RELATIVE EFFICIENCY OF TWO CLAM RAKES AND THEIR CONTRASTING IMPACTS ON SEAGRASS BIOMASS

Fishing gear and techniques are continually being developed and modified as alternatives to traditional fishing methodologies. As new equipment becomes available, most individual fishermen carry out their own field trials and peer interviews to determine which gear best meets their needs. Nevertheless, both quantitative comparisons of the relative efficiencies of alternative methodologies (e.g., Medcof and MacPhail 1964; Caddy 1973) and controlled scientific tests of the environmental impacts of contrasting techniques (e.g., Glude and Landers 1953; Caddy 1973; Fonseca et al.[1]) are necessary to provide the biological basis for resource managers to develop sound management policies. Quantitative data on the relative costs and benefits of alternative fishing methodologies are especially important in the estuaries, where fishing intensity often brings the demands of different fisheries into conflict.

Here we provide relative cost and benefit data for two different clam rakes, both available to hard clam (*Mercenaria mercenaria*) fishermen along the east and gulf coasts of the United States. At a study site in coastal North Carolina, we estimated the efficiency of hard clam capture by each rake in two habitats—a seagrass bed and a sand flat. We also employed replicate trials of both clam rakes within the seagrass bed to estimate relative impacts of raking on seagrass biomass. We chose damage to seagrass as a measure of important environmental impact because most coastal resource managers now recognize the direct and indirect contributions of seagrass beds to coastal zone fisheries production (e.g., Thayer et al. 1975).

Materials and Methods

The Contrasting Gear

We compared two clam rakes, known in North Carolina as the pea digger and the bull rake (Fig. 1). The pea digger (also called the potato rake in New England) is a traditional implement of hand rakers in North Carolina. It resembles a garden rake, having a wooden shaft (handle) about 1.2 m long, leading to a steel head with 3-6 prongs, each about 14 cm long, with 3.5 cm gaps. It is used by making forward and/or backward strokes which penetrate the sediments to a shallow depth (3-8 cm, depending upon substrate compaction and habitat). Whenever a rake prong encounters a clam, a distinctive scraping noise signals the clammer to excavate more deeply and to unearth the catch. The pea digger used in this study weighed 1.2 kg, had a wooden shaft 1.3 m long, and prongs 14 cm long.

The bull rake (also known as the shinnecock rake) has been introduced recently to North Carolina from Long Island Sound (see description in Glude and Landers 1953). It is a heavier, more robust implement, usually weighing from 8 to 11 kg. The rake consists of a steel basket attached to a metal (steel or aluminum) shaft which ends in a t-shaped handle. The basket has a rectangular opening (usually 18 × 48 cm) with teeth extending outward along the lower lip of the basket. The basket is formed by a grate of steel bars spread about 2-3 cm apart. The rake is used by pushing the teeth to a 14 cm depth into the sediments and then pulling it with short, quick jerks. The depth of penetration varies only slightly with substrate type. As the rake is pulled along through the sediments, clams, shells, and (if present) seagrass and debris are forced into the basket. When the rake seems heavy enough to suggest a full basket, it is removed from the water where the clams can be sorted. Because of its longer (and extendable) handle, the bull rake is often used from boats and can extend the depth at which hand clammers can work effectively. The bull rake used in this study (Fig. 1) weighed 8.6 kg, had a 1.8 m steel shaft and teeth 4 cm long, extending from a basket made of 0.7 cm steel rods 2.2 cm apart.

Although other hand rakes are used by clammers along the east and gulf coasts (including especially the "Jersey" rake), we chose to test the pea digger and bull rake because they fall at opposite ends of a size spectrum. Of all commonly used clam rakes, the pea digger is the lightest implement, has the fewest teeth, and digs to the shallowest depths in the sediments, whereas the bull rake falls at the opposite extreme for each of those three criteria.

The Study Site

Gear trials were conducted during June 1981 in two habitats along the southern (barrier island) margin of Back Sound, near Beaufort, N.C. This general study area and its physical environment are described in several previous publications (Sutherland and Karlson 1977; Nelson 1979; Peterson 1982). Water temperature was about 22°C during our study. Specific sites were chosen in an unvegetated sand flat and a

[1] Fonseca, M.S., G. W. Thayer, A. J. Chester, and C. Foltz. 1981. The impact of scallop harvesting on eelgrass (*Zostera marina* L.) meadows. Unpubl. manuscr., 15 p. Southeast Fish. Cent. Beaufort Lab., Natl. Mar. Fish. Serv., NOAA, Beaufort, NC 28516.

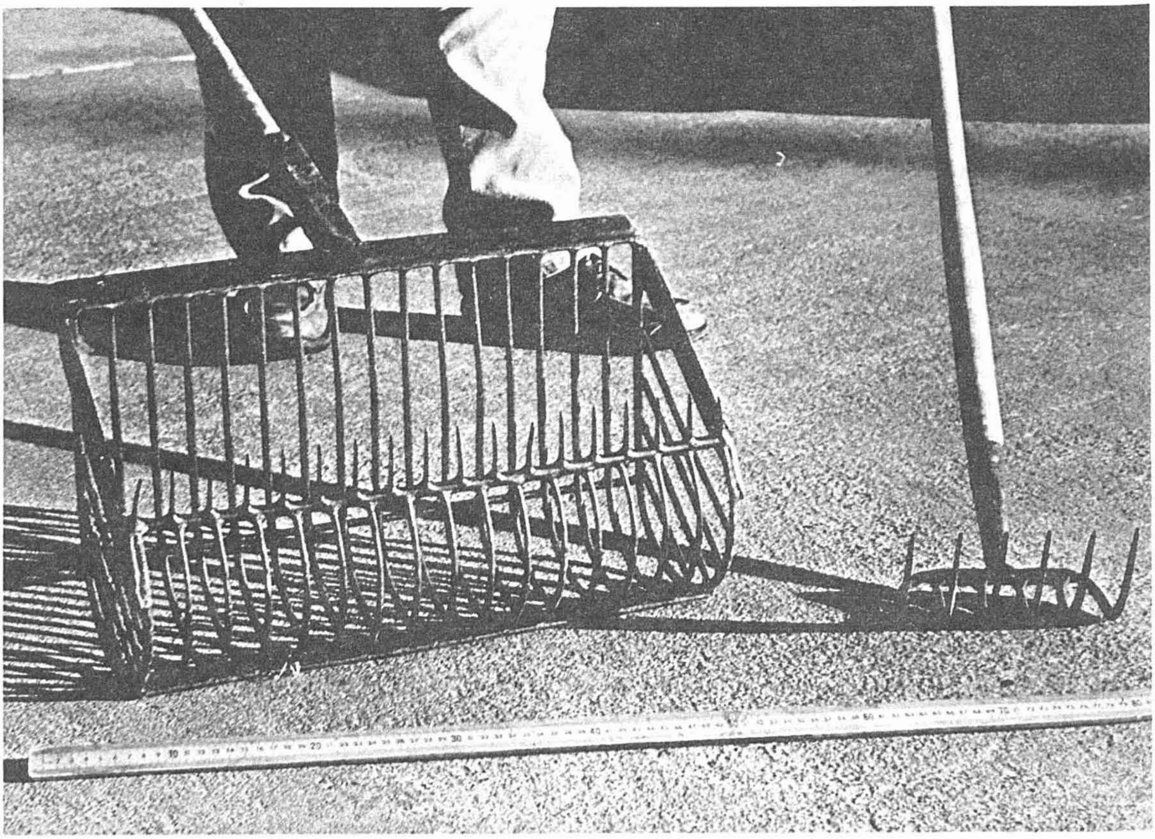

FIGURE 1.—Differences between the bull rake (left) and pea digger (right) in number and spacing of teeth, and head size and mass.

nearby seagrass bed (about 80% *Zostera marina* and 20% *Halodule wrightii*). Three replicate sediment cores, taken in April 1981 at each site to a depth of 20 cm and analyzed by standard sieving techniques (Ingram 1971; Folk 1974), revealed that sediments in both habitats were predominantly medium, fine, and very fine sands. In the seagrass bed, however, the sediment size distribution shifted substantially towards finer size classes: Average percent dry weights in the three decreasing size classes (medium, fine, and very fine sands) were 13.9, 44.7, and 18.3%, respectively, as compared with 28.8, 64.1, and 2.9% in the sand flat. Furthermore, the seagrass sediments contained 20.6% silt and clay, whereas the sand-flat sediments contained only 2.3% by weight within these mud size classes. The sand flat held relatively little shell debris, whereas buried empty clam shells were common in the seagrass bed. Average density of seagrass shoots in the seagrass habitat was 496 ($\pm$1 SD of 165) M^{-2},, based on eight 0.5 m^{-2} samples. We selected all specific study plots in water $<$1 m deep at low tide, for ease of access. Our study plots were located at about midrange of the depth occupied by seagrasses in the Beaufort area.

Sand-Flat Methods

We chose 2 $\times$ 4 m plots in pairs, matching plots in space, water depth, and surface appearance of the substrate. We marked each plot by inserting a 1.6 m stake at each corner. One plot (chosen at random) of each of the 14 selected pairs was raked systematically for 6 min using a bull rake, while the other matching plot in each pair was raked systematically for 6 min with a pea digger. Prior to our use of the two rakes, we had carefully observed the usage of each rake by several professional clammers in the field so that we could employ each device in a way that closely resembled its customary usage. We used only backward strokes in deploying the pea digger, which penetrated 3-6 cm into the sediments in both habitats. During the 6-min raking period, variable proportions of the 2 $\times$ 4 m plots were raked (including occasional larger areas). In each plot the actual area raked was marked in the field and recorded. We also recorded the numbers of hard clams, collected from each trial, broken down into legal (≥2.54 cm thickness) and illegal sizes. The actual area raked inside 5 pairs of plots was then systematically sieved by hand through 6 mm mesh to a depth of 12 cm to estimate the numbers of legal- and illegal-sized clams missed during raking. These observations permit a quantitative comparison of the two rakes: 1) Rate of hard clam capture and 2) efficiency of hard clam capture for both size classes of clams in the sand-flat habitat.

Seagrass Bed Methods

We chose matched 2 × 2 m plots, which we then marked with 1.6 m stakes. Plots used here were smaller than in the sand flat, because the presence of seagrasses and higher clam densities slowed the raking and reduced the area covered in 6 min. We selected 5 groups of 3 plots each, two for application of each rake and a third as a control to estimate initial seagrass biomass. Raking, sieving, and data recording were carried out in the same fashion as in the sand flat. In addition to measuring the area covered by each rake in 6 min for each plot and counting the numbers of hard clams (in the two size classes) collected, we also excavated by hand and placed into buckets all fresh seagrass material left behind in each raked area and from a 1 m^2 area within each control plot. We returned all seagrass material to the laboratory where we washed away salt and sediments, separated by clipping aboveground components (blades and shoots) from belowground components (roots and rhizomes), and weighed each separately after drying to constant weight at 105°C. These data permit a quantitative comparison of the two rakes in 1) rate of hard clam capture and 2) efficiency of hard clam capture for both legal- and illegal-sized clams in the seagrass habitat, analogous to the sand-flat contrasts. By subtracting the dry weight of seagrass remaining in raked areas from the dry weight in the matched controls, we were also able to estimate the mass of above- and belowground seagrass removed by each rake. We then used these figures to estimate the relative environmental impact of each rake in the form of estimated dry weight of seagrass removed 1) per unit time, 2) per unit area raked, and 3) per legal-sized clam captured in the seagrass habitat.

Results

Sand-Flat Habitat

The pea digger produced significantly more legal-sized hard clams per unit time of use in the sand-flat habitat, with a mean catch more than 50% higher than that of the bull rake (Table 1). The rate of capture of illegal-sized clams was equally low for both rakes in this habitat. Although both rakes were 100% efficient in their capture of legal-sized clams inside the areas raked in this environment, the pea digger covered significantly more area during a fixed period of time (Table 1) and, therefore, was able to catch more clams than the bull rake. Because of equal capture efficiency, the average numbers of legal-sized and illegal-sized clams caught per unit area raked did not differ significantly between rakes in the sand-flat environment (Table 1).

TABLE 1.—Hard clam capture rate per unit time, per unit area raked, and capture efficiency of two clam rakes from 14 paired replicate plots of a sand flat. Complete excavation to estimate capture efficiency was done for only 5 of the 14 pairs. *F*-tests revealed no significant difference between treatments in variance, except for area raked which required a log transformation prior to performing the *t*-test.

	Sand flat		
	Average ±1 SD		
Statistic	Bull rake	Pea digger	*t*-test[1]
1) No. clams caught/6 min			
legal-sized[2]	3.9 (±3.3)	6.1 (±2.1)	*
illegal-sized	0.2 (±0.4)	0.2 (±0.4)	ns
2) Area raked (m^2/6 min)	5.66(±0.37)	6.67(±0.90)	**
3) No. clams caught/m^2			
legal-sized	0.70(±0.59)	0.93(±0.34)	ns
illegal-sized	0.04(±0.08)	0.03(±0.06)	ns
4) Efficiency of capture[3]			
legal-sized	100% (±0.0)	100% (±0.0)	ns
illegal-sized[4]	25%	33%	ns

[1]* = $P < 0.05$; ** = $P < 0.01$; ns = $P > 0.05$, in a two-tailed paired *t*-test.
[2]≥2.54 cm thick.
[3]Back-transformed mean of arcsin-transformed percents of clams captured.
[4]Insufficient densities of small clams prohibited replicate estimates of capture efficiency, thus these percents are based on pooled totals (4 and 3, respectively) and were tested by Fisher's exact test.

Seagrass Habitat

In the seagrass bed, the two rakes again differed significantly in average catch of legal-sized clams per 6 min of raking; however, in contrast to the sand-flat results, the bull rake was the more productive implement (Table 2). The bull rake also tended to catch more small clams per unit time, although the numbers of clams caught in this size class were small and the differences between rakes not statistically significant (Table 2). The greater return from use of the bull rake was mainly a consequence of the significantly greater area raked per unit time. The number of clams captured per unit area actually raked and the efficiency of clam capture in areas actually raked did not differ significantly between rakes for either size class of hard clam (Table 2).

A 6-min application of the bull rake in the seagrass habitat caused an estimated loss of seagrass biomass that was more than double the estimated loss caused by 6 min of pea digger use (Table 3). Both aboveground and belowground components of the seagrass demonstrated this statistically significant difference between rakes. The bull rake also produced a greater estimated loss of seagrass biomass per unit area raked, an effect that was also significant for both aboveground and belowground components (Table 3). An estimated 87% of the initially present seagrass dry weight was removed by the bull rake in a 1 m^2 area that was completely raked. The magnitude of this effect was similar for components both above (89%) and below (83%) ground. In contrast, the pea digger removed only an estimated 47% of seagrass dry weight per unit area completely raked, with the impact falling less heavily on roots and rhizomes (37% decline) than on shoots (55% decline). The two rakes did not differ significantly in estimated seagrass biomass removed per legal-sized clam collected, although the estimated loss of belowground dry weight per clam collected by the bull rake was almost double the estimated loss caused by the pea digger (Table 3).

Discussion

By use of replicated field trials, we compared the effectiveness of two clam rakes in two contrasting ways. We estimated in each of two habitats the rate of hard clam capture per unit time, as would be appropriate if harvest time were limiting. We also converted our data into estimates of harvest per unit area raked, as would be appropriate if suitable clamming habitat—rather than time—were limited. We view these measures as endpoints in a spectrum of possibilities with the first more appropriate for managers of clam resources that are abundant relative to the intensity of harvest, and the second more relevant to clam resources subjected to very intense harvest pressure. By examining both endpoints, we hope to bracket actual prevailing conditions.

Our harvest data imply that habitat strongly influences the relative effectiveness of these two clam rakes. In unvegetated sandy sediments, the pea digger captured significantly more legal-sized hard clams per unit time than the bull rake (Table 1). In a seagrass bed, the relative effectiveness was reversed (Table 2). The difference between rake effectiveness was not a consequence of greatly differing efficiencies of clam capture within raked areas, but rather of differing rates of areal coverage. Because of approximately equal efficiencies of clam capture, the rakes did not differ significantly in hard clam capture per unit area raked in either habitat.

We suspect that the pea digger's advantage in unvegetated sandy sediments was dependent upon two confounded factors: 1) The relatively low densities of both living and dead hard clams, and 2) the absence of living seagrass. In areas with low hard clam densities, the pea digger will glide over unproductive bottom without creating frequent contacts that require excavation. Thus, more area can be covered than with a bull rake, which must be pulled more deeply through the sediments regardless of the scarcity of clams. Entanglements with roots of living seagrasses may tend to slow the progress of the pea digger which must plow through mats of seagrass, whereas the greater inertia of the moving bull rake is less influenced by encountering a small obstacle. Because these two factors (clam abundance and sea-grasses

TABLE 2.—Hard clam capture rate per unit time, per unit area raked, and capture efficiency of two clam rakes from six paired replicate plots in a seagrass bed. F-tests revealed no significant difference between treatments in variance, except for area raked which required a log transformation prior to performing the t-test.

Statistic	Seagrass bed: Average ±1 SD: Bull rake	Seagrass bed: Average ±1 SD: Pea digger	t-test[1]
1) No. clams caught/6 min			
legal-sized[2]	9.2 (±3.1)	5.8 (±2.6)	*
illegal-sized	1.2 (±1.2)	0.5 (±0.8)	ns
2) Area raked (m^2/6 min)	1.95(±0.06)	1.53(±0.32)	*
3) No. clams caught/m^2			
legal-sized	4.70(±1.54)	4.06(±2.01)	ns
illegal-sized	0.60(±0.61)	0.29(±0.46)	ns
4) Efficiency of capture[3]			
legal-sized	83%(±6)	69%(±12)	ns
illegal-sized[4]	20%(±20)	18%(±40)	ns

[1]* = $P<0.05$; ns = $P>0.05$, in a two-tailed paired t-test.
[2]≥2.54 cm thick.
[3]Back-transformed mean of arcsin-transformed percents of clams captured.
[4]$n = 5$ for this comparison, because one plot had no illegal-sized clams.

TABLE 3.—Comparison of environmental impacts on seagrass of two different clam rakes used in seven paired replicate plots. F-tests revealed no significant difference between treatments in variance for any comparison.

Estimated impact	Seagrass bed: Average ±1 SD: Bull rake	Seagrass bed: Average ±1 SD: Pea digger	t-test[1]
1) Dry wt removed (g/6 min)			
shoots	121.6(±43.1)	54.2(±39.8)	**
roots and rhizomes	81.2(±31.9)	26.3(±21.9)	*
total	202.8(±69.3)	80.5(±58.3)	**
2) Dry wt removed[2] (g/m^2 raked)			
shoots	60.3(±17.5)	37.4(±24.0)	**
roots and rhizomes	40.2(±13.2)	17.6(±11.4)	*
total	100.5(±26.9)	54.9(±31.5)	**
3) Dry wt removed (g/6 min) per legal clam caught			
shoots	21.2(±21.6)	15.5(±22.4)	ns
roots and rhizomes	14.1(±15.2)	7.5(±11.0)	ns
total	35.3(±36.7)	23.0(±33.3)	ns

[1]* = $P<0.05$; ** = $P<0.01$; ns = $P>0.05$ in a two-tailed paired t-test.
[2]Average seagrass dry weight (g/m^2 ±1 SD) in the 7 control (1 m^2) plots: shoots - 67.7 (±19.8); roots - 48.2 (±15.7); total - 116.0 (±32.4).

cover) are confounded in our study, we cannot distinguish between them. However, because most studies have consistently demonstrated higher densities of marine benthic infauna, including hard clams, in seagrass meadows than in nearby unvegetated bottom (e.g., O'Gower and Wacasey 1967; Santos and Simon 1974; Orth 1977; Brook 1978; Stoner 1980; Peterson 1982), we suspect that our habitat-specific differences in rake effectiveness can be generalized. Nevertheless, exceptions are likely to exist, implying that our results on relative catch efficiency should be applied only where hard clam abundances are known to be greater in the seagrass habitat.

We chose to estimate the dry weight of seagrass removed as a measure of environmental damage because many studies have identified, and most coastal resource managers now recognize, the value of preserving meadows of seagrass. For instance, seagrasses have been identified as locally significant producers of fixed carbon to fuel estuarine and coastal food chains and as providers of nursery habitat for juvenile finfishes and shellfishes, many of which are either commercially harvested or else serve as significant food items for commercially harvested species (e.g., Thayer et al. 1975). Our raking and seagrass harvest results demonstrate that the bull rake removed more seagrass than the pea digger per unit time of use and per unit area raked. Furthermore, differences between rakes in estimated seagrass removal tended to be greater for the belowground than the aboveground components of the seagrass. Because roots and rhizomes probably provide the source of vegetative propagation, a potentially important mode of spread in seagrasses, the bull rake may have more long-lasting effects on seagrass cover than the pea digger, as well as a greater immediate impact. Seagrass that is removed by raking probably enters the detrital pool and thus continues to fulfill one of its important functions. However, the loss of seagrass may reduce the value of the grass bed as a nursery habitat. We did not collect any data to test this possibility, but the dependence of bay scallops on seagrass surface area for juvenile attachment sites and the dependence of various juvenile fishes on seagrass cover for predator protection and on seagrass surface for foraging habitat (e.g., Thayer et al. 1975) imply that the value of a seagrass bed is diminished by uprooting significant amounts of seagrass.

This study was designed to provide estuarine resource managers with some of the biological information needed to manage and regulate clamming in shallow estuarine habitats. We have demonstrated that the superior effectiveness of the more massive bull rake in a seagrass habitat is accompanied by substantially more uprooting of seagrass than is caused by raking with a pea digger. However, environmental planners and resource managers must apply these results with caution in their attempts to weigh the benefits of permitting bull rake usage in seagrass beds against the potential costs associated with increased uprooting of seagrasses. Our experiments were restricted to a single seagrass system; changing the seagrass type or the sediment grade may yield different results. More importantly, we made no direct measurements of the cost of seagrass removal. It is likely that, because the amount of uprooted seagrass appears to be an increasing function of clamming intensity, the impact of removal could be negligible in some areas where clamming intensity is low relative to the areal extent of the seagrass habitat. Thinning of seagrass may even be beneficial under some conditions by stimulating growth of the plants left behind. Recovery by growth may be rapid enough at certain seasons to render the impact of seagrass removal insignificant to the production of associated vertebrate and invertebrate species.

Although we calculate the seagrass removal per unit resource harvested (Table 3), quantitative estimates of the cost of seagrass removal are necessary to convert these biological data into a management criterion. Even if resource managers choose to prohibit the use of bull rakes inside seagrass beds on the basis of the enhanced loss of seagrass biomass per unit time, per unit area, and per unit resource (clam) collected (Table 3), this prohibition should probably be restricted to seagrass meadows. Even though the bull rake is not as effective as the pea digger in harvesting clams on an unvegetated sand flat (Table 1), it may well be a superior implement in other habitats, such as soft muds. It is also used in deeper waters (Glude and Landers 1953), where short-handled rakes without baskets are ineffective and where seagrass is sparse or absent. We are aware that any habitat-specific regulation of a fishery requires more intense enforcement to be effective than an outright prohibition of certain gear, but the deeper water and unvegetated mud-bottom usages of bull rakes (Glude and Landers 1953) suggest that the bull rake deserves a place in the repertoire of legal clamming gear, despite its threat to seagrass.

Acknowledgments

We thank D. Cecelski of Duke University Marine Laboratory for carrying out a pilot study of these two clam rakes in spring 1981. M. E. Colby, S. A. Hughes, C. A. Peckham, K. C. Pierce, and G. W. Safrit provided assistance in the field and laboratory. The shellfisheries group at the North Carolina Division of Marine Fisheries provided useful advice, especially M. Marshall, F. Munden, D. Spitsbergen, and M. Street. M. S. Fonseca, G. W. Thayer, and two anonymous reviewers helped improve the manuscript. This study was sponsored by the University of North Carolina Institute of Marine Sciences and by the Office of Sea Grant, NOAA, U. S. Department of Commerce under grant No. NA81AA-D-00026, North Carolina Department of Administration.

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HETEROCARPUS LONGIROSTRIS MACGILCHRIST FROM THE NORTHERN MARIANA ISLANDS

In March and April 1981 the National Marine Fisheries Service Honolulu Laboratory chartered the FV *Typhoon* to conduct a fisheries resource survey in the waters of the Commonwealth of the Northern Mariana Islands. One of the major objectives of this survey was the investigation of deepwater pandalid shrimp stocks. Although not previously recognized as a species of commercial interest (Holthuis 1980), *Heterocarpus longirostris* MacGilchrist 1905 was caught in sufficient numbers on this cruise to suggest a commercial potential.

Heterocarpus longirostris has been recorded in the literature from a few specimens caught in the Indian Ocean. MacGilchrist (1905) reported taking two male specimens at 1,754 m in the Bay of Bengal; Balss (1925), one female specimen taken at 1,143 m off Nias Island, Sumatra; and Calman (1939), one female specimen taken at 914-1,463 m in the Maldive area. Catches from this cruise constitute a first record of this species from the Pacific Ocean. *Heterocarpus longirostris* is very similar to *H. laevigatus* in general morphology. *Heterocarpus longirostris* differs from *H. laevigatus* in that the preorbital dorsal surface of the rostrum is multidentate and there is a blunt point posteriorly on the carina of the third abdominal somite. In *H. laevigatus* the dorsal surface of the rostrum is edentate in advance of the orbit and the posterior portion of the third abdominal somite is rounded. Further differences are discussed in MacGilchrist (1905).

The FV *Typhoon* fished for shrimp in the Saipan-Tinian area using traps baited with chopped fish, usually skipjack tuna, *Katsuwonus pelamis*. The traps consisted of half-round frames of iron rebar (91 × 72 × 42 cm) wrapped with 13 × 25 mm or 13 × 13

FISHERY BULLETIN: VOL. 81, NO. 2, 1983.