# Effects of an increase in trap mesh size on an overexploited coral reef fishery at Discovery Bay, Jamaica

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ABSTRACT: One of the most popular management tools for Caribbean reef fisheries is a minimum mesh size for traps. It is believed that increasing the mesh size of traps in overexploited fisheries will result in higher catch rates in the long term, but lower catch rates in the short term. This study represents the first attempt to document the short-term and long-term effects of partly replacing small mesh with a larger mesh size in an artisanal coral reef fishery. A community level mesh exchange program was initiated in the Discovery Bay trap fishery in March 1991, whereby active fishers were given large mesh (1.5 inch: 3.8 cm) wire to construct traps in exchange for handing in their small mesh (1 inch: 2.5 cm and 1.25 inch: 3.2 cm) traps. Although the total number of active traps and the total number of hauls per month did not significantly change in the fishery, the proportion of small mesh traps decreased substantially as a result of the mesh exchange program, leading to a concurrent reduction of fishing mortality in smaller sized fish. Changes in the fish populations were examined by comparing catch-per-unit-effort (CPUE as number of fish per trap per haul, and kg per trap per haul); mean size of individual fish; catch composition; and length frequency distributions for the 2 most common species, for both 1.25 inch and 1.5 inch traps in 3 separate 6 mo periods (July to December) in 1990 (10 mo before the implementation of the mesh exchange program), 1991 (immediately after the implementation of the mesh exchange program) and 1994 (3 yr after the implementation of the mesh exchange program). The results indicate that reef fish populations at Discovery Bay, and hence yields to the fishery, have increased in the 3 yr since the mesh exchange program was implemented. The number of fish caught per trap haul has increased; the total weight of the catch per trap haul, at least of the smaller mesh sizes, has increased; the catch composition has shifted towards larger and more valuable species; the mean size of fish taken by the fishery is larger; and the population of 1 narrow-bodied species investigated has shifted towards larger size classes since the increase in mean mesh size in the fishery. However, despite an increase in the gross catch per week by the trap fishery, catch rates still differ markedly between small and large mesh traps, with small mesh traps catching less per haul but more per week than large mesh traps. As a consequence, fishers still using small mesh traps are benefitting the most from recovery of the reef fish populations, which demonstrates the need for further efforts to eliminate the smaller mesh traps from the fishery.

KEY WORDS: Coral reef fishery · Trap mesh size · Fishery management

## INTRODUCTION

The focus of this study is the artisanal trap fishery of Discovery Bay, on the north coast of Jamaica (18° 28' 00" N, 77° 24' 30" W), a locally important fishery which provides essential protein and employment to the economically depressed coastal community (Berkes & Shaw 1986, Allison 1992, Aiken 1993, Sandeman & Woodley 1994). However, the coral reefs on this coast of Jamaica are thought to be among the most overfished reefs in the English-speaking Caribbean (Government of Jamaica 1994, Hughes 1994, Roberts 1995). This trap fishery is nevertheless typical of many others throughout the Caribbean, which are producing yields considerably lower than estimated potential

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long-term sustainable yields as a result of depressed stock abundances caused by a combination of overexploitation and habitat degradation (e.g. Munro 1983, Rogers 1985, Russ 1991, Bohnsack 1993, FAO 1993, Hunte & Mahon 1994, Koslow et al. 1994). The catches are characterized by a high proportion of low valued species, a small mean size for all species, and a scarcity or even complete disappearance of the larger species (e.g. all large Serranidae; Sary 1995).

Management of trap fisheries in the Caribbean, and particularly management of the Jamaican north coast trap fishery, is urgently needed, but presents many difficult problems (Munro & Smith 1984, Mahon 1990, Koslow et al. 1994). For example, the very large fishery on this coast, with approximately 2450 licensed fishers using about 900 registered boats, is concentrated on a very narrow (<1 km wide) island shelf. In addition, a large proportion of fishers are not licensed and boats are not registered. The fishery uses a relatively non-selective gear, and the multi-species catch is landed at many dispersed landing sites (79 are officially recognized by the Data Collection Unit of the Jamaican Fisheries Division) along the 250 km coastline. The situation is exacerbated by the fact that the fishery has a tradition of unlimited entry, that the fishing grounds are easily accessible, that the resource is already heavily overexploited, and that alternative employment opportunities are lacking (Allison 1992, Chakalall 1992, Aiken 1993). As a consequence, the Jamaican north coast trap fishery, like many other trap fisheries in the region, is almost completely unregulated. However, most countries in the region are attempting at least partial management of their trap fisheries (e.g. Mahon 1987, Burnett-Herkes & Barnes 1991, Chakalall 1992, Kimmel & Appledorn 1992, NMFS 1996).

Management tools considered suitable for reducing fishing mortality in reef fisheries include gear restrictions, fish sanctuaries, and limited entry. There are several reviews of management options for reef fisheries (e.g. Munro & Williams 1985, Mahon 1990, Medley et al. 1993, Sale et al. 1994, Munro 1996). One of the most popular proposed management tools for Caribbean reef fisheries is a minimum mesh size for traps (CFMC 1985, Mahon 1990, Chakalall 1992, Hunte & Mahon 1994). It is argued that a minimum mesh size regulation could alleviate overfishing by reducing mortality of juvenile fish (Hunte & Mahon 1994). Thus, increasing the mesh size of traps in overexploited fisheries is expected to result in higher catch rates in the long term after fish population biomass has increased, but lower catch rates in the short term as catch rates of juveniles are reduced (CFMC 1985). However, there is currently little information available to managers on the time frame that would be required

for catches to improve, except for the growth rates of some species (Munro 1983, Picou-Gill et al. 1991), nor is there general agreement on what minimum mesh size is most appropriate to enhance reef fisheries (Hunte & Mahon 1994). All previous field studies of fishtrap mesh size selectivity have compared catch rates of different mesh size traps fished in the same area at the same time. The results of these studies may not, therefore, be appropriate to estimate long-term catch rates of some mesh sizes, because the sampled fish populations are not in equilibrium with all the mesh sizes used in the experiment (Hunte & Mahon 1994). This study represents the first attempt to document the short-term and long-term effects on the resource of introducing a larger mesh size, partly replacing small mesh sizes, in an artisanal trap fishery. Specifically, we examine changes in catch per trap haul and catch composition (by family group) immediately after and 3 yr after implementation of the mesh exchange program, in an attempt to understand and quantify any changes in fish abundance and community structure, and to consider the implications of these changes for fishers. We also examine changes in the mean size and length-frequency distribution of 2 common species immediately after, 1 yr after and 3 yr after implementation of the mesh exchange program, in an attempt to monitor and interpret shifts in population size structure of these species following the mesh exchange, and use these results to make inferences about other members of the reef fish community.

## METHODS

**Introduction of a larger mesh size.** A community level mesh exchange program was initiated in the Discovery Bay trap fishery in March 1991 by the Fisheries Improvement Program (FIP) of the University of the West Indies (UWI), whereby active fishers were given large mesh [1.5 inch (3.8 cm)] wire to construct traps in exchange for handing in their small mesh [1 inch (2.5 cm) and 1.25 inch (3.2 cm)] traps (see Sary et al. 1991 and Woodley 1994 for details of the program).

**Data collection.** Most catch and effort data were collected in 3 representative 6 mo periods (July to December) in 1990 (10 mo before the implementation of the mesh exchange program), in 1991 (immediately after the implementation of the mesh exchange program) and in 1994 (3 yr after the implementation of the mesh exchange program). In the July to December periods of 1990 and 1991, catch and effort data were collected at the 2 fish landing beaches in Discovery Bay (Fig. 1) once a week, on randomly selected days. On these sampling days, all the catches landed at a site by consenting fishers were sorted to species, counted and
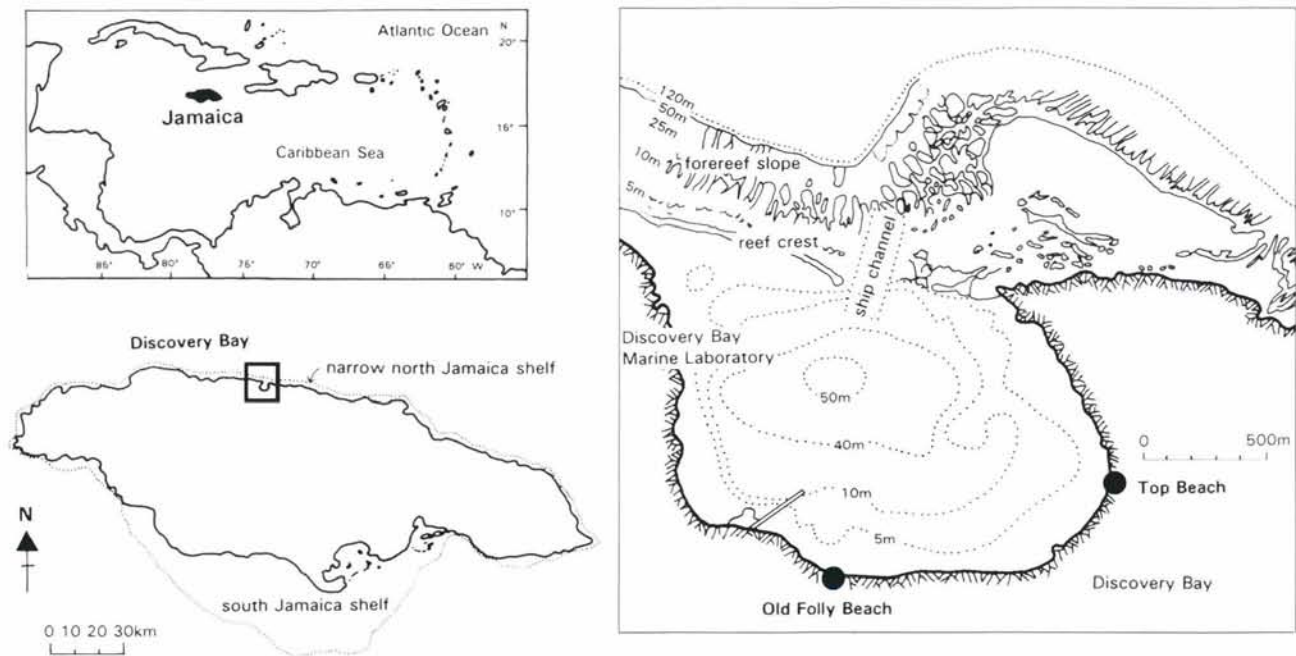
Fig. 1. Map of Jamaica showing the extent of the island shelf and the location of the study area, Discovery Bay. Also shown are geographical position of Jamaica in the Caribbean and topography of Discovery Bay showing reef outlines and location of the 2 main fish landing sites (●) (adapted from Woodley & Robinson 1977)

weighed to the nearest 0.01 kg. Information on the number of traps hauled, average soak time and mesh size of each fishtrap was also collected concurrently from the fishers wherever possible. From July to December 1994, catch and effort data were collected directly (once or twice a week) from a subsample of 13 cooperative (38% of all) Discovery Bay trap fishers operating from both landing sites. During this period of data collection, the catch from each mesh size was kept separate by the fishers and was further sorted to species, counted and weighed to the nearest 0.01 kg. Information on the number of traps of each mesh size hauled and the soak times was also collected concurrently from the fishers.

The total number of traps of various mesh sizes in use in the Discovery Bay trap fishery, before (1990) and immediately after (1991) the implementation of the mesh exchange program, was estimated by observation and from interviews with fishers as reported in Sary et al. (1991). The total number of traps of each mesh size in use 3 yr after (1994) the implementation of the mesh exchange program was estimated by a formal survey of all active trap fishers in Discovery Bay, conducted between October and December 1994.

The total number of traps hauled per month (from March 1990 to October 1992) was estimated by extrapolation of data collected at the 2 fish landing beaches once a week, on randomly selected days. On these sampling days the total number of trap fishers going to

sea was noted and the total number of traps hauled by each fisher sampled was recorded.

Fork lengths (FL) of all individuals of the 2 most common species encountered in the sampled catches of both small mesh and large mesh traps, redband parrotfish *Sparisoma aurofrenatum* and ocean surgeon *Acanthurus bahianus*, were measured to the nearest 1 mm in four 6 mo (July to December) sampling periods (i.e. in 1990, 1991, 1992 and 1994).

**Data analyses.** Changes in finfish catch per haul (i.e. CPUE as number of fish per trap per haul and kg per trap per haul) for both 1.25 and 1.5 inch traps were examined by comparing the CPUE of all fishers sampled in each of the 3 separate 6 mo periods (July to December) in 1990, 1991 and 1994. The data did not follow a normal distribution, and thus non-parametric analyses of variance were used to compare CPUE among years for 1.25 inch mesh traps and for 1.5 inch mesh traps. Differences in CPUE were first tested with the Kruskal-Wallis non-parametric ANOVA; if a significant difference was found, 2 years were compared at a time using the Mann-Whitney U-test.

Changes in finfish species composition of fishtrap catches were examined by comparing CPUE (as kg fish per trap per haul) at the family level in the three 6 mo periods (July to December) in 1990, 1991 and 1994. Family groupings followed those of Koslow et al. (1988) except for the Miscellaneous group (MIX) which here included the families Sciaenidae, Chaetodonti-

dae, and Pomacanthidae (for which there were very few representatives), as well as others not included in any fish group by Koslow et al. (1988). A complete list of all species within each group is given by Sary (1995). The CPUE data did not follow a normal distribution. Therefore, CPUE of each fish group was compared between years using Mann-Whitney $U$-tests for 1.25 inch mesh traps and for 1.5 inch mesh traps.

Mean weight of individual finfish caught was calculated from available data on the number and weight of finfish per trap, for the three 6 mo periods (July to December) in 1990, 1991 and 1994. The data did not follow a normal distribution, and thus non-parametric analyses of variance were used to compare fish weight among years for 1.25 inch mesh traps and for 1.5 inch mesh traps. Differences in fish weight were first tested with the Kruskal-Wallis non-parametric ANOVA; when a significant difference was found, 2 years were compared at a time using the Mann-Whitney $U$-test.

Changes in the population size structure of the 2 most common species in the trap catches, the redband parrotfish *Sparisoma aurofrenatum* and the ocean surgeon *Acanthurus bahianus* were examined by comparing mean FLs in the four 6 mo periods (July to December) in 1990 (10 mo before the implementation of the mesh exchange program), 1991 (immediately after the implementation of the mesh exchange program), 1992 (1 yr after the implementation of the mesh exchange program), and 1994 (3 yr after the implementation of the mesh exchange program). The data followed a normal distribution, and thus parametric ANOVA was used to compare mean sizes among sampling periods for 1.25 inch mesh traps and for 1.5 inch mesh traps.

Changes in fishing effort as a result of the mesh exchange program were examined by comparing the annual mean number of trap hauls per month (data were available from March 1990 to October 1992) between 1990 (the year before the mesh exchange program was implemented), 1991 (the year the mesh exchange program was implemented) and 1992 (the year after the mesh exchange program was implemented). The data followed a normal distribution and

thus a parametric ANOVA was used to compare means among years for all mesh size traps in the fishery.

Changes in soak time of traps (in days) were examined by comparing the reported soak time of traps of all fishers sampled in each of 3 separate 6 mo periods (July to December) in the years 1990, 1991 and 1994. The data did not follow a normal distribution, and thus Kruskal-Wallis non-parametric ANOVA was used to compare soak time among years for 1.25 inch mesh traps and for 1.5 inch mesh traps.

## RESULTS

### Changes in fishing pressure

The total number of fishtraps being used in the Discovery Bay trap fishery did not appear to change substantially as a result of the mesh exchange program. There were approximately 324 in use immediately before and 325 in use immediately after the implementation of the mesh exchange program (Sary et al. 1991), and 3 yr after the program was implemented, the number of traps in the fishery changed only slightly (to approximately 285). Likewise, mean number of trap hauls per month did not vary significantly between 1990 (107 hauls per month), 1991 (127 hauls per month), and 1992 (149 hauls per month) (ANOVA: $F = 1.352$, n = 32, p = 0.274). Furthermore, soak time, although different for the large and small mesh traps, did not change as a result of the mesh exchange program (Table 1; for 1.25 inch mesh traps, Kruskal-Wallis test: $H = 1.23$, n = 311, p = 0.541; for 1.5 inch mesh traps, Mann Whitney test: $U = 1400$, n = 123, p = 0.156).

However, the proportions of small mesh traps changed substantially from 94% (1 inch mesh: 68; 1.25 inch mesh: 236; 1.5 inch mesh: 20) in 1990 (10 mo before the implementation of the mesh exchange program) to 32% (1 inch mesh: 4; 1.25 inch mesh: 99; 1.5 inch mesh: 222) in 1991 (immediately after the implementation of the mesh exchange program) and to 58% (1 inch mesh: 10; 1.25 inch mesh: 155; 1.5 inch mesh: 120) in 1994 (3 yr after the implementation of the mesh exchange program).

Table 1. Fishing pressure in the Discovery Bay trap fishery shown as total number of traps, relative abundance of small mesh traps, and mean soak times in days for 1.25 inch mesh fishtraps and for 1.5 inch mesh fishtraps from July to December in 1990, 1991 and 1994. n: number of traps sampled

| Year | Total no. of fishtraps | Relative abundance of small mesh fishtraps (%) | 1.25 inch mesh fishtraps | | 1.5 inch mesh fishtraps | |
|------|------|------|------|------|------|------|
| | | | n | Soak time (d) | n | Soak time (d) |
| 1990 | 324 | 94 | 835 | 3.1 | | |
| 1991 | 325 | 32 | 276 | 3.5 | 201 | 6.0 |
| 1994 | 285 | 58 | 360 | 2.6 | 411 | 4.8 |

## Changes in catch per unit effort (CPUE)

A total of 1322 catches from 1.25 inch mesh fishtraps and 644 catches from 1.5 inch mesh fishtraps were examined altogether.

### Catch per haul of 1.25 inch mesh fishtraps

Mean catch weight per haul (as kg per trap per haul) for 1.25 inch mesh traps in 1990, 1991, and 1994 is given in Table 2a. Catch weight per haul showed significant variation among years (Kruskal-Wallis test: $H = 13.819$, n = 326, p = 0.001). All 2-sample tests also indicated significant differences in catch weight per haul between years. Catch weight per haul in 1990 was significantly higher than in 1991 (Mann-Whitney test: $U = 5604.5$, n = 208, p = 0.030). Catch weight per haul in 1994 was significantly higher than in both the earlier years (Mann-Whitney tests: for 1990 vs 1994, $U = 7071.5$, n = 259, p = 0.038; for 1991 vs 1994, $U = 2692$, n = 185, p < 0.001).

Mean catch number per haul (as fish per trap per haul) for 1.25 inch mesh traps in 1990, 1991, and 1994 is given in Table 2b. Catch number per haul showed significant variation among years (Kruskal-Wallis test: $H = 14.894$, n = 290, p = 0.001). However, 2-sample tests indicated that there was no difference in catch number per haul between 1990 and 1991 (Mann-Whitney test: $U = 3524$, n = 172, p = 0.178), but that catch number per haul in 1994 was significantly higher than in both the earlier years (Mann-Whitney tests: for 1990 vs 1994, $U = 5430$, n = 238, p = 0.002; for 1991 vs 1994, $U = 2126$, n = 170, p < 0.001).

In summary, the catch per haul of 1.25 inch traps, after an initial decline, has shown a significant increase from 1990 to 1994 (23% by weight and 42% by number) with the implementation of the mesh exchange program.

### Catch per haul of 1.5 inch mesh fishtraps

Mean catch weight per haul (as kg per trap per haul) for 1.5 inch mesh traps in 1991 and 1994 is given in Table 2a. Catch weight per haul showed no significant difference between 1991 and 1994 (Mann-Whitney test: $U = 1818$, n = 136, p = 0.181).

Mean catch number per haul (as fish per trap per haul) for 1.5 inch mesh traps in 1991 and 1994 is given in Table 2b. Catch number per haul was significantly higher in 1994 than in 1991 (Mann-Whitney test: $U = 1438.5$, n = 131, p = 0.026).

In summary, the catch per haul of 1.5 inch traps has shown a significant increase from 1991 to 1994 in the

Table 2. Mean catch per haul for 1.25 inch and for 1.5 inch mesh fishtraps in the Discovery Bay trap fishery from July to December in 1990, 1991 and 1994. Catches are shown by (a) fish weight in kg, and (b) fish number. n: number of fishtraps sampled

| (a) kg per trap per haul | | | | |
|---|---|---|---|---|
| Year | 1.25 inch mesh fishtraps | | 1.5 inch mesh fishtraps | |
| | n | kg | n | kg |
| 1990 | 590 | 0.79 | | |
| 1991 | 207 | 0.60 | 176 | 0.83 |
| 1994 | 367 | 1.03 | 444 | 1.24 |

| (b) No. of fish per trap per haul | | | | |
|---|---|---|---|---|
| Year | 1.25 inch mesh fishtraps | | 1.5 inch mesh fishtraps | |
| | n | no. fish | n | no. fish |
| 1990 | 721 | 5.9 | | |
| 1991 | 234 | 5.2 | 200 | 4.0 |
| 1994 | 367 | 8.5 | 444 | 6.0 |

number of fish per haul (50%) with the implementation of the mesh exchange program. The corresponding increase in weight per haul (43%), however, was not significant.

### Catch per unit time for all fishtraps

Estimated weekly catches in the Discovery Bay fishery for 1 inch (data from Sary 1995), 1.25 inch and 1.5 inch mesh traps and total weekly catch by all traps are given in Table 3. In 1990 the catch per week by 1 inch traps was very similar to that by 1.25 inch traps, while in later years the samples are too small for changes to be considered. The 1.25 inch traps show a reduced catch per week in 1991, but a considerable increase in 1994. Catch per week by 1.5 inch traps (on which no data are available for 1990) also apparently increased considerably between 1991 and 1994. Overall, there was a marked reduction (−38%) in total trap catch per week in 1991 and a substantial increase by 1994 to a level 15% greater than in 1990.

## Changes in catch composition

### 1.25 inch mesh fishtraps

The mean catch composition of 1164 traps of 1.25 inch mesh (as kg per trap per haul by family groups) in 1990, 1991 and 1994 is given in Table 4. Catch composition differed significantly among all years (Pearson 3 × 13 chi-square contingency test: $\chi^2 = 289.7$, p < 0.001) and between all pairs of years (Pearson 2 × 13 chi-square contingency test: for 1990 vs

Table 3. Estimated weekly catch (kg) for the Discovery Bay trap fishery, shown separately for each mesh size trap in use from July to December in 1990, 1991 and 1994, and as a gross weekly total across all traps

| Trap type | Year | Soak time (d) | No. of hauls wk$^{-1}$ | Catch per haul (kg) | Catch wk$^{-1}$ (kg) | Total no. of traps (kg) | Total catch wk$^{-1}$ |
|---|---|---|---|---|---|---|---|
| 1 inch mesh | 1990 | 2.9 | 2.41 | 0.69 | 1.66 | 68 | 113 |
| | 1991 | 3.6 | 1.94 | 1.40 | 2.72 | 4 | 11 |
| | 1994 | 2.6 | 2.69 | 0.77 | 2.07 | 10 | 21 |
| 1.25 inch mesh | 1990 | 3.1 | 2.26 | 0.79 | 1.78 | 236 | 421 |
| | 1991 | 3.5 | 2.00 | 0.60 | 1.20 | 99 | 119 |
| | 1994 | 2.6 | 2.69 | 0.97 | 2.61 | 155 | 405 |
| 1.5 inch mesh | 1990 | – | – | – | – | 20 | 19[a] |
| | 1991 | 6.0 | 1.17 | 0.83 | 0.97 | 222 | 215 |
| | 1994 | 4.8 | 1.46 | 1.19 | 1.74 | 120 | 208 |
| All meshes | 1990 | | | | | 324 | 553 |
| | 1991 | | | | | 325 | 345 |
| | 1994 | | | | | 285 | 634 |

[a]Estimated total catch assuming same catch rates as in 1991

1991, $\chi^2 = 126.9$, $p < 0.001$; for 1990 vs 1994, $\chi^2 = 168.0$, $p < 0.001$; for 1991 vs 1994, $\chi^2 = 68.6$, $p < 0.001$). Over all years, small parrotfish (SSC), surgeonfish (ACN), squirrelfish (HOL), snappers (LUT) and the miscellaneous fish (MIX) were the most important groups (Table 4). However, their relative importance (as shown by rank in Table 4) varied between years.

The percent difference in catch per haul of each fish group between pairs of years is shown in Fig. 2. Between 1990 and 1991, only the small groupers (SSR) showed a large increase in abundance (Fig. 2a), but the change was not significant (Mann-Whitney test: $U = 1897$, n = 143, $p = 0.221$). Most groups (9 of the 13) showed decreases in abundance (Fig. 2a), although

only the decreases in the groups HOL and puffers/boxfish (TET) were significant (Mann-Whitney tests: for HOL, $U = 2970$, n = 143, $p < 0.001$; for TET, $U = 2442$, n = 143, $p = 0.022$).

Between 1990 and 1994, most groups (8 of the 13) showed increases in abundance (Fig. 2b), and the increases in the groups SSC, grunts (HAM), SSR and MIX were significant (Mann-Whitney tests: for SSC, $U = 4265$, n = 217, $p = 0.001$; for HAM, $U = 6921$, n = 217, $p = 0.015$; for SSR, $U = 4533$, n = 217, $p = 0.002$; for MIX, $U = 6743$, n = 217, $p = 0.037$). On the other hand, significant decreases in abundance (Fig. 2b) occurred in the groups TET, large parrotfish (LSC), and ACN (Mann-Whitney tests: for TET, $U = 6368$, n = 217, $p =$

Table 4. Catch composition (as mean kg per trap per haul for each fish group) of 1.25 inch and 1.5 inch mesh fishtraps in the Discovery Bay trap fishery from July to December in 1990, 1991 and 1994. Numbers in parentheses represent fish group ranks. SSC: small Scaridae; LSC: large Scaridae; ACN: Acanthuridae; HAM: Haemulidae; HOL: Holocentridae; LUT: Lutjanidae; SSR: small Serranidae; LSR: large Serranidae; MUL: Mullidae; CAR: Carangidae; BAL: Balistidae and Monacanthidae; TET: other tetraodontiformes; MIX: miscellaneous

| Family code | 1.25 inch mesh fishtraps | | | | | | 1.5 inch mesh fishtraps | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 (n = 590) | | 1991 (n = 207) | | 1994 (n = 367) | | 1991 (n = 176) | | 1994 (n = 444) | |
| | kg | Rank | kg | Rank | kg | Rank | kg | Rank | kg | Rank |
| SSC | 0.22 | (1) | 0.24 | (1) | 0.36 | (1) | 0.20 | (1) | 0.05 | (6) |
| LSC | 0.06 | (5) | 0.03 | (6) | 0.03 | (9) | 0.09 | (4) | 0.10 | (4) |
| ACN | 0.12 | (2) | 0.10 | (2) | 0.11 | (3) | 0.16 | (2) | 0.44 | (1) |
| HAM | 0.04 | (9) | 0.04 | (5) | 0.05 | (8) | 0.05 | (6) | 0.24 | (2) |
| HOL | 0.07 | (3) | 0.03 | (7) | 0.08 | (4) | 0.02 | (9) | 0.03 | (7) |
| LUT | 0.03 | (10) | 0.02 | (9) | 0.11 | (2) | 0.16 | (3) | 0.14 | (3) |
| SSR | 0.02 | (12) | 0.05 | (4) | 0.06 | (6) | 0.00 | (11) | 0.01 | (11) |
| LSR | 0.04 | (7) | 0.00 | (13) | 0.00 | (13) | 0.00 | (13) | 0.00 | (13) |
| MUL | 0.06 | (6) | 0.02 | (8) | 0.06 | (5) | 0.01 | (10) | 0.01 | (12) |
| CAR | 0.00 | (13) | 0.00 | (12) | 0.02 | (11) | 0.05 | (5) | 0.07 | (5) |
| BAL | 0.03 | (11) | 0.01 | (10) | 0.02 | (10) | 0.03 | (8) | 0.03 | (9) |
| TET | 0.07 | (4) | 0.00 | (11) | 0.02 | (12) | 0.00 | (12) | 0.02 | (10) |
| MIX | 0.04 | (8) | 0.05 | (3) | 0.06 | (7) | 0.05 | (7) | 0.03 | (8) |

(a) Percent change between 1990 and 1991
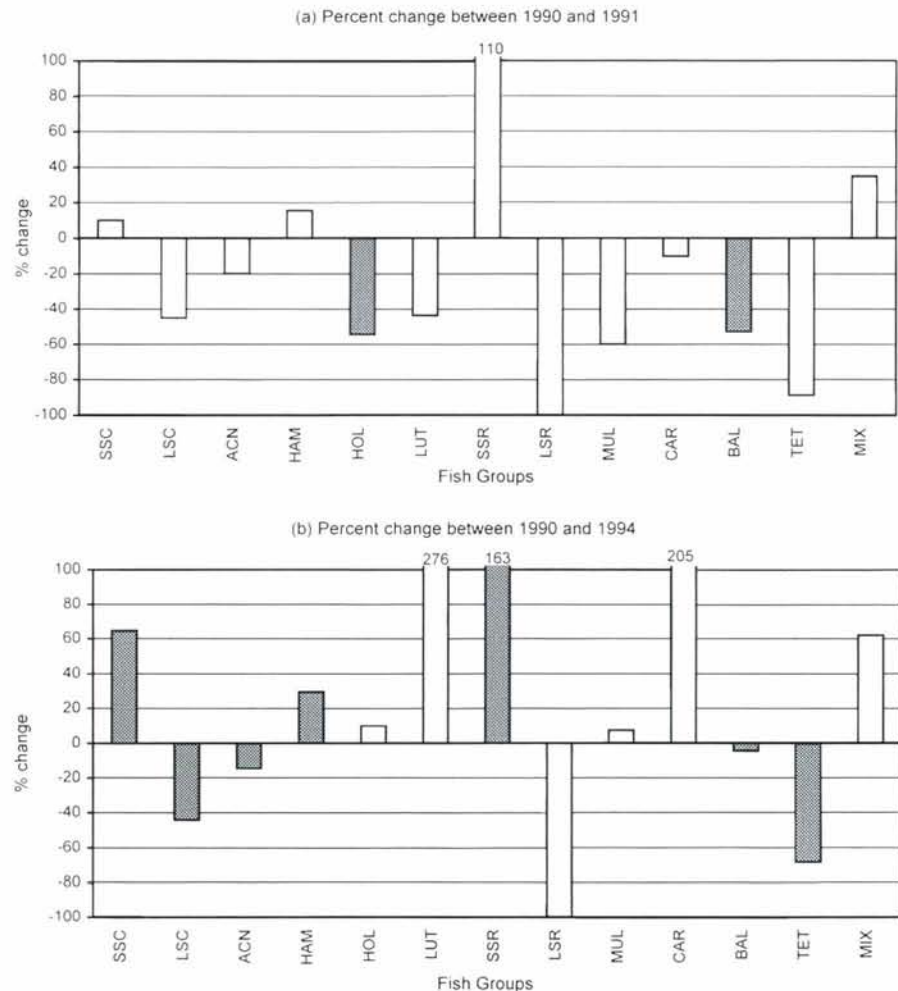
(b) Percent change between 1990 and 1994

Fig. 2. Percent change in catch composition (as mean kg per trap per haul for each fish group) of 1.25 inch mesh fishtraps in the Discovery Bay trap fishery (a) between 1990 (July to December) and 1991 (July to December), and (b) between 1990 (July to December) and 1994 (July to December). Shading indicates significant changes (Mann-Whitney tests, p < 0.05). SSC: small Scaridae; LSC: large Scaridae; ACN: Acanthuridae; HAM: Haemulidae; HOL: Holocentridae; LUT: Lutjanidae; SSR: small Serranidae; LSR: large Serranidae; MUL: Mullidae; CAR: Carangidae; BAL: Balistidae and Monacanthidae; TET: other tetraodontiformes; MIX: miscellaneous

0.037; for LSC, $U = 6808$, n = 217, p = 0.025; for ACN, $U = 7250$, n = 217, p = 0.002).

### 1.5 inch mesh fishtraps

The mean catch composition of 620 traps of 1.5 inch mesh (as kg per trap per haul by family groups) in 1991 and 1994 is given in Table 4. Catch composition differed significantly between the 2 years (Pearson 2 × 13 chi-square contingency test: $\chi^2 = 327.9$, p < 0.001). Over all years, ACN, LUT, SSC, and HAM were the most important groups (Table 4). However, their relative importance (as shown by rank in Table 4) varied between years.

The percent difference in catch per haul of each fish group between 1991 and 1994 is shown in Fig. 3. Most groups (9 of the 13) showed increases in relative abundance (Fig. 3). However, only for ACN was the increase significant (Mann-Whitney test: $U = 1324$, n = 131, p = 0.017). The group SSC was the only one showing a significant decrease (Mann-Whitney test: $U = 2226$, n = 131, p = 0.015).

### Changes in individual fish weight

Mean individual fish weight in 1.25 inch mesh traps in 1990, 1991 and 1994 is given in Table 5. Individual fish weight showed no significant variation among years (Kruskal-Wallis test: $H = 3.39$, n = 288, p = 0.183).

Mean individual fish weight in 1.5 inch mesh traps in 1991 and 1994 is given in Table 5. Individual fish weight was significantly higher in 1991 than in 1994 (Mann-Whitney test: $U = 2412$, n = 132, p = 0.022).

Table 5. Mean weight (kg) of individual fish taken by 1.25 inch mesh fishtraps and by 1.5 inch mesh fishtraps in the Discovery Bay trap fishery from July to December in 1990, 1991 and 1994. n: number of traps sampled

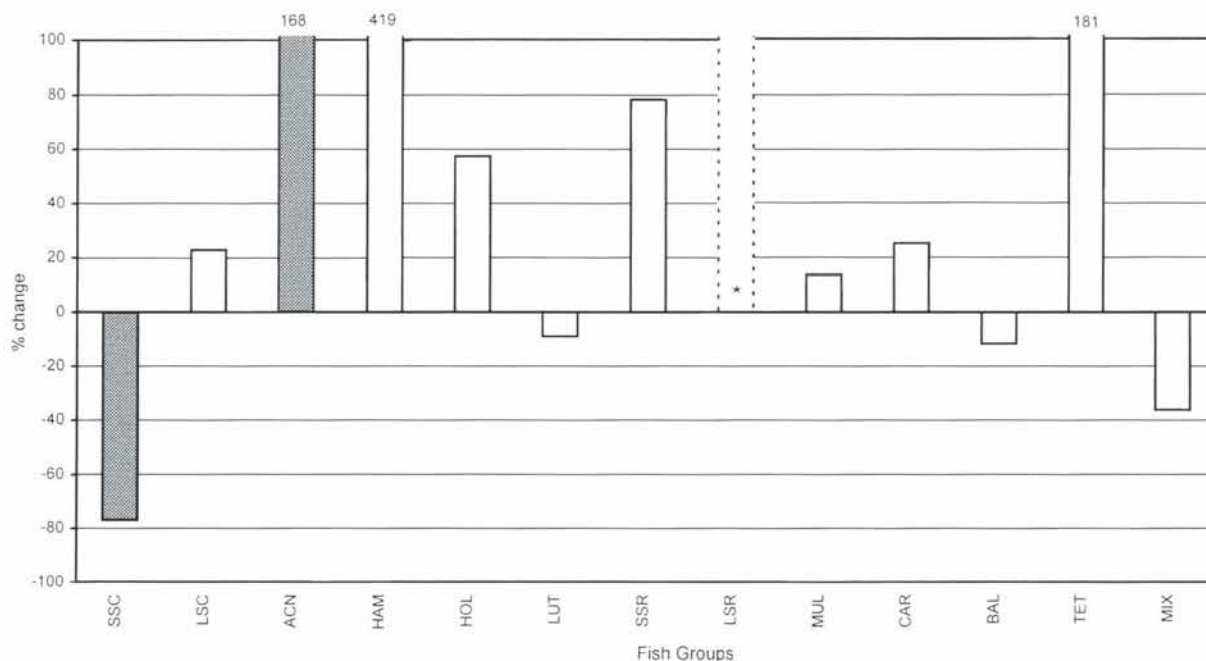| Year | 1.25 inch mesh fishtraps | | 1.5 inch mesh fishtraps | |
|------|------|------|------|------|
| | n | kg | n | kg |
| 1990 | 712 | 0.12 | | |
| 1991 | 218 | 0.13 | 189 | 0.24 |
| 1994 | 367 | 0.12 | 444 | 0.20 |

Fig. 3. Percent change in catch composition (as mean kg per trap per haul for each fish group) of 1.5 inch mesh fishtraps in the Discovery Bay trap fishery between 1991 (July to December) and 1994 (July to December). Shading indicates significant changes (Mann-Whitney tests, p < 0.05). Abbreviations as in Fig. 2. (*) % change is infinite (i.e. from 0 to 0.01 kg trap$^{-1}$ haul$^{-1}$, but not significant

## Changes in length-frequency distribution of 2 common species

### Redband parrotfish

Mean lengths of 1952 redband parrotfish taken by 1.25 inch mesh traps in 1990, 1991, 1992 and 1994 are given in Table 6 and the length-frequency distributions are given in Fig. 4a. Mean lengths showed significant differences among years (ANOVA: $F = 49.556$, n = 1952, p < 0.001). Results of Tukey's multiple range test showed that mean sizes in 1990 and 1991 were similar to one another, but significantly smaller than the mean sizes in 1992 and 1994 (Table 6, Fig. 4a).

Mean lengths of 181 redband parrotfish taken by 1.5 inch mesh traps in 1991, 1992 and 1994 are given in Table 6 and the length-frequency distributions are given in Fig. 4b. Mean lengths showed significant differences between years (ANOVA: $F = 5.365$, n = 181, p < 0.001). Results of Tukey's multiple range test showed that mean lengths in 1991 and 1994 are similar and significantly smaller than the mean size in 1992 (Table 6, Fig. 4b).

### Ocean surgeon

Mean lengths of 995 ocean surgeon taken by 1.25 inch mesh traps in 1990, 1991, 1992 and 1994 are given in Table 7 and the length-frequency distributions are given in Fig. 5a. Mean lengths showed significant differences between years (ANOVA: $F = 6.136$, n = 995, p < 0.001). Results of Tukey's multiple range test showed that mean sizes in 1990, 1991 and 1994 are similar and significantly larger than the mean size in 1992 (Table 7, Fig. 5a).

Mean lengths of 1414 ocean surgeons caught in 1.5 inch mesh traps in 1991, 1992 and 1994 are given in Table 7 and the length-frequency distributions are

Table 6. *Sparisoma aurofrenatum*. Mean size [fork length (FL) in mm] of redband parrotfish caught in 1.25 inch and 1.5 inch mesh fishtraps from July to December in 1990, 1991, 1992 and 1994. n: number of fish in sample; *in same column indicates no significant difference between years (Tukey's multiple range test, p > 0.05)

| Year | 1.25 inch mesh fishtraps | | | 1.5 inch mesh fishtraps | | |
|------|------|--------|---------|------|--------|---------|
|      | n    | FL(mm) | (SD)    | n    | FL(mm) | (SD)    |
| 1990 | 484  | 161.4  | (14.66)* | 0    | –      | –       |
| 1991 | 211  | 161.9  | (13.07)* | 79   | 178.8  | (15.82)* |
| 1992 | 216  | 172.5  | (15.28) * | 50   | 188.1  | (15.66) |
| 1994 | 1041 | 170.0  | (16.81) * | 52   | 177.5  | (22.74)* |

given in Fig. 5b. Mean lengths showed significant differences between years (ANOVA: $F = 27.903$, n = 1414, p < 0.001). Results of Tukey's multiple range test showed that mean sizes in 1991 and 1994 are similar and significantly larger than the mean size in 1992 (Table 7, Fig. 5b).

## DISCUSSION

### Reduction in fishing pressure

The north coast of Jamaica is considered one of the most overfished reef areas in the Caribbean (Government of Jamaica 1994, Hughes 1994) primarily because of the heavy fishing pressure exerted on juvenile fish by a large number of small mesh traps fishing along the narrow island shelf (Sandeman & Woodley 1994). This study observed the effects of reducing fishing pressure on the overexploited reef fish community at Discovery Bay, on the north coast of Jamaica, by increasing the average trap mesh size in the trap fishery there.

Although the total number of active traps and the total number of hauls per month did not significantly change in the Discovery Bay fishery during the study period (1990 to 1994), the proportion of small mesh traps decreased substantially as a result of the Fisheries Improvement Project's mesh exchange program, implemented in 1991. Presumably, a concurrent reduction of fishing mortality in smaller fish occurred.
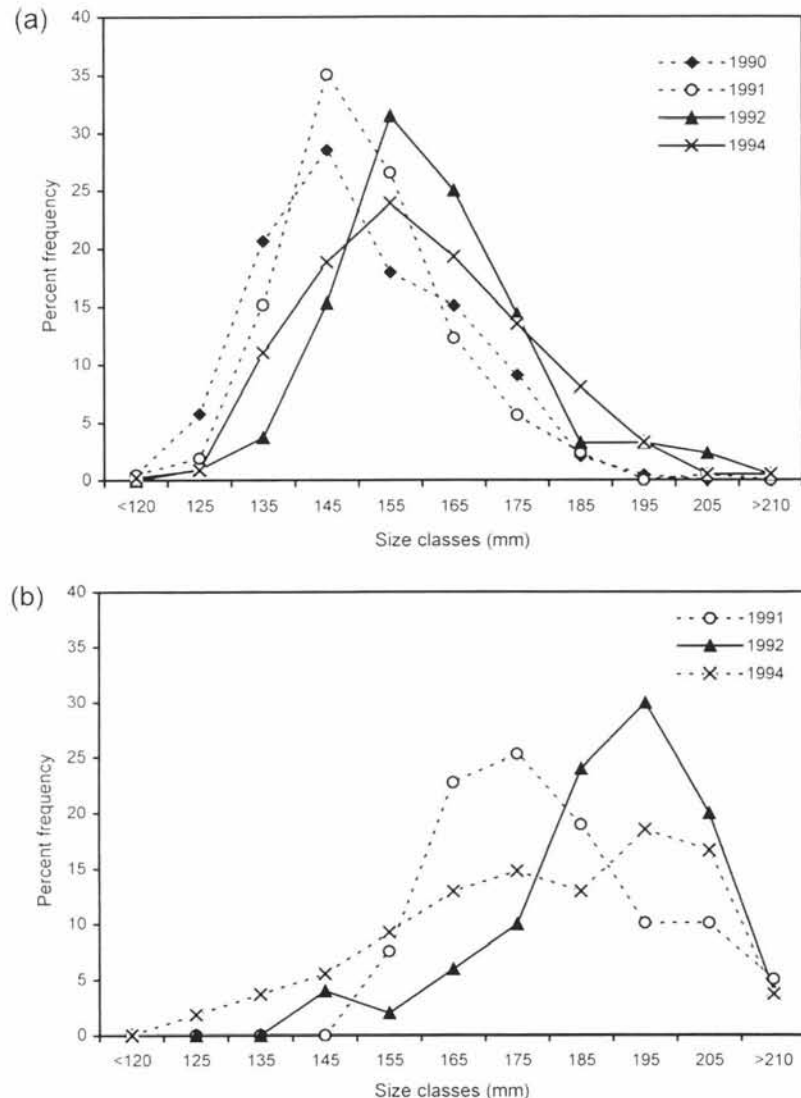


Fig. 4. *Sparisoma aurofrenatum.* Size frequency distribution of redband parrotfish from July to December in 1990, 1991, 1992 and 1994, caught in (a) 1.25 inch mesh fishtraps and (b) 1.5 inch mesh fishtraps. Same style lines (i.e. dashed or solid) indicate that means are not significantly different (ANOVA, p > 0.05)

Table 7. *Acanthurus bahianus.* Mean size [fork length (FL) in mm] of ocean surgeon caught in 1.25 inch and 1.5 inch mesh fishtraps from July to December in 1990, 1991, 1992 and 1994. n: number of fish in sample; *in same column indicates no significant differences between years (Tukey's multiple range test, p > 0.05)

| Year | 1.25 inch mesh fishtraps | | | 1.5 inch mesh fishtraps | | |
|------|------|------|------|------|------|------|
| | n | FL | (SD) | n | FL | (SD) |
| 1990 | 342 | 146.3 | (19.74)* | 0 | – | – |
| 1991 | 193 | 149.3 | (20.13)* | 239 | 155.5 | (17.41)* |
| 1992 | 164 | 141.3 | (18.23) | 326 | 149.8 | (16.14) |
| 1994 | 296 | 148.0 | (17.44)* | 849 | 157.8 | (16.38)* |

### Changes in CPUE and catch composition

The mesh exchange program appeared to have few significant short-term effects on fish populations at Discovery Bay, but some impact on trap catches in the fishery. During the period immediately after the implementation of the mesh exchange program, the catch per haul of small mesh (1.25 inch) traps dropped significantly in terms of weight (−24%), but not numbers. This short-term drop in catches appears to have resulted from many fish groups with large and deep-bodied species (e.g. ACN, LSC, LUT) being reduced in the catches of the small mesh traps after the large mesh (1.5 inch) was introduced in the fishery. This
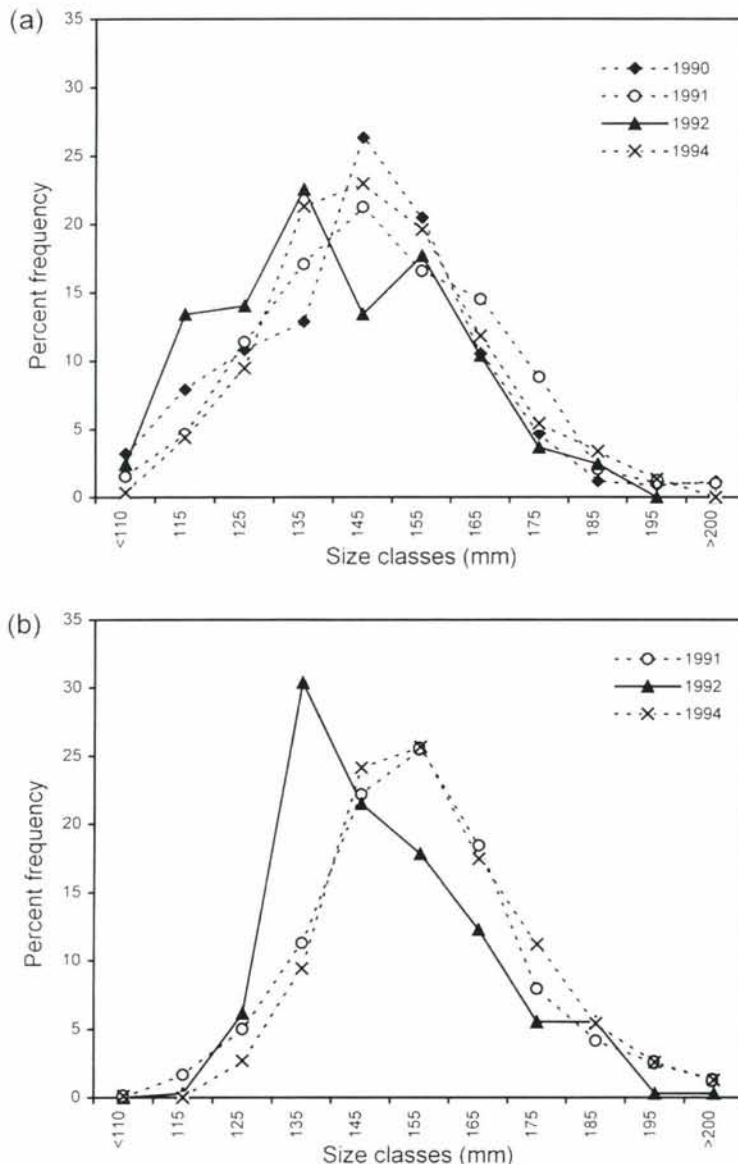
Fig. 5. *Acanthurus bahianus*. Size frequency distribution of ocean sur-
geon from July to December in 1990, 1991, 1992 and 1994, caught in
(a) 1.25 inch mesh fishtraps and (b) 1.5 inch mesh fishtraps. Same style
lines (i.e. dashed or solid) indicate that means are not significantly differ-
ent (ANOVA, p > 0.05)

some species, that the fishing power of traps
decreases with increasing mesh size (Hunte
& Mahon 1994).

However, despite the possible higher se-
lectivity of the large mesh traps for certain
species compared with small mesh traps,
the overall catch rate (catch per week) of
large mesh traps was lower (0.97 kg or
4.7 fish per week) than small mesh traps
(1.2 kg or 10.4 fish per week) immediately
after the implementation of the mesh ex-
change program, since mean soak time for
large mesh traps (6 d) was significantly
greater than for small mesh traps (3.5 d).
This result is consistent with previous field
studies which have compared catch rates of
traps of different mesh sizes fished concur-
rently in the same area, and have reported
substantially lower catch rates for the larger
mesh traps (Hunte & Mahon 1994). Further-
more, gross catch per week for the trap fish-
ery was greatly reduced (from 553 kg to
345 kg per week) immediately after the
mesh exchange due to removal of the more
efficient small mesh traps.

Long-term effects of the mesh exchange
program on fish populations were more pro-
nounced. Catches per haul (as kg per trap
per haul and as fish per trap per haul) were
significantly higher in the trap fishery 3 yr
after the implementation of the mesh
exchange program than either before or
immediately after. For example, small mesh
traps had a mean catch per haul that was
significantly higher, 23% by weight and
42% by number, in 1994 than in 1990
(before the implementation of the larger
mesh program). Large mesh traps also had
an increased catch per haul in the 3 yr since
they were introduced, in both weight and
number of fish, but only the increase in
number was significant.

Overall catch rates (catch per week) of
small mesh (1.25 inch) and large mesh
(1.5 inch) traps had both increased substantially by
1994. Although the catch rate of large mesh traps re-
mained considerably less (1.7 kg or 10.4 fish per week)
than that of small mesh traps (2.6 kg or 22.6 fish per
week), it was about the same (by weight) as small
mesh traps had been in 1990, before the mesh ex-
change. That increase, coupled with the increased
catches by the remaining 1.25 inch traps, ensured that
the overall catch per week in 1994, 3 yr after the mesh
exchange, exceeded that in 1990. However, fishers still
using small mesh traps are benefitting from the recov-

short-term change in catches was not likely to be
caused by changes in the fish population, but perhaps
reflects a higher selectivity of large mesh traps than
small mesh ones for the large and deep-bodied fish, so
that the introduction of the larger mesh traps actually
caused a short-term decrease in the catch of the small
mesh traps. The varying selectivity of the 2 mesh sizes
may have been further enhanced by fishers deliber-
ately targeting large fish with large mesh traps using
different trap location, depth, and bait. This result
appears to contradict earlier suggestions, at least for

ery of reef fish populations more than those fishers using large mesh traps. This demonstrates the need for further efforts to eliminate the smaller mesh traps from the fishery, if the full benefits of the mesh exchange are to be realised.

The increased number of fish caught by large mesh traps presumably resulted from an increased abundance of larger fish. This suggests that the reduction in the number of small mesh traps allowed a higher proportion of small fish to avoid capture and to grow large enough to be caught by large mesh traps.

Similarly, the increase in the number of fish caught by small mesh traps suggests an increase in the abundance of small fish. This could be due to a reduction in recruitment overfishing, with at least some species being allowed to grow larger and thus contribute more to the spawning biomass of the population, which could in turn have resulted in increased numbers of juvenile settlers to the reef and subsequently to improved recruitment to the fishery. However, 3 yr is probably too short a time for all this to have occurred in many of the commercially important species (e.g. snappers, groupers and grunts) since several years may elapse between larval settlement and recruitment to the fishery (see Munro 1983, Thresher 1984, Richards & Lindeman 1987, Roberts 1996, and Sadovy 1996 for reviews of reef fish growth, reproduction and recruitment). An increased number of small fish may also have resulted from greater conspecific attraction of juveniles by an increased number of resident adults. Note however that studies on effects of resident adult fish abundance on the settlement rates of conspecific juveniles have produced contradictory results (see Sale 1976, Williams 1980, Doherty 1983, Shulman 1985, Sweatman 1985, Jones 1987a, b, Stimson 1990, Forrester 1995). Alternatively, given that there were fewer small mesh traps, the increase in the number of fish per haul of the small mesh traps in Discovery Bay could have resulted from a reduction in gear competition.

The increase in mean weight of the catch per haul of both trap types, 3 yr after the implementation of the mesh exchange program, resulted from traps catching more fish and not from either trap type catching larger fish. In fact, the mean size of individual fish in small mesh traps did not change over the period of study, whilst in large mesh traps it actually dropped by 17%. A reduction in the mean size of fish caught may be expected in a growing population, with increased numbers of young fish growing large enough to be caught by the large mesh traps. The fact that mean size of fish in large mesh traps remained considerably larger than in small mesh traps, both immediately after (85% larger) and 3 yr after the mesh exchange program (67% larger), is consistent with the findings of previous studies which have addressed mesh selectivity directly

and reported that larger mesh traps target larger fish (Bohnsack et al. 1989, Rosario & Sadovy 1991).

The community structure of fish vulnerable to fish traps in Discovery Bay appeared to undergo few short-term changes as a result of the implementation of the mesh exchange program, as indicated by the catch composition of small mesh traps in 1990 and 1991. For example, the 2 family groups accounting for the majority of the catch weight of small mesh traps in 1990 (SSC: 27%; ACN: 15%), remained similarly important in 1991 (SSC: 39%; ACN: 15%).

However, the species composition of catches by large mesh traps in 1991, immediately after their introduction, differed slightly from that of small mesh traps in 1991, with 3 groups accounting for the majority of the catch weight (SSC: 23%, ACN: 19% and LUT: 19%). This is not surprising given the expected differences in size (and thus species) selectivity of different mesh sizes. It is also consistent with previous comparative fishing experiments which have demonstrated that the species composition of the catch may change substantially with changes in mesh size, primarily due to size selectivity, such that smaller species contribute proportionately less to the catch as mesh size increases (Hunte & Mahon 1994).

Long-term changes in catch composition at Discovery Bay were more marked than the short-term changes, with the catch composition of both mesh size traps shifting towards larger species groups 3 yr after the implementation of the mesh exchange. For example, in the small mesh traps, LUT replaced ACN as the second most important group by weight, while the groups SSC, HAM, SSR and MIX also showed significant increases. In the large mesh traps ACN, HAM, and LUT became the 3 most important groups. The long-term shifts in species composition observed since the mesh exchange may therefore indicate an increased availability of larger and deeper-bodied fish to traps, perhaps due to a shift in community structure. Note that the results of earlier studies comparing the species composition of catches of different mesh size traps fished concurrently during relatively short study periods (e.g. Bohnsack et al. 1989, Rosario & Sadovy 1991) were likely to have been biased by species availability, since sampled populations would not have been in equilibrium with the larger mesh sizes used in these experiments, and therefore it has been suggested that an even higher proportion of large species be expected at equilibrium than was found in these studies (Hunte & Mahon 1994).

In both trap types, there were long-term increases in CPUE of several groups of carnivorous fish [e.g. jacks (CAR), SSR, and HAM]. However the CPUE of herbivorous fish (e.g. SSC, LSC and ACN) did not increase in both trap types. This suggests that all size classes of some carnivorous fish increased in abundance more,

as a result of the reduction in fishing pressure at Discovery Bay brought about by the mesh exchange program, than did herbivorous fish. Interestingly, decreases in the abundance of piscivorous species have proved to be the most readily detectable effect of increased fishing pressure (e.g. Koslow et al. 1988, Luchavez & Alcala 1988, Russ & Alcala 1994, Jennings & Polunin 1996) whilst large increases in the abundance of carnivorous fish are the first sign of reduced fishing pressure, especially in reserves (e.g. Russ 1985, Alcala 1988, White 1988, Polunin & Roberts 1993, Watson & Ormond 1994, Russ & Alcala 1996).

The results presented here suggest that the changes observed in catch per haul, catch per week, size of individual fish, and species composition in the Discovery Bay trap fishery 3 yr after the implementation of the mesh exchange program reflect changes in the reef fish populations.

## Changes in population size structure

In order to focus better on the observed changes in fish size, the mean sizes and length-frequency distribution of the 2 most common species in trap catches, the redband parrotfish *Sparisoma aurofrenatum* and the ocean surgeon *Acanthurus bahianus*, were examined for changes resulting from the introduction of the larger mesh into the fishery. The 2 species differ in body shape and life history characteristics, and therefore are expected to respond differently to a mesh size change (Munro 1983, Ward 1988, Hunte & Mahon 1994).

### Redband parrotfish

Redband parrotfish caught in small mesh traps 1 yr and 3 yr after the implementation of the mesh exchange program were significantly larger those caught before and immediately after the implementation of the program. Since the results were obtained from traps of a single mesh size over time, the change in mean size was not due to a change in the size selectivity of the mesh, but appears to represent a shift in the redband parrotfish population toward larger size classes. The pattern of change was similar in the large mesh traps, except that sample sizes were much smaller.

The rapid response of the redband parrotfish population to a change in mesh size is probably a consequence of its narrow, rounded, soft body and ability to squeeze through a mesh (see Ward 1988), resulting in a steeper gear selection curve. This would allow the population to benefit (through a reduction in fishing mortality on small sizes) even from a small increase in the mean mesh size of traps.

### Ocean surgeon

The mean size of ocean surgeon in small mesh traps, on the other hand, was not significantly different in periods before, immediately after and 3 yr after the implementation of the mesh exchange program, and was in fact significantly lower 1 yr after the program was implemented. The pattern was also similar in the large mesh traps. Thus, this deep-bodied species did not appear to benefit, in terms of an increase in mean size, from the increase in mesh size. The decrease in mean size of the ocean surgeon 1 yr after the implementation of the mesh exchange program appears to support the argument that fishing mortality may increase on larger (or deep-bodied) fish after a mesh size increase, if for example fishers alter their fishing behaviour in an attempt to compensate for short-term losses (Hunte & Mahon 1994). Nevertheless, during the same time period, the weight per haul of all ACN has significantly increased in trap catches, thus the number of ACN available to the fishery appears to have increased, even if the mean size of individuals has not.

## Problems with a single sample

This study has documented a number of changes in the reef fish populations at Discovery Bay, as reflected in trap catches over the 3 yr following the mesh exchange program. However, one must consider the possibility that factors other than the changes in fishing gear were responsible.

For example, the carrying capacity of the coral reefs for reef fish may have increased significantly during the 4 yr study period. It is true that their carrying capacity declined significantly in the 1980s due to a loss of 3-dimensional complexity following outbreaks of coral disease and the passing of 2 major hurricanes. Moreover, the structural complexity is not regenerating as a result of a decrease in herbivory due to the mass mortality of *Diadema antillarum*, and to fishing, which has allowed algae to predominate on the reefs, in what some researchers are calling a new stable state (Liddell & Ohlhorst 1993, Hughes 1994). We have observed no major change that would have caused an increased carrying capacity between 1990 and 1994. Furthermore, even if reef carrying capacity had improved, it is unlikely to have resulted in increased abundance of reef fish populations that are severely depressed through overexploitation.

Secondly, the fishing pressure from other gear might have decreased at Discovery Bay since the mesh exchange program was implemented. Casual observation and fisher interviews do not indicate that to be the

case; indeed, it has more likely increased. It is known, for example, that several spearfishers in Discovery Bay have improved their efficiency over the last 3 yr by employing gill nets to encircle schools of fish to prevent their escape. These efficient, shallow water 'drive-net' operations target the same fish stocks as traps. Therefore, the observed changes in reef fish populations and in the fishtrap catches occurred despite the continually poor state of reefs and the high fishing effort by other gears in Discovery Bay.

Thirdly, there may have been spontaneous increases in fish populations, part of the real but unexplained variability in recruitment and survival due to weather and other variables. In principle, monitoring catch data at a nearby control site with an overexploited trap fishery, with similar additional fishing pressure, and no mesh size change, over the 4 year period may have allowed better interpretation of the observed changes. However, the extra cost and effort that this would have involved was deemed prohibitive, especially given the difficulties of finding a control site to meet the specific criteria. Furthermore, it was felt that entering into the confidence of a second nearby fishing community without encouraging a mesh size increase there would have seriously compromised the trust between the researchers and fishers in the Discovery Bay community.

It is desirable to follow a rigid experimental design in fishery management projects so that the results of monitoring programs can be validated and confident conclusions drawn (McAllister & Peterman 1992). This is not always possible, yet for reef ecosystems, such as at Discovery Bay, which are believed to be in a critical state near collapse, the urgency of action is so great that local management measures to reduce the degree of overexploitation must be implemented before detailed scientific assessment is performed (Wilkinson 1992). Nonetheless, if existing procedures for the collection of catch and effort data were refined, and observed combinations of gear, effort and catch composition were treated as a series of experimental manipulations, we could begin to elucidate the strategies which have produced desirable yields or shifts (Jennings & Polunin 1996). The Fisheries Improvement Project's mesh exchange program was one such attempt.

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