches in kilograms and effort in standard trap-nights. CPUE includes only standard trap catches.

Date (mo/d/yr)	Standard trap catch	Pyramid trap catch	Corrected cumulative catch	Daily effort	CPUE
1/9/84	62.52	—	31	20	3.13
1/10/84	42.30	37.65	102	18	2.35
1/11/84	64.61	—	175	20	3.23
1/12/84	44.96	23.86	241	17	2.64
1/13/84	85.80	6.72	322	20	4.29
1/14/84	42.90	22.98	401	19	2.26
1/15/84	47.79	—	458	15	3.19
1/16/84	34.27	6.60	503	14	2.45
1/17/84	34.57	3.18	542	19	1.82
1/18/84	34.57	2.41	579	20	1.73
1/19/84	39.01	9.37	622	20	1.95
1/20/84	41.23	—	667	20	2.06
1/21/84	27.10	—	701	20	1.36
1/22/84	26.75	—	729	14	2.05
1/23/84	32.98	—	760	15	2.20
Total	663.36	112.77		271	

traps by a ratio of 5.76 to 1. Thus, one set of the large trap was roughly equivalent to one set of a string of five standard traps, but the former was much more variable in its performance. Overall, a total of 776.13 kg of *H. laevigatus* were removed from the study area during the 16-d experiment. These averaged 28 g each (16 shrimp/lb).

The data presented in Table 1 are arranged to be fitted by the Leslie model (Ricker 1975). The CPUE was computed each day based solely on standard trap catch and effort statistics, although cumulative

removals included catches from the large commercial trap. As in Ricker (1975), CPUE is regressed against corrected cumulative catch, defined as the cumulative catch prior to the start of an interval plus half the catch taken during the interval (see also von Geldern 1961).

Standard daily CPUE is plotted against cumulative catch removed in Figure 3. The slope of the regression is significantly less than zero (one-tailed test, $t = -2.80$, $df = 13$, $P = 0.01$). Estimates of slope, intercept, and mean squared error were -0.001945 trap-night $^{-1}$, 3.334 kg/trap-night, and 0.3754 (kg/trap-night) 2 , respectively. Consequently, the catchability coefficient is estimated to be $\hat{q} = 0.001945$ trap-night $^{-1}$ and the initial population size prior to the start of fishing to be $\hat{n} = 1,714$ kg. Confidence intervals for these estimates are $P(0.0004 < q < 0.0034) = 0.95$ and $P(1150 < n < 6005) = 0.95$ (Ricker 1975). Notice that the confidence interval for the estimate of initial population biomass (n) is asymmetrical about the point estimate.

Crittenden (1983) and others have warned against unequal variance in plots of CPUE against cumulative catch. To test for this possibility, the absolute values of the residuals from Figure 3 were ranked and the corrected cumulative catches were ranked. A Spearman rank correlation coefficient was then calculated, resulting in $r_s = -0.189$, $P = 0.50$. From this analysis there is no evidence of heteroscedasticity. Further, there is little to suggest curvilinearity in Figure 3. A runs test (Tate and Clelland 1957) on the signs of the residuals indicates they are

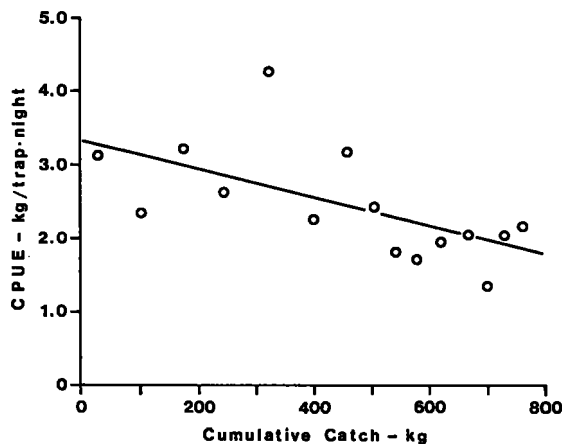


FIGURE 3.—Leslie model applied to *Heterocarpus laevigatus* at Alamagan. Each point represents 1 day of fishing. Data from Table 1.

randomly sequenced ($P > 0.40$). This result supports the assumption of constant catchability.

At the time the experiment was terminated, 776 kg of shrimp had been removed by trapping. An estimate of the concomitant catch rate can be calculated from the regression equation of Figure 3. This estimate of CPUE is 1.82 kg/trap-night. When the *Townsend Cromwell* returned to the study site, 4 mo later, the mean catch rate was 1.91 kg/trap-night (42 effective standard trap-nights of effort, $s = 1.33$), this based on a total catch of 80.08 kg *H. laevigatus*. The preceding calculations include only those traps which were baited comparably to the experimental traps (three chopped Pacific mackerel). Traps with two whole baits ($n = 42$) yielded an average catch rate of 1.39 kg/trap-night ($s = 1.09$).

Length-Frequency Distributions

Examination of size-composition data can help interpret changes in weight CPUE. Declining trap catch rates could, for example, represent fewer individuals of the same size. Conversely, a decline in the average size of individuals caught with no change in numbers would also result in declining CPUE.

The three length-frequency distributions of *H. laevigatus* sampled during the period of experimental fishing are presented in Figure 4. For each distribution the date of capture, depth of capture, sample size, and mean carapace length are provided. Although appearing superficially similar, the results of ANOVA show that significant differences exist in size composition among the three samples ($F = 10.03$, $df = 2, 343$, $P < 0.001$). These differences, however, do not explain the decline in CPUE. The data in the figure show that the mean size of *H. laevigatus* actually increased over time, and that the overall decline in CPUE observed in Figure 2 must therefore have been due to a decrease in the number of shrimps caught.

DISCUSSION

Powell (1979) has shown that the shape of the descending limb of length-frequency distributions can provide useful information concerning the relationship between mortality and growth. Specifically, the ratio of Z (instantaneous total mortality rate) to K (von Bertalanffy growth coefficient) is defined in a simple way by the interrelationship of the least size when fully vulnerable to the gear, the mean size in the catch of fully recruited individuals, and the

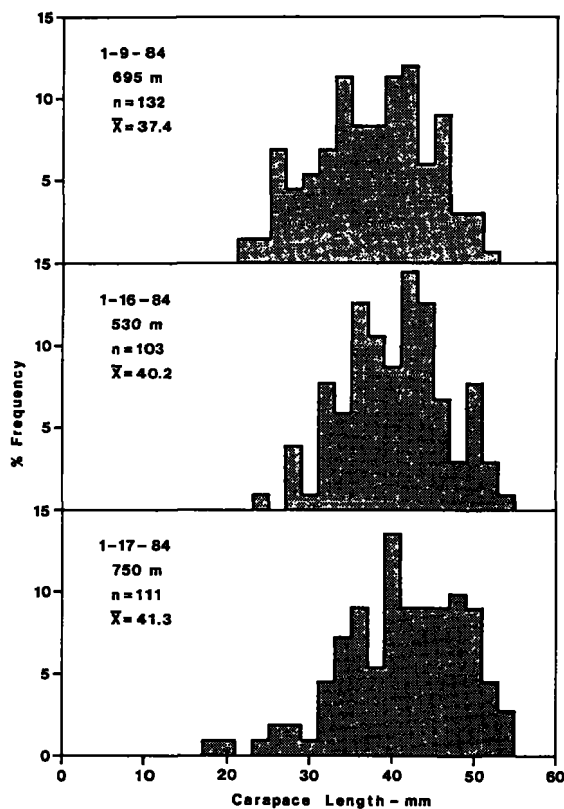


FIGURE 4.—Length-frequency distributions of *Heterocarpus laevigatus* taken in shrimp traps.

von Bertalanffy asymptotic size (L_{∞}). This is true if the following conditions hold: 1) the growth of individuals follows a deterministic von Bertalanffy growth curve, 2) mortality is constant and uniform for all ages, and 3) recruitment is constant and continuous over time (Beverton and Holt 1956).

Results presented in Dailey and Ralston (1986) provide the basis for estimating the minimum CL when *H. laevigatus* becomes fully recruited to the trap fishery. They provide a regression equation relating carapace width (CW) to CL. In this study the smallest mesh dimension of standard shrimp traps was 1.27 cm. This provides a logical cutoff point for measurement of least CW for shrimp that are fully vulnerable to the gear. Based on their functional regression this corresponds to 30 mm CL.

It is evident from the three panels in Figure 4 that the size distribution of *H. laevigatus* above 30 mm CL is characterized by both rising and descending portions. As shown by Powell (1979) this indicates a Z/K ratio of less than unity (i.e., instantaneous mortality rate is less than the growth coefficient).

Alternatively, it is possible that the rising portions of the length distributions are not representative of the population sampled, but are instead a reflection of behavioral interactions among shrimp of different sizes. Chittleborough (1974), for example, has shown that the presence of large individuals of the decapod crustacean *Panulirus cygnus* inhibited smaller conspecifics from entering baited traps, even though smaller lobsters were vulnerable to the traps in the absence of large ones. If this kind of behavioral interaction was also in evidence here, the effective least size of *H. laevigatus* when fully vulnerable to the traps may be as large as 41 mm CL, the mode of the pooled length-frequency distribution. This would indicate a Z/K ratio of 2.0 because of the linearity of the descending portions of the size-frequency distributions. Only further experimentation will resolve this issue.

With respect to the intensive fishing experiment it is useful to consider whether or not the basic assumptions of the Leslie model were violated during the course of the study. The first of these was closure of the population. Two factors support the contention that the study population was effectively isolated and that the effects of immigration and emigration were negligible. First, the hydrographic survey showed that the study site comprised a semi-isolated extension of the main island. Continuity of prime habitat (600-800 m depth) with the island proper extended along two narrow corridors to the southeast and southwest. The shrimp has been taken as shallow as 400 m and as deep as 950 m in the Mariana Archipelago, but the 600-800 m depth range encompasses the preponderance of the region's shrimp stock (Moffitt and Polovina fn. 2), although elsewhere (e.g., Fiji, Vanuatu, and Samoa) the depth distribution apparently extends into somewhat shallower water (King 1984). The second factor arguing for closure is that the catch rate of *H. laevigatus* remained low after a 4-mo hiatus in fishing. If movements or migrations of shrimp were biologically significant over this time interval, a larger change in CPUE would be expected. It is tempting to attribute the small increase in catch rate (4.9%) to some type of biological recovery, but the estimate of mean squared error in CPUE from Figure 3 ($0.3754 \text{ kg}^2/\text{trap-night}^2$) indicates that background variation is too large for the observed difference to be significant. Regardless, the data support the assumption that the population is closed.

The second assumption was that growth, natural mortality, and recruitment are negligible factors in accounting for changes in CPUE. That the experiment was completed in only 16 d and the popula-

tion was reduced an estimated 45.3% are persuasive elements here. Additionally, the size-frequency data show no indication of a major alteration in population structure. As long as the selective properties of the fishing gear remain unchanged, alterations in the length composition of the catch are not expected over short time intervals, at least due to the direct effects of fishing. Further, no recruitment of small shrimp is evident. That the mean size of *H. laevigatus* seemed to increase as the experiment progressed might support the hypothesis that growth of the stock was significant. An alternate explanation, however, is that size structure varies with depth of capture. Results from the Hawaiian Islands (Gooding 1984; Dailey and Ralston 1986) have now demonstrated this. The three samples presented in Figure 4 are confounded by this variable; other unknown factors may also have affected the shrimp size-frequency data (e.g., sexual dimorphism, contagious dispersion, sampling error, etc.). In addition, the estimated growth rate from the data (3.9 mm CL over 8 d = 0.49 mm/d) is biologically untenable.

Other investigators, notably Schnute (1983) and Crittenden (1983), have cautioned against the effects of changing catchability and unequal variance on Leslie model estimates. From the data gathered, there is little statistical evidence to suggest that these factors affected parameter estimates and I therefore assume that 0.001945 trap-night⁻¹ and 1,714 kg are reasonable estimates of standard trap catchability and virgin population size, respectively.

Given that the virgin biomass of *H. laevigatus* in the study area was 1,714 kg, the next question is: How large an area was intensively fished? From Figure 2 it is clear that there is no simple answer to this question. A number of sets were located in areas peripheral to the main trapping area. Designating the stippled bordered area as the effective area fished is arbitrary, but provides a useful starting point to allow calculation of shrimp densities. This area was calculated to be 312 ha, corresponding to a projected density of 5.5 kg of exploitable *H. laevigatus* per hectare. Since individuals weighed 28 g each, on average, this is equivalent to 1 exploitable shrimp/51 m² of bottom, a remarkably low density. Furthermore, a catchability coefficient of 0.001945 trap-night⁻¹ indicates that one unit of standard trap effort can reduce a 312-ha population of shrimp by about 0.2%. This is certainly a significant impact. The vulnerability to trapping that this species demonstrates is cause for attention and careful resource management.

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