# Performance of Wire Fish Traps on the Western Coast of Puerto Rico

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## RESUMEN

Se recopiló información de la captura, esfuerzo y tamaño de especies individuales capturadas con nasas de alambre en la costa oeste de Puerto Rico, durante 1973-1974. La efectividad de las nasas varió de acuerdo con el tipo de nasa, tamaño de la malla, lugar y fecha (época del año). Durante el otoño (Septiembre-Octubre), la pesca fué mayor en aguas poco profundas con los tres tipos de nasa, y el tamaño promedio fué mas pequeño. En la primavera (Mayo-Junio), se obtuvo más peces en las nasas de malla de 1" que en las de 1¼" y hubo notable diferencia en la tasa de captura entre los distintos tipos de nasas dentro de una localidad en cuanto al número de peces capturadas. Tasas de captura (kg por nasa por día) en la primavera fué aproximadamente 2/3 de la tasa de captura en el otoño. Los resultados sugieren que la selección de un tipo de nasa a otro puede ser más importante cuando los peces son más vulnerables a la captura.

La información fué además analizada para determinar la composición de especies en la captura, así como la relación existente entre la captura y el tiempo de sumersión por los diferentes tipos de nasas, tamaños de la malla, localidades y épocas del año. La composición de las capturas obtenidas de las nasas de peces en Puerto Rico y Jamaica y el tamaño medio de las diferentes especies en cada pesquería fueron comparadas como medio de evaluar los efectos de la pesca con nasas en poblaciones naturales de peces de arrecifes.

## INTRODUCTION

Wire fish traps are widely used by small-scale fishermen on coralline shelves thoughout the Caribbean (Swingle et al., 1970; Munro et al., 1971; Sylvester and Dammann, 1972; Stevenson, 1978) to harvest spiny lobsters and a variety of reef fish. Traps are commonly deployed from small, open boats in nearshore waters (10-15 m) on rough bottom and harvest many species which are not captured by other gear. In deeper waters near the shelf edge, traps harvest species of snappers and groupers which are also captured by hook and line (Sylvester, 1974). Traps efficiently remove the smaller species (parrotfish, surgeonfish, grunts, and others) from reefs, and the use of traps has led to the depletion of reef fish populations in heavily fished areas such as the south coast of Jamaica (Munro et al., 1971). The use of small-meshed traps is particularly dangerous since they capture a large proportion of immature fish. Effective management of trap fisheries might include mesh size regulations as well as limitations on the number of traps set per unit area.

Many reef fish are known to have very limited home ranges (Bardach, 1958; Randall, 1962; Springer and McErlean, 1962; Moe, 1972) and therefore are susceptible to overfishing in areas with high trap densities.

Although accurate catch figures are not available, there is no doubt that fish traps play a very important role in supplying fresh fish for local consumption, especially on the many Caribbean islands. Much of the 1968 yield of 289,000 metric tons (MT) reported from shelf areas in the Caribbean was presumably derived from fish traps and potential yields of demersal fishes for the Caribbean and the Bahamas (excluding the Gulf of Mexico) could possibly be increased to 750,000 MT (Munro, 1973a). A significant factor which has limited the production of demersal reef stocks in the Caribbean is the restricted mobility of traditional trap fisheries and low fishing intensities on offshore banks (Munro, 1973b).

Traps are constructed of galvanized chicken wire with wooden or welded metal frames. Different types of traps are used in different areas and include the chevron or arrowhead trap, Z trap, S trap and simple rectangular traps. These trap designs have been described in more detail by Munro et al. (1971). Chicken wire meshes are hexagonal in shape. Mesh sizes used for traps vary from 1.9-5.1 cm (¾-2 inches) in minimum aperture. Trap dimensions are also variable. Chevron traps have a single entrance funnel whereas S and Z traps have two entrances.

Thanks to the efforts of Munro and co-workers in Jamaica, a great deal is known about the performance of fish traps (Munro et al., 1971; Munro, 1973b; Munro, 1974a). Most importantly, catch has been observed to level off asymptotically after some optimum soak time. Fish continue to enter a trap at a more or less constant rate, but daily escapement is a fixed proportion of the number of fish in a trap. Catch reaches a maximum when the ingress of fish equals escapement. Fish escape through the entrance funnels, probably as a result of random movements inside the trap. Catch is therefore proportional to trap volume as long as the number and size of the entrance funnels remain constant. There are also indications that traps fill to the saturation point more rapidly when the stock density on the reef is higher.

The highly variable catch rates and species composition of trap catches depend on a complex set of behavioral attributes specific to each species of fish on the reef and on the location of each trap on the reef. High and Beardsley (1970) observed a number of behavioral characteristics of fishes in and near traps during a Tektite II mission in the Virgin Islands, including conspecific attraction, use of the trap as a residence or territory, and attraction of predators. For these reasons, changes in species composition can be expected the longer that traps are left on the bottom. Traps placed in the vicinity of the normal home ranges of reef species perform more efficiently than traps placed at a distance from reef features. Furthermore, underwater observations in Jamaica have shown that catch/day soaked and mean daily ingress into unbaited traps responded to lunar periodicity. Low catches were observed shortly after the quarter moon when tidal currents were minimal.

Since some fish die or are eaten inside traps, they are self-baiting. In fact, the addition of chopped fish as bait to traps in Jamaica resulted in reduced catch rates (Munro et al., 1971). Unbaited traps observed during the Tektite II mission caught as many fish as baited traps (High and Beardsley, 1970), but Sylvester and Dammann (1973) reported lower catch rates for unbaited traps.

A number of authors have compared the performance of different trap designs. Although the high variability in catch among trap hauls has limited the significance of these results to generally unacceptable levels, there is a consistent tendency towards higher catch rates in S and Z traps. Munro et al. (1971) reported that unbaited S traps produced 29% more fish by number and 25% more fish by weight than Z traps of equivalent size in inshore Jamaican waters and that cheveron traps caught roughly one-half as much as Z traps. On lightly exploited grounds of Pedro Bank, however, the catch rate of baited wooden-framed S and Z traps was the same, once corrections were made for changes in volume. Crossland (1976) observed larger catches ofsnapper in Z traps than in rectangular or cylindrical traps in New Zealand. Sylvester and Dammann (1973) reported higher catch rates for S traps than for chevron traps in the Virgin Islands and much lower catch rates for square and round traps. In deeper water (150 m) on the east coast of Puerto Rico, Cole (1976) reported higher catch rates for baited Z and chevron traps than for baited S traps.

Research conducted during 1973-74 on the southwest coast of Puerto Rico was aimed at estimating growth and mortality rates necessary for the determination of maximum yields for 10 species of reef fish which accounted for 80% of the landings of the offshore trap fishery from length-frequency data. Results indicated slight overexploitation of two of the larger species in 3.4 and 4.2 cm mesh traps,[1] but significant underutilization of five smaller species (Stevenson, 1978). Reductions in mesh size were not recommended, however, since they would increase the catch of immature fishes and could severely limit the recruitment of young fish to the fishing grounds. This paper presents the results of gear studies carried out during the course of this research.

The catch rates of S, Z and chevron traps with different mesh sizes were compared in different locations and times of year on the west coast of Puerto Rico in order to test the hypothesis that the traditional chevron trap in Puerto Rico was not the most efficient design and to provide additional information on the performance of wire fish traps in this fishery. Changes in catch rates and species composition were related to design, mesh size, location and soak time. Observed changes by location were in part due to season and depth differences. Various comparative measures of trap performance were evaluated in Puerto Rico and from heavily exploited reefs and lightly exploited offshore banks in Jamaica in order to determine the most effective indicator of relative fishing intensity.

## Background

The principal fishing ground for the Puerto Rico trap fishery is located on the 520 km² coralline shelf off the southwest coast of the island (Fig. 1). Total landings in 1976 from the west coast reached 52% of the estimated 2700 MT

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[1] These dimensions refer to the maximum aperture of meshes which measure 1 inch and 1¼ inches in minimum aperture.

for the entire island (Abreu Volmar, 1978). The trap fishery accounted for 60% of the total island landings by weight in 1976. Traps are set in 10-60 m. Inshore trap fishing is conducted in shallower water with small, open boats equipped with outboards. Offshore trap fishing is conducted by a small fleet of larger sloop-rigged sailboats equipped with inboard engines and gasoline powered trap haulers. These vessels make 4-5 weekly trips of approximately 10 hours each. Traps are set in groups of approximately 50 and each group is hauled once every 4-6 days. In offshore areas, wire fish traps are individually buoyed and usually constructed of 4.2 or 3.4 cm mesh wire stretched over metal or wooden frames. Most traps are chevron (arrowhead) design of 0.60-0.70 $m^3$ volume and catch both fish and lobsters. Lobster predominates during the dry season (November-April) and accounted for 37% of the ex-vessel revenue generated by the trap fishery in 1976. Traps are unbaited except during the lobster season when surgeonfish are killed and left in the traps. Despite the small size of fish which are captured, over 90% of the catch is landed. Many of the fishermen who use traps also go handline fishing for snapper and grouper in deeper water on the shelf edge.

## METHODS

Eighteen wire fish traps were constructed and deployed in September 1973 in fishing locations A and B on the southwest coast of Puerto Rico. Three traps of each of three designs (S, Z and chevron) were set in each location along with traps belonging to David Rodriguez, owner and operator of the sloop *Estrella Mary*. Each group of traps was hauled in conjunction with the normal fishing activities of the vessel. Sr. Rodriguez was in charge of placing and retrieving the traps. The objective was to reproduce actual commercial fishing activity as closely as possible. All traps were constructed of 3.4 cm mesh wire with metal frames and identical entrance sizes. Chevron traps were slightly smaller (0.70$m^3$) than S and Z traps (0.85 $m^3$).

Fishing was continued aboard the *Estrella Mary* during May-June 1974 and September-October 1974. During the second sampling period, data were collected from the experimental traps and from traps belonging to Sr. Rodriguez. Non-experimental traps (some chevron and some Z traps) were of slightly different size, had larger entrances and were made with 4.2 cm mesh wire. All traps sampled during the third sampling period belonged to different fishermen. All were chevron traps of 0.60 $m^3$, but were constructed with both wooden and metal frames and both mesh sizes. A few 5.1 cm mesh traps (1½ inches minimum aperture) were also sampled. A total of 39 trips was made aboard several different vessels during 13 weeks of sampling.

Data recorded during each trip were the numbers and weight of each species captured per trap haul and the lengths of individual fish belonging to the most common species. Catch data were recorded for 280 trap hauls and over 10,000 individual fish were measured. Weights were approximated to the nearest quarter pound (.11 kg) on a composite basis for all individuals of a given species in a given haul. Relevant data such as location, depth, trap design, mesh size, volume, entrance size, frame type and soak time (in days) were also recorded for each haul. No data were collected for lobster. Depth was recorded only as a range for each location since it varied from trap to trap

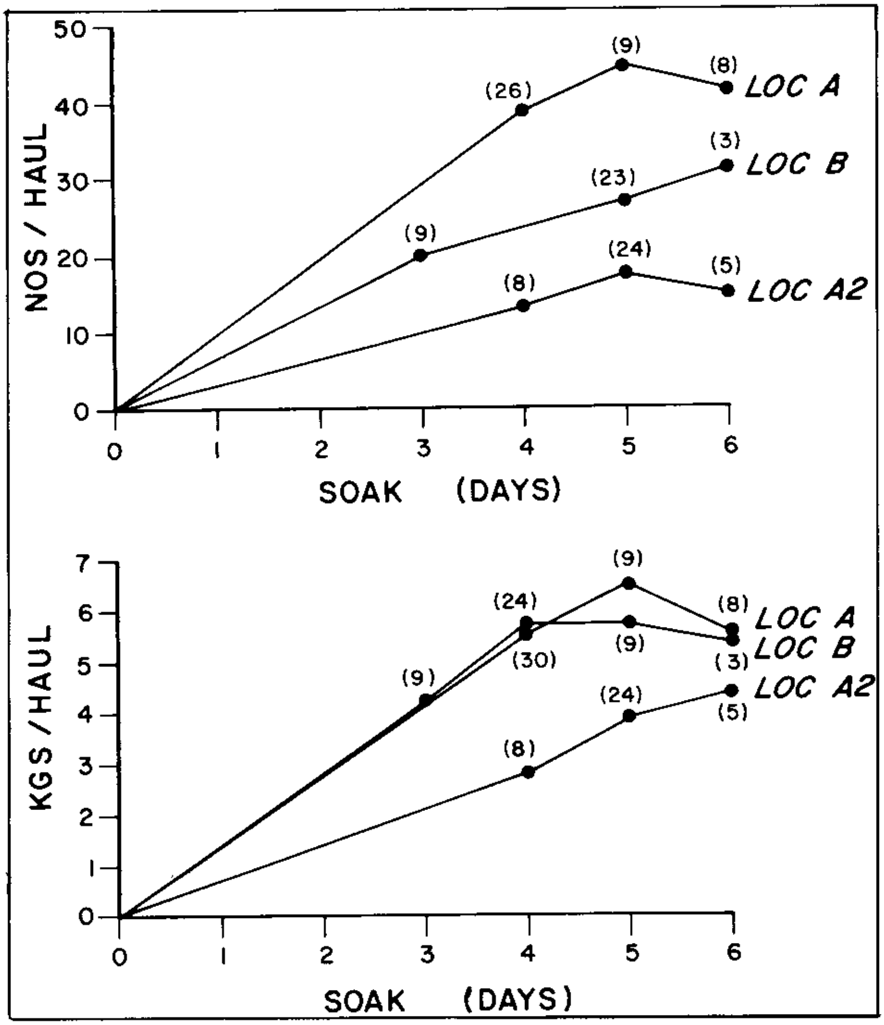

Fig. 1. Mean number and weight of fish captured per trap haul by soak time for three locations on the west coast of Puerto Rico during 1973 and 1974. All trap designs and volumes were combined within each location. Mesh size for all traps was 3.1 cm. Numbers in parentheses equal the number of trap hauls. No data were collected for short soak times (less than 3 or 4 days) and increases in catch were only presumed to be linear.

and could not be verified from the vessel.

## RESULTS

### Catch by Soak Time

Catch was first related to soak in order to determine the optimum soak period for individual locations and times of year. Data obtained over soak periods longer than two days (Fig. 1) in some cases showed catch declining after five days while in other cases catch increased until the sixth day. It was unclear whether the "filling rate" depended on the maximum catch/haul (and therefore on the density of fish available for capture) since the numbers of fish caught/haul peaked after 5 days in location A2, but was still increasing in location B where the maximum catch/haul was higher. True optimum soak depends, of course, on economic considerations and must take into account the total number of traps hauled as well as soak time (Austin, 1976).

Although few data were collected for soak times less than 4 days and none for soaks less than 3 days, the results suggested a near-linear relationship between catch and soak. If this were indeed the case, there would be reason for questioning Munro's (1974a) assertion that the rate of escapement from traps is a constant proportion, over time, of the number of fish in the trap.

Since catch is clearly a function of soak time, and since most of the traps sampled during this study were hauled after the catch was either declining or no longer increasing at a rapid rate, catch statistics were expressed on a per haul than a per trap/day basis. Furthermore, the variation in catch rates by location and time of year required that all subsequent catch comparisons be performed on a per location basis.

### Catch and Mean Weight by Season, Location and Depth

Mean catch (numbers and weight) per haul was compiled for all designs, volumes and mesh sizes by location (Table 1). Individual data sets were compiled for a group of traps sampled in a specific location and some locations may have been sampled during more than one season. The results clearly indicated that traps in shallower water during September-October 1973 caught more fish in terms of numbers (significant at $\partial$ .05), but only slightly more in terms of weight. Also, fish captured in deeper water were larger. During May-June 1974, depths in the two locations were the same and differences in catch and average weight were probably caused by variations in mesh size and entrance size. Fewer fish (numbers and weight) were caught in location C3 during September-October 1974 than in locations A3 and B3, a difference which was probably caused by depth. In this case, however, the shallower location produced lower catches. The results suggested that 30 m was the optimum depth for trap fishing.

### Catch and Mean Weight by Design

In order to compare the performance of the three different trap designs, mean catch per haul was compared for the four locations in which different designs were tested concurrently (Table 2). The results for the three locations in which S traps were used consistently showed a higher catch rate for S traps and, at least in terms of weight, higher catch rates for Z traps than for (A) chevron traps. In location B2, Z traps performed better than A traps. These results confirmed earlier tests of unbaited S, Z and A traps in shallow Jamaican waters (Munro et al., 1971). The mean weight results indicated that no design consistently captured larger fish than any other.

### Catch and Mean Weight by Mesh Size

Since catch data collected by location during the first two seasons were for the same mesh sizes, only the September-October 1974 data were analyzed for

Table 1. Mean catch (numbers and weight) per haul and mean weight per fish by location, depth and time of year on the west coast of Puerto Rico, 1973-74. Data for all volumes, designs, mesh sizes and entrance sizes have been combined

| Time of Year | Location | Depth (m) | Design | Mesh (cm) | Volume ($m^3$) | Entrance | Numbers N | Numbers X | Weight (kg) N | Weight (kg) X | Mean weight per fish (kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sept.-Oct. 1973 | A | 30 | A,S,Z | 3.4 | 0.70-0.85 | Small | 43 | 40.2 | 47 | 5.71 | 0.152 |
| | B | 40-50 | A,S,Z | 3.4 | 0.70-0.85 | Small | 44 | 26.3 | 48 | 5.54 | 0.206 |
| May-June 1974 | A2 | 30 | A,S,Z | 3.4 | 0.70-0.85 | Small | 37 | 16.0 | 37 | 3.73 | 0.233 |
| | B2 | 30 | A,Z | 4.2 | 0.60-0.85 | Large | 38 | 12.5 | 38 | 4.02 | 0.321 |
| Sept.-Oct. 1973 | A3 | 20-40 | A | 3.4,4.2,5.1 | 0.60 | Large | 43 | 18.0 | 43 | 3.80 | 0.211 |
| | B3 | 20-40 | A | 3.4,4.2 | 0.60 | Large | 52 | 19.9 | 52 | 3.75 | 0.188 |
| | C3 | 20 | A | 3.4,5.1 | 0.60 | Large | 14 | 13.1 | 14 | 2.74 | 0.209 |

N = number of trap hauls

Table 2. Mean catch (numbers and weight) per haul and mean weight per fish by design and volume for individual locations on the west coast of Puerto Rico during September-October 1973 and May-June 1974. Mesh and entrance sizes were identical for all traps hauled in each location

|  |  |  | Numbers |  | Weight (kg) |  | Mean weight |
|---|---|---|---|---|---|---|---|
| Location | Design | Volume (m$^3$) | N | X | N | X | per fish (kg) |
| A | A | 0.70 | 14 | 38.8 | 13 | 5.51 | 0.156 |
|  | S | 0.85 | 14 | 41.8 | 17 | 5.86 | 0.149 |
|  | Z | 0.85 | 15 | 39.9 | 17 | 5.72 | 0.152 |
| B | A | 0.70 | 14 | 26.4 | 15 | 4.01 | 0.196 |
|  | S | 0.85 | 15 | 28.7 | 16 | 6.48 | 0.232 |
|  | Z | 0.85 | 15 | 23.9 | 17 | 4.68 | 0.185 |
| A2 | A | 0.70 | 5 | 5.8 | 5 | 1.57 | 0.271 |
|  | S | 0.85 | 17 | 21.2 | 17 | 4.33 | 0.204 |
|  | Z | 0.85 | 15 | 13.5 | 15 | 3.77 | 0.280 |
| B2 | A | 0.60 | 23 | 10.0 | 23 | 3.54 | 0.352 |
|  | Z | 0.85 | 15 | 16.3 | 15 | 4.77 | 0.292 |

differential trap performance by mesh size (Table 3). Data compiled from chevron traps of equal volume and entrance size revealed that smaller mesh traps consistently caught more fish (numbers and weight) and smaller fish. Difference were significant ($\partial = .10$) for numbers in all three cases. These results were expected given the size selectivity of traps and the high proportion of small fish species on the reef.

## Species Composition by Time of Year, Depth, Trap Design, Mesh Size and Soak Time

Catch information was collected for approximately 50 species which accounted for the entire catch in 280 trap hauls sampled on the west coast of Puerto Rico in 1973 and 1974. Statistical analyses were performed for 30 species and species groups by location (time of year and depth), trap design, mesh size and soak time since each of these variables was expected to affect species composition. A total of 5950 fish weighing 1222 kg was sampled.

Species composition varied by time of year, location, and depth. During September-October 1973, the species composition in 86 hauls in locations A and B (Fig. 1) varied considerably (Table 4). All traps sampled were of nearly equal volumes (0.70-0.85 m$^3$), had small entrances and were covered with 3.1 cm mesh wire. Goatfish were abundant in both samples while red hinds *(Epinephelus guttatus)* predominated in shallower water and squirrelfish *(Holocentrus ascensionis)* and jacks (*Caranx ruber)* predominated in deeper water. Dramatic changes in species composition were observed in shallow water (30 m) in the spring. The catch was composed primarily of grunts (*Haemulon plumieri*), parrotfish and small squirrelfish *(Holocentrus rufus)*. In both seasons, 10 species accounted for 82-93% of the catch in numbers and 67-86% by weight.

Table 3. Mean catch (numbers and weight) per haul and mean weight per fish by mesh size for individual locations on the west coast of Puerto Rico during September-October 1974. Volumes and entrance sizes were identical for all traps hauled in each location

| Location | Mesh (cm) | Numbers | | Weight (kg) | | Mean weight per fish (kg) |
|---|---|---|---|---|---|---|
| | | N | X | N | X | |
| A3 | 3.4 | 11 | 30.1 | 11 | 4.37 | 0.145 |
| | 4.2 | 14 | 15.1 | 14 | 3.77 | 0.250 |
| | 5.1 | 13 | 9.2 | 13 | 2.21 | 0.242 |
| B3 | 3.4 | 26 | 24.8 | 26 | 4.02 | 0.162 |
| | 4.2 | 26 | 15.0 | 26 | 3.48 | 0.232 |
| C3 | 3.4 | 7 | 20.1 | 7 | 3.87 | 0.192 |
| | 5.1 | 7 | 6.0 | 7 | 1.61 | 0.268 |

In order to test the separate effects of depth, trap design, and soak time — and their possible interactions — on catch rates for individual species, mean catch (numbers and weight) data from locations A (30 m) and B (50 m) were compiled for each species with trap design and soak time as treatments. Multiple analyses of variance revealed significant treatment effects for nine species and interactions for six of those species (Table 5). For some species, significant responses were indicated for both the numbers and weight captured, and for others, separate responses were observed. The actual mean number of fish captured per haul in location A, for designs A, S, and Z and soaks of 4, 5, and 6 days were presented separately for five species (Table 6), and for 3, 4, 5, and 6 days for a single species in location B (Table 7). Catches for the remaining four species which showed significant treatment effects were very low.

A significant depth effect for numbers and weight was indicated for five species. Four species were more common in shallower water while one *(Holocentrus ascensionis)* was more frequently captured in deeper water. For the common shallow water species, fewer than one fish/haul was captured in 50 m. This depth effect, however, was dependent on trap design for three species and on soak for two (Table 5). An independent depth effect was observed only for *Epinephelus guttatus.*

An independent effect of trap design was observed for three species. Parrotfish *(Sparisoma aurofrenatum)* were more frequently captured in S traps and small squirrelfish *(H. rufus)* in Z traps. In both cases, this response depended on depth and soak time. Mean catches increased with longer soaks most noticeably in the preferred trap designs (Table 6). The vermilion snapper *(Rhomboplites aurorubens)* was captured exclusively in deeper water, but in such small quantities that conclusions about its preference for designs or soak times would be risky. The same was true for *Ocyurus chrysurus,* the yellowtail snapper.

A soak effect was observed for five species which depended on design in two

Table 4. Percent frequency by weight for principal species captured in 3.1 cm mesh chevron fish traps for three locations and two times of year on the west coast of Puerto Rico, 1973-74. All traps were of nearly equal volumes (0.70-0.85 $m^3$) with identical entrance sizes. Percent frequencies less than 1.0 were included with “others”

| Species | Sept-Oct ’73 Location A (30m) | May-June ’74 Location B (50m) | Sept-Oct ’74 Location A2 (20-40m) |
|---|---|---|---|
| Serranidae (groupers) | | | |
| *Epinephelus guttatus* | 24.2 | 5.2 | 13.2 |
| *Cephalopholis fulva* | 10.8 | 2.6 | 9.2 |
| Pomadasyidae (grunts) | | | |
| *Haemulon plumieri* | 7.8 | 1.3 | 23.6 |
| *Haemulon aurolineatum* | 5.5 | | |
| *Haemulon flavolineatum* | | | 3.5 |
| *Haemulon melanurum* | | 1.7 | |
| Holocentridae (squirrelfish) | | | |
| *Holocentrus rufus* | 3.6 | | 7.5 |
| *Holocentrus ascensionis* | 9.2 | 27.6 | 2.7 |
| Scaridae (parrotfish) | | | |
| *Sparisoma aurofrenatum* | 6.4 | 1.0 | 6.3 |
| *Sparisoma chrysopterum* | 1.1 | | 7.9 |
| Carangidae (jacks) | | | |
| *Caranx ruber* | 4.2 | 15.5 | 2.5 |
| *Caranx bartholomaei* | | 9.5 | |
| Lutjanidae (snappers) | | | |
| *Lutjanus buccanella* | | 2.6 | |
| *Rhomboplites aurorubens* | | 1.7 | |
| Mullidae (goatfish) | | | |
| *Mulloidichthys martinicus* | | | 3.5 |
| *Pseudupeneus maculatus* | 13.5 | 13.7 | 3.8 |
| Monacanthidae (filefish) | | | |
| *Catherhines macrocerus* | | | 1.9 |
| Balistidae (triggerfish) | | | |
| *Balistes vetula* | 3.1 | 5.9 | 2.6 |
| Chaetodontidae (angelfish) | | | |
| *Pomacanthus* spp. | | 1.7 | |
| Ostraciontidae (trunkfish) | 4.2 | 7.0 | 4.1 |
| Others | 6.4 | 3.0 | 7.7 |
| Total number of hauls | 42 | 44 | 37 |
| Total weight sampled (kg) | 250 | 239 | 138 |

cases and (discounting *R. aurorubens*) on depth in another. Catches of small squirrelfish and tomtate grunts *(Haemulon aurolineatum)* increased with longer soaks, as did catches of large squirrelfish *(H. ascensionis)*, but only in deeper water. Catch increased markedly with longer soaks for the grunts in all three trap designs. Red hinds *(E. guttatus)* showed higher overall catches at

Table 5. Nine species of reef fish captured in fish traps in location A and B on the west coast of Puerto Rico during September-October 1973 which showed significant responses ($\alpha = .05$) of mean catch per haul to the variables depth, design and soak and their interactions. Significant responses in both numbers (nos) and weight (kg) captured are designated by asterisks

| | Mean catch/haul varies by: | | | | | | |
|---|---|---|---|---|---|---|---|
| Species | Depth | Design | Soak | Depth & Soak | Depth & Design | Soak & Design | Depth & Soak & Design |
| *Epinephelus guttatus* | * | | | | | | |
| *Sparisoma aurofrenatum* | * | * | nos | | * | * | * |
| *Holocentrus rufus* | * | * | nos | | * | nos | |
| *Holocentrus ascensionis* | * | | | * | * | | |
| *Calamus pennatula* | nos | | | | | nos | |
| *Lactorophrys* spp. | nos | | | | | | |
| *Haemulon aurolineatum* | * | | * | * | | | |
| *Ocyurus chrysurus* | nos | | nos | | | | |
| *Rhomboplites aurorubens* | | * | kgs | kgs | kgs | kgs | kgs |

Table 6. Mean numbers captured per haul by soak time and trap design for five species of reef fish in location A (depth = 30 m) on the west coast of Puerto Rico during September-October 1973. Total number of trap hauls = 48. All traps were of nearly equal volume with identical entrances and 3.1 cm mesh

*Epinephelus guttatus*

| | Designs | | | |
|---|---|---|---|---|
| Soak | A | S | Z | Totals |
| 4 | 10.4 | 6.0 | 4.4 | 6.8 |
| 5 | 10.0 | 11.5 | 6.7 | 9.6 |
| 6 | 3.7 | 3.5 | 8.3 | 5.4 |
| Totals | 8.9 | 7.0 | 5.6 | 7.1 |

*Sparisoma aurofrenatum*

| | Designs | | | |
|---|---|---|---|---|
| Soak | A | S | Z | Totals |
| 4 | 2.4 | 2.6 | 1.3 | 2.1 |
| 5 | 2.5 | 5.2 | 7.7 | 5.4 |
| 6 | 2.3 | 16.5 | 1.7 | 5.6 |
| Totals | 2.4 | 4.8 | 2.6 | 3.3 |

*Holocentrus rufus*

| | Designs | | | |
|---|---|---|---|---|
| Soak | A | S | Z | Totals |
| 4 | 0.3 | 1.6 | 2.3 | 1.4 |
| 5 | 0.0 | 1.5 | 4.7 | 2.2 |
| 6 | 3.7 | 0.0 | 9.3 | 4.9 |
| Totals | 1.0 | 1.4 | 4.2 | 2.2 |

*Holocentrus ascensionis*

| | Designs | | | |
|---|---|---|---|---|
| Soak | A | S | Z | Totals |
| 4 | 4.4 | 4.1 | 3.7 | 4.1 |
| 5 | 8.5 | 4.0 | 2.7 | 4.6 |
| 6 | 2.3 | 0.0 | 4.3 | 4.4 |
| Totals | 4.6 | 3.5 | 3.6 | 3.9 |

*Haemulon aurolineatum*

| | Designs | | | |
|---|---|---|---|---|
| Soak | A | S | Z | Totals |
| 4 | 2.3 | 1.3 | 1.3 | 1.6 |
| 5 | 1.0 | 3.0 | 1.3 | 2.0 |
| 6 | 7.3 | 13.5 | 10.7 | 10.1 |
| Totals | 3.2 | 3.2 | 3.1 | 3.2 |

Table 7. Mean numbers captured per haul by soak time and trap design for one species of reef fish in location B (depth = 50 m) on the west coast of Puerto Rico during September-October 1973. Total number of trap hauls = 45. All traps were of nearly equal volume with identical entrances and 3.1 cm mesh

| | | *Holocentrus ascensionis*<br>Designs | | |
|---|---|---|---|---|
| Soak | A | S | Z | Totals |
| 3 | 6.3 | 3.7 | 7.3 | 5.8 |
| 4 | - | - | - | - |
| 5 | 6.9 | 12.1 | 14.5 | 11.0 |
| 6 | 7.7 | 23.0 | 14.0 | 14.9 |
| Totals | 6.9 | 12.7 | 12.9 | 10.7 |

intermediate soak times, but not in all designs. The interdependence of trap design and soak time was strong for the parrotfish *(S. aurofrenatum)*. Highest catches were observed at 5 days, in Z traps and at 6 days in S traps, whereas no changes were observed by soak in A traps. Given the depth dependence of this species, it therefore showed a three-way depth-design-soak interaction.

The effects of mesh size were evaluated by testing for treatment effects and interaction in two-way plots of mesh size and soak time for all species captured in location A3 during September-October 1974 (Table 8). All traps sampled were of equal volume (0.60 $m^3$) with large entrances. All traps were chevron traps. Three species showed significant ($\partial$ = .10) mesh effects while one *(E. guttatus)* responded only to soak time. A soak-mesh interaction was observed for one species, *Haemulon aurolineatum*. The results showed that the two smaller species *(H. aurolineatum* and *Pseudupeneus maculatus)* were selectively retained in 3.1 cm mesh traps while larger squirrelfish were retained in 5.1 cm traps.

## ALTERNATIVE TRAP FISHING STRATEGIES

This evaluation of trap design features and fishing practices has suggested that optimum fishing strategies can be developed for improving the economic return from trap fisheries. A fundamental assumption is that fish traps may be more selective in terms of the species of fish which are captured than has previously been assumed. Subtle changes in the size and species composition of trap hauls as a result of variable depth, soak time, design and mesh size and the interactions between these factors may significantly affect the value of the catch as much as design features (for example, volume) which affect overall catch rates. To adequately assess these effects, however, would require a large number of repetititve trap hauls and a careful control of the variables which influence catch and species composition. The present study has made only a beginning in this direction.

The results of this study have confirmed earlier work (Wolf and Chislett, 1971; Munro et al., 1971; Munro, 1974a) which demonstrated that (1) smaller meshed traps catch more and smaller fish, (2) S and Z traps perform better

Table 8. Mean numbers captured per haul by soak time and mesh size (in maximum aperture) for three species of reef fish in location A3 (depth 20-40 m) on the west coast of Puerto Rico during September-October 1974. Total number of trap hauls = 43. Traps were of equal volume and design with identical entrances

*Pseudupeneus maculatus*

Mesh size (cm)

| Soak | 3.1 | 4.2 | 5.1 | Totals |
|---|---|---|---|---|
| 4 | 14.0 | - | 0.0 | 7.5 |
| 5 | 19.3 | 4.0 | 2.6 | 5.1 |
| Totals | 15.4 | 4.0 | 1.6 | 5.9 |

*Holocentrus ascensionis*

Mesh size (cm)

| Soak | 3.1 | 4.2 | 5.1 | Totals |
|---|---|---|---|---|
| 4 | 0.1 | - | 0.4 | 0.3 |
| 5 | 1.0 | 0.0 | 3.9 | 1.6 |
| Totals | 0.4 | 0.0 | 2.6 | 1.2 |

*Haemulon aurolineatum*

Mesh size (cm)

| Soak | 3.1 | 4.2 | 5.1 | Totals |
|---|---|---|---|---|
| 4 | 0.9 | - | 0.0 | 0.5 |
| 5 | 7.3 | 0.1 | 0.4 | 1.0 |
| Totals | 2.6 | 0.1 | 0.3 | 0.8 |

than other trap designs, (3) an "optimum" soak time exists beyond which traps cease to catch more fish. This study showed that unbaited S traps may, in fact, catch more fish than Z traps, although a larger sample size was needed within individual locations to statistically demonstrate these differences. Optimum soak times varied slightly according to the time of year and the location of the traps, but averaged about 5 days. The mean catch rate of 5.1 cm mesh traps was less than half the rate of 3.4 cm mesh traps over the same soak period.

Traps set in deeper water (50) m) caught slightly less than traps set in shallower water (30 m) during the Fall 1973 fishing season and the species composition was quite different. Similar changes in species composition were observed between two shallow water locations fished in two different fishing seasons. Small groupers, parrotfish, small squirrelfish and grunts were more common in shallower waters while jacks and larger squirrelfish predominated in deeper water. Two species of snapper were caught in small quantities only at the deeper location. Depth acted interactively with design and soak for several species in determining catch rates.

Longer soak times increased the catch of a number of smaller, less valuable species whereas intermediate soak times seemed to produce a greater yield of small groupers. Significant interdependence was observed between soak and design for parrotfish and between soak and depth for larger squirrelfish, demonstrating that catch responded only to changes in soak time for particular trap designs or at particular depths. Z traps captured more small squirrelfish in shallow water and S traps captured more small parrotfish than the other two designs, also in shallow water. Chevron traps seemed to catch more red hinds *(Epinephelus guttatus)*, a higher-priced species, than the other two designs, but neither design nor soak effects were significant.

Several smaller, more elongated species were clearly selected by size in the smaller-meshed traps. Goatfish and tomtate grunts were too small to be retained in significant quantities in meshes larger than 3.4 cm. As pointed out in an earlier study of this fishery (Stevenson, 1978), a reduction in mesh size designed to increase the yield of the smaller species could seriously deplete the stocks of the larger species on the reef, both by simple removal and by reducing the number of spawning adults in the population.

These results showed that the use of traps of a particular design and/or mesh size in certain depths and for certain soak times increased or decreased the capture of certain species. As an example of a possible strategy to maximize the catch of an individual species, more red hinds were caught in chevron traps of intermediate mesh size (4.2 cm) set in 30 m for 4-5 days. In general, longer soak times increased the catch of smaller, less valuable species.

Management decisions designed to lead to full utilization of multi-species reef fishery resources for optimum economic and social benefit without depleting stocks may have to consider trap design and soak time as well as mesh size. Maintaining a certain species mix and mean size-at-capture may be management objectives equally important as maintaining sustained overall catch rates at some maximum level.

## COMPARATIVE MEASURES OF RELATIVE FISHING PRESSURE

The deployment of large numbers of small-meshed traps in a limited reef area would clearly threaten populations of reef fish which do not move freely from one reef to another. To be effective, the management of trap fisheries may involve both mesh size regulations and limitations on the numbers of traps set per unit area of reef. As pointed out by Munro (1974b), and as suggested by the results of this study, different species will respond differently to each solution. Ultimately, since reef fish communities are composed of so many species, any management effort must be directed at maximizing yield only for certain selected species. The overexploitation of some species may be an unavoidable consequence of effective management policy.

To illustrate the possible implications of a "no regulation policy" in Puerto Rico and to evaluate the relative intensity of trap fishing on the west coast of the island, several parameters of the Puerto Rican trap fishery have been compared with values from elsewhere in the Caribbean, particularly in Jamaica where unregulated trap fishing with small-meshed traps in nearshore waters has reportedly depleted the populations of larger reef species and reduced the mean lengths-at-capture for those species which remain (Munro et al., 1971).

The overall catch per unit effort estimated from 280 trap hauls in this study was 4.25 kg/haul for 4-6 day soaks or somewhat less than 1 kg/trap-day. Yield estimates from experimental trap fishing on Mona and Vieques Islands in Puerto Rico (Table 9) were presumably higher for comparable soak periods, assuming that the reported catch rates per trap-day would have continued to increase after 12-18 hour soak periods. The reported figure for the Virgin Islands was very high given the extremely short soak time. High values were also reported for south Florida and the offshore Jamaican banks. Since the response of catch to soak time is not linear, catch per unit effort data were not satisfactory for comparative productivity purposes without a standardized unit of effort which takes into account the "filling rate" of traps in relation to a given stock density on the reef. Munro (1974a) has proposed the theoretical framework for standardizing catch per unit effort data from trap fisheries.

Comparable estimates of the "filling rate" of traps in Puerto Rico and Jamaica and their maximum catch in numbers per trap haul suggested that the western Puerto Rican shelf supports a higher density of fish. Larger Z traps (1.1-1.4 $m^3$) with 4.1 cm meshes set in 7-14 m on the Port Royal reefs on the south shore of Jamaica in 1970 filled after 7-10 days and contained approximately 12-14 fish per trap. In Puerto Rico, smaller traps (0.60-0.85 $m^3$) of various designs and mesh sizes filled after 5 days in some locations. The effect, however, of trap volume must be considered when comparing filling rates. The smaller traps used in Puerto Rico would be expected to fill more rapidly. The overall mean catch rate in Puerto Rico was 21.25 fish/haul and reached 40 fish/haul in one location, suggesting higher stock densities than in Jamaica.

Comparative catch rates per unit area of shelf were slightly lower in Puerto Rico (1.1 $g/m^2$ in Jamaica and 0.8 $g/m^2$ in Puerto Rico), suggesting that standing stocks there were not higher and contradicting the indications mentioned above. The original abundance of fish on the more prolific Jamaican reefs was probably much higher, however, and has been reduced to a much greater degree by fishing than in Puerto Rico. Munro (1973b) estimated that catch per unit area exceeds 0.8 $g/m^2$ (equals 0.8 metric $tons/km^2$ or 8 kg/ha) for shelf areas in the Caribbean which are intensively harvested.

The diversity of fishes caught on the Jamaican inshore reefs was much higher than in Puerto Rico. Nine species of fish and one species of lobster accounted for 50% by weight of the catch in Jamaica and the remaining 50% was comprised of nearly 100 species (Munro, 1974a). Ten species accounted for about 75% of the catch in Puerto Rico and the entire catch was made up of only 40-50 species. This difference in diversity is almost certainly due to depth differences and the amount of live coral growth. Coral growth on the west coast of Puerto Rico is very sparse (Almy and Carrion, 1963). Estimates of the possible impact of trap fishing on the diversity of natural reef fish populations based on the species composition in the catch must account for natural phenomena which affect species diversity independently of fishing.

Table 9. Comparative mean catch rates by weight for experimental trap fishing in various locations in the Caribbean since 1970

| Location | Depth | Year | Mean Catch Rate | No. Hauls | Average Soak (Hrs) | Remarks |
|---|---|---|---|---|---|---|
| South Florida* | 3-40m | 1975 | 12.3 kg/haul | 257 | 108 | 1.8 $m^3$ rectangular traps, 1½″-2″ mesh; 9.25 kg/haul snappers |
| Offshore Jamaican banks‡ | 40-60m | 1970 | 8.4 kg/haul | 226 | 18 | Baited 2.1 $m^3$ Z-traps, 1¼″ mesh |
| Puerto Rico‡ (east coast) | 40-200m | 1974 | 2.25 kg/trap-day | 115 | 18 | Baited, four designs, 1″ and 1¼″ mesh; 75% snappers |
| Puerto Rico‡ (west coast) | 40-250m | 1973 | 1.0 kg/trap-day | 527 | 24 | Baited, four designs, 1″ and 1¼″ mesh; 50% catch snappers |
| Mona Island ‡ (Puerto Rico) | 60-200m | 1973 | 3.4 kg/trap-day | 80 | 12 | Baited, four designs, 1″ and 1¼″ mesh; 65% snappers |
| Pedro Bank§ (Jamaica) | - | 1971-73 | 5.5 kg/haul | - | 20-24 | Various designs, sizes and meshes; All traps baited |
| U.S. Virgin Islands‖ | 12-25m | 1972-73 | 1.8 kg/haul | - | 1.5 | Baited traps, various designs |

*References:* *Craig, 1976; ‡Wolf & Chislett, 1971; ‡Cole, 1976; §Munro, 1974a. and ‖Sylvester & Dammann, 1973

Perhaps the most useful indicator of the relative impact of trap fishing in different locations was the mean or modal size of fish retained in traps of a given mesh size. A comparison of the observed lengths-at-capture ($l'$) and mean lengths beyond $l'$ (Table 10) for eight species captured in 4.2 cm mesh traps in Puerto Rico and on inshore and offshore Jamaican fishing grounds clearly revealed the effect of more intensive fishing on the inshore Jamaican reefs. Observed lengths from Puerto Rico were, in most cases, lower than values from the offshore banks where fishing was less intense and higher than values from the inshore reefs. Comparisons of this kind are more reliable when fishing is conducted in similar depths. Although traps were set in only 7-14 m on the inshore reefs, fishing was in the same general depth range on the offshore banks as in Puerto Rico (10-50 m).

## SUMMARY

The performance of wire fish traps on the west coast of Puerto Rico was studied during three sampling periods in 1973 and 1974. The numbers and weight of approximately 30 species were recorded by haul for 280 trap hauls. Traps were set in 20-50 m depths. Changes in catch rates and species composition were related to trap design, mesh size, location and soak time. All data were collected aboard commercial fishing vessels and the deployment and retrieval of traps was supervised by an experienced commercial fisherman. Notable variations in catch rates by location, depth and time of year and the use of different trap types between locations required that all data be analyzed by location.

Mean catch rates for all trap types were 4.25 kg/haul (range 2.7-5.7 kg/haul by location) and 21.2 fish/haul (range 12.5-40.2 fish/haul by location) Soak times ranged from 3 to 6 days. Maximum catch rates were observed at 5 days in several locations. Design comparisons suggested that traditional chevron traps used in Puerto Rico were less effective than either S or Z traps and that catch rates in S traps were higher than in Z traps. In addition, small-meshed traps captured more fish (numbers and weight) than larger-meshed traps.

The species composition of catches varied by time of year, location and depth. Statistical analyses of catch rates obtained as a function of depth, trap design and soak time were performed for individual species captured during 97 trap hauls in September-October 1973. Significant depth and soak effects were indicated for five species and trap design effects for three species. In most of these cases, the effects of depth, design and soak on mean catch rates were interdependent. Small parrotfish were more frequently captured in S traps and small squirrelfish in Z traps. Catches of small squirrelfish and tomtate grunts increased with longer soaks as did catches of large squirrelfish in deeper water. An identical analysis of soak and mesh size effects was performed with 43 trap hauls from September-October 1974. Two small species (goatfish and tomtate grunts) were selectively retained in 3.1 cm (1 inch minimum aperture) mesh traps while more large squirrelfish were captured in 5.1 cm (1½ inch minimum aperture) mesh traps. These results suggested that management decisions may well have to consider the effects of different trap fishing strategies on species composition as well as on overall catch rates.

Table 10. Observed lengths-at-first-capture ($l'$) and calculated mean lengths beyond $l'$ ($\bar{l}$) in length-frequency data compiled from 4.2 cm mesh (maximum aperture) fish traps on the west coast of Puerto Rico, 1973-74, the inshore Jamaican (Port Royal) reefs and several offshore Jamaican banks, 1969-73

| Species | Location | $l'$ (cm) | $\bar{l}$ (cm) |
|---|---|---|---|
| *Epinephelus guttatus* | Puerto Rico | 23 | 27.6 |
| | California Bank | 28 | 33.3 |
| | Pedro Bank | 30 | 36.4 |
| *Cephalopholis fulva* | Puerto Rico | 20 | 23.1 |
| | Serranilla Bank | 24 | 26.4 |
| | California Bank | 22 | 24.8 |
| | Pedro Bank | 25 | 27.1 |
| *Caranx ruber* | Puerto Rico* | 17 | 22.6 |
| | Puerto Rico† | 26 | 29.2 |
| | Port Royal | 16 | 18.9 |
| | Serranilla Bank | 25 | 28.1 |
| | Pedro Bank | 20 | 26.4 |
| *Haemulon plumieri* | Puerto Rico | 19 | 24.1 |
| | Port Royal | 15 | 19.3 |
| | Pedro Bank | 27 | 29.4 |
| *Pseudupeneus maculatus* | Puerto Rico | 18 | 20.1 |
| | Port Royal | 19 | 20.4 |
| | Pedro Bank | 19 | 21.5 |
| *Holocentrus rufus* | Puerto Rico‡ | 18 | 18.9 |
| | Port Royal | 16 | 17.2 |
| | California Bank | 18 | 18.7 |
| | Pedro Bank | 18 | 18.9 |
| *Sparisoma aurofrenatum* | Puerto Rico | 18.5 | 20.3 |
| | Port Royal | 17 | 18.2 |
| | Pedro & Calif. Banks | 17 | 19.5 |
| *Sparisoma chrysopterum* | Puerto Rico§ | 27 | 29.1 |
| | Port Royal | 21 | 22.4 |

*3.4 and 4.2 cm meshes, 20-40 m deep.
†Various mesh sizes, 40-60 m deep.
‡3.4 and 4.2 cm meshes.
§Various mesh sizes.

Differences in the size of fish retained in traps of a given mesh size proved to be the most useful indicator of relative fishing intensity on different fishing grounds. For a number of species, the modal lengths of fish captured in 4.2 cm mesh traps in Puerto Rico were lower than on offshore Jamaican banks where fishing was less intensive and higher than on inshore Jamaican reefs where fishing has been heavy for many years.

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