A Fishery-Independent Assessment of Bermuda's Coral Reef Fish Stocks by Diver Census Following the Fish Pot Ban - A Progress Report

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ABSTRACT

Bermuda imposed a fish pot ban in April 1990. Beginning in June 1991, a series of monthly visual census samples were taken of the reef fish assemblages at each of four stations distributed around the perimeter of the Bermuda reef platform. The study utilized the Bohnsack and Bannerot method, a stationary diver census technique, in a repeated measures design to assess changes in abundance in key species as well as in fish community structure. A total of 69 species in 24 families have been recorded to date with the parrotfishes (Scaridae) generally dominating the assemblages in terms of species richness and in biomass. Statistical power analysis indicated that mean abundance of four selected parrotfish species was estimated at an acceptable level of accuracy. Comparisons of abundance estimates between the first and second year of the study for the selected parrotfish species indicated that there were relatively small differences in abundance. However, a comparison of the second and third year revealed that the mean abundance of three of these four species had increased significantly in the third year.

KEYWORDS: Abundance, Bermuda, Scaridae, *Scarus*, *Sparisoma*, Visual Census.

INTRODUCTION

After a number of years of intensive fishing pressure on the Bermuda reef platform and the offshore banks, a fish pot ban was imposed in April 1990 in response to significant declines in a variety of reef fish species (Butler *et al.*, 1993; Luckhurst and Ward, in press) which were being harvested with this gear type. The ban was imposed for an indefinite period with the objective of allowing these stocks of coral reef fishes to recover from this fishing pressure. Fish pots, which are largely non-selective in terms of the species caught, were believed to have been the principal cause of depleted stock levels of a range of reef fish species including carnivores, omnivores and herbivores. The two most important families of herbivores are the parrotfishes (Scaridae) and surgeonfishes (Acanthuridae). They are generally considered to be the most significant groups of fish grazers on coral reef algae (Choat, 1991). When grazing pressure is reduced by declining abundance of these species, ecological consequences may be considerable. As algal growth increases on the reef, it inhibits the settlement of coral larvae thus reducing the growth potential of hermatypic corals. It may also influence overall benthic community structure (Lewis, 1986).

Parrotfishes were taken in large numbers by fish pots before the ban (reported landings for the three years preceeding the ban, 1987-89 were approximately 92,300 Kg, 73,400 Kg and 55,000 Kg respectively). They often comprised the single largest category in fish pot catches on the reef platform (Luckhurst and Ward, in press). As a consequence, parrotfishes are an important focus of this study and are the specific subject of this paper. Data are presented for the four most abundant parrotfish species to examine their abundance patterns over the first 31 months of the study to determine if there is evidence of recovery of these stocks in the absence of fishing mortality with fish pots.

It was considered necessary to monitor stock levels for a minimum of three annual cycles to determine if there were seasonal as well as longer term changes in abundance estimates. The original research proposal recommended the concurrent use of fish pots and a fishery-independent method of assessing abundance of stocks (*i.e.* diver census). However, the socio-political climate in the wake of the fish pot ban was considered to be unsuitable for using fish pots even for research purposes and, as a consequence, this component was omitted.

The fish census method employed for this study has been used for monitoring long term changes in fish populations and community structure in Biscayne National Park, Florida (Bohnsack *et al.*, 1992) and in the U.S. Virgin Islands where the effects of Hurricane Hugo on reef fish populations were documented (Beets, 1993). Sedberry *et al.* (in press) utilized this method to make comparisons of fish communities between protected and unprotected areas of the Belize reef ecosystem in order to evaluate the effects of marine sanctuary designation.

METHODOLOGY

The method used in this study is a stationary sampling diver census technique (Bohnsack and Bannerot, 1986). This method was selected over other visual census methods because it is objective (the same protocol is used in collecting every sample) and it is repeatable so that relatively large sample sizes can be accumulated for statistical analysis. The method provides quantitative data on frequency of occurrence, abundance, fish size estimates and community composition. Furthermore, a diver census technique allows the collection of data on species which are not vulnerable to being caught in fish pots as well as observations on the presence and abundance of post-larval recruits and juvenile fishes which swim through the mesh of a trap without being captured. For purposes of assessment, the technique does not provide specimens in hand to examine. However, supplementary collecting of specimens can help to validate field size estimates and to verify observational data. The lack of specimens is compensated for by the fact that high levels of consistency can be achieved by experienced divers using this technique.

This stationary sampling technique differs from most other commonly used fish census methods because the diver does not swim along a transect line recording fish within a defined distance from the line or move in a random manner over the reef listing species as they are encountered. This has two advantages: first, a stationary diver is better able to concentrate on data collection and to keep track of fish moving in and out of the area and second, less air is consumed by a stationary diver making this a more efficient method of data collection per unit of bottom time.

At the beginning of the study, four sampling sites were chosen to ensure broad geographical coverage of the Bermuda reef platform. The sites are: 1) east of North Rock 2) outside Western Blue Cut 3) west of Southwest Breaker and 4) outside John Smith's Bay (Figure 1). These sites are all seaward of the line of breaking reefs around the platform and each site is a large patch of relatively homogeneous reef habitat. All sampling sites were a minimum of 10,000 m ' in area. The depth range for each site is the same (9 - 12 m). This relatively shallow depth range allows adequate bottom time for divers to conduct their sampling and permits repetitive dives to complete the required number of samples. Monthly sampling is conducted at each site with the four sites being completed in the shortest time period that sea conditions will allow (ideally four consecutive days). During the first year of the study, a total of 10 samples (censuses) per site were taken by two divers (the author and a second observer) doing two dives each in a day. All censuses were conducted between 1000 and 1500 hours. Starting at the beginning of the second year, the total was reduced to eight samples taken by one diver (the author) in two consecutive dives.

An abbreviated outline of the sampling methodology follows: at each randomly selected point within the habitat patch the diver estimates a radius of 7.5 m (24 ft) to give the perimeter of an imaginary cylinder extending from the reef substrate to the surface. The radius is initially verified with a tape measure carried by the diver. Each sample begins by listing all species observed in the section of the cylinder within the field of view. The diver rotates in one direction scanning the imaginary cylinder and listing each new species as it is encountered. Effort has been focused on diurnally active species which swim above or within the reef infrastructure and are amenable to this visual census technique. No attempt was made to systematically search for cryptic species or those with secretive behaviour. This scanning process continues for five minutes and typically includes a minimum of three complete rotations. Any species observed after this five minute period is not listed. No statistical data are recorded during this listing period with the exception of schools of fish moving through the cylinder. These are counted when first observed because they are unlikely to remain in the sampling area. Next the diver records statistical data

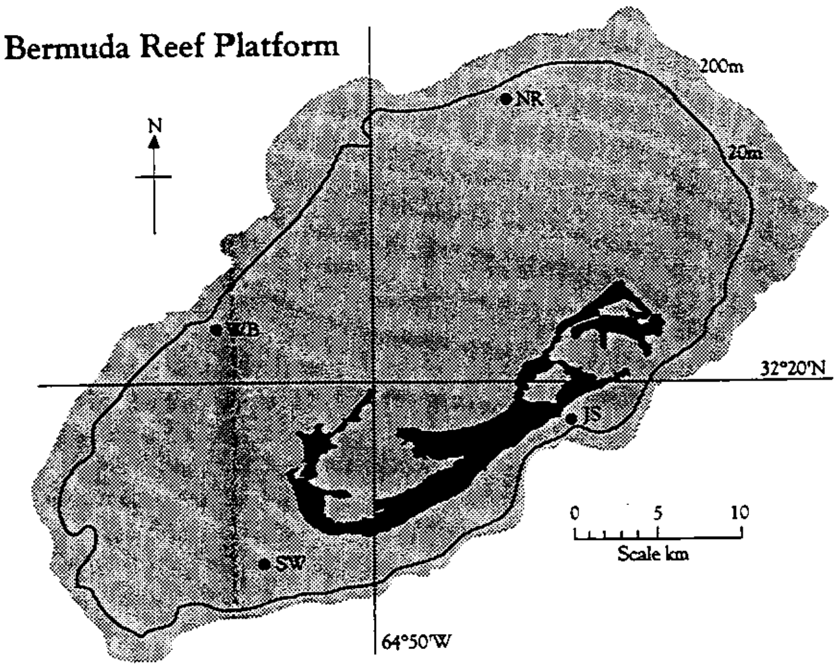

Figure 1. Location of study sites around the Bermuda reef platform. Station codes : NR - North Rock, WB - Western Blue Cut, SW - South West Breaker, JS - John Smith's Bay.

for each of the species listed in the initial sampling period. The estimated number of individuals and the minimum, maximum and average length of each observed species on the list is recorded. If only a small number of individuals are present then size estimates are recorded for each individual. In addition, the number of individuals of the terminal phase colouration of each species of parrotfish (which is always male) was also noted. Actual counts of each species were therefore made at random times following the initial listing period. The average census takes about 15 minutes to complete. Fish sizes are estimated as fork length to the nearest 1 cm. Data are recorded in pencil on waterproof plasticized paper attached to a plastic clipboard. These data are then input directly into a computer for analysis. In the 31 months that the program has been running, a total of 990 censuses have been conducted.

RESULTS and DISCUSSION

To date, 69 species in 24 families have been recorded. The parrotfishes and wrasses (Labridae) dominate the samples in terms of species richness (nine and eight species respectively) and the parrotfishes are the largest group in terms of biomass in the majority of samples. Conversion of length estimates to weight (Bohnsack and Harper, 1988) for the parrotfishes provides more accurate estimates of the biomass contribution of this ecologically significant group. Preliminary analysis of 10 randomly selected samples indicated that the biomass contribution of scarids ranged between approximately 37% and 68% of the total sample biomass. This analysis will be published separately.

STATISTICAL POWER ANALYSIS

As there are practical and logistical limitations to the number of samples which can be taken in a defined sampling period, it is necessary to determine what level of accuracy can be achieved in estimating abundance with a given sample size. I conducted an analysis of the accuracy of estimating the mean abundance of each of five species of parrotfish using the technique of Eckblad (1991). I employed the following equation to estimate accuracy at different sample sizes (N):

accuracy = (coefficient of variation) (t (.05) value of N) / (square root of N)

In order to estimate population level responses, I pooled the data from the four sites to examine the levels of accuracy achieved in estimating mean abundance in the first year of the study (N = 40 samples / month). When the number of samples was reduced at the beginning of the second year (N = 32 samples/month) due to operational constraints, I repeated the analysis to determine how the reduced sample size would affect the accuracy of the estimates of abundance. The analysis for the first year (Figure 2) revealed

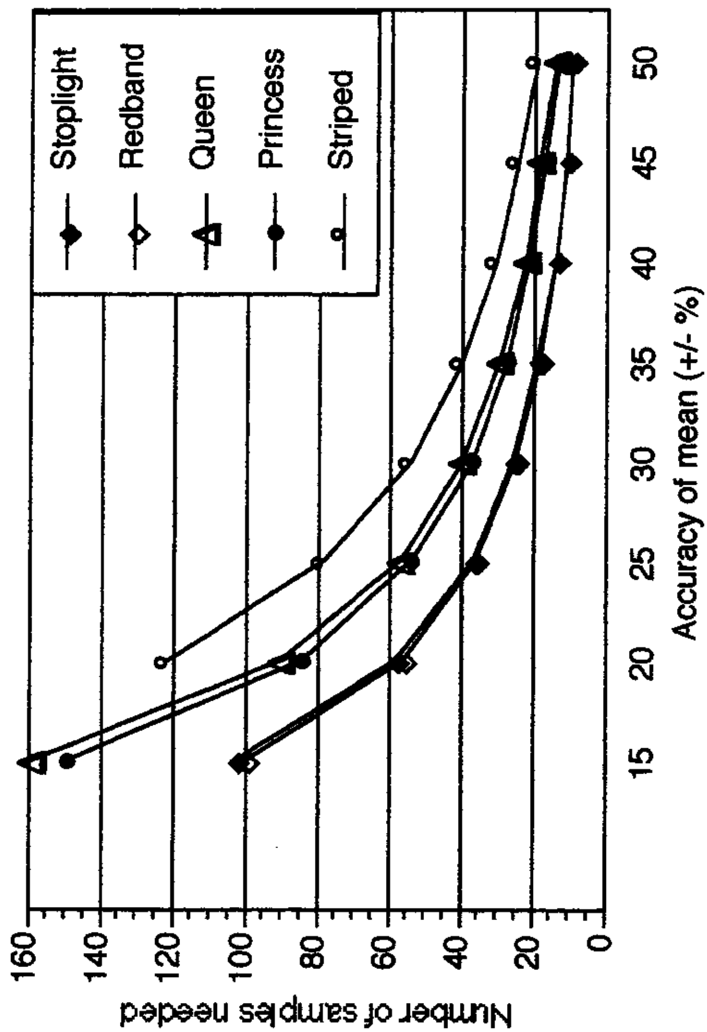

Figure 2. Power analysis for five species of parrotfish with total monthly sample size N = 40.

relatively similar levels of accuracy between species with the Stoplight (*Sparisoma viride*) and the Redband (*S. aurofrenatum*) parrotfishes exhibiting approximately +/- 24% accuracy of the mean. The Queen (Scarus vetula) and the Princess (*S. taeniopterus*) parrotfish estimates of abundance were ~ +/- 30% accurate while the Striped parrotfish (*S. iserti*) was determined to be ~ +/- 35% accurate. The same analysis for the second year (Figure 3) indicated some differences. The Redband and the Princess parrotfishes improved in accuracy to ~ 22% and ~ 26% respectively, while accuracy for the Queen and Stoplight parrotfishes declined slightly to ~ 33 % . The accuracy of the Striped parrotfish estimates of mean abundance declined to such a degree in the second year (Figure 3) that this species could no longer be used as an indicator species because the accuracy of the estimates became too unreliable for year over year comparisons to be made. This occurred because estimates of mean abundance declined and coefficients of variation increased in the second year samples (smaller N). The power analysis equation (above) is sensitive to such variations which results in greater inaccuracy in estimating mean abundance. The reason for the apparent decline in abundance in the second year is unknown.

PATTERNS OF ABUNDANCE

The mean abundance estimates have been plotted to compare means in the same month in each year. This was done to take into account any seasonal changes in abundance which might occur as a result of species movements into or out of the study areas. The data represent the mean abundance of all specimens of a given species equal to or greater than 10 cm fork length (FL). A separate analysis of post-larval recruits and juveniles in the 1 - 9 cm FL category is being conducted to examine seasonal patterns of recruitment and settlement. The Princess parrotfish appears to show the most significant signs of recovery over the study period (Figure 4). An examination of the graphs indicates that there is no clear difference in the first two years of the study but starting in the third year (June 1993) there is a steady increase until September which then appears to stabilize and to be maintained. Following an F_{max} test on the data for homogeneity of variances (Sokal and Rohlf, 1969), an analysis of variance (ANOVA) was conducted on the abundance data. The F_{max} value (1.813) was below the F critical value (2.36) thus indicating homogeneity of variances. The ANOVA analysis comparing abundance levels in the second year with those in the third indicated a significant difference ($F = 2.361$, $p = 0.0013$). This is with seven months data in the third year. It remains to be determined whether this trend will continue for the remaining five months of the year. A second analysis will be conducted at the completion of the third year before any conclusion about a sustained recovery may be drawn.

The abundance patterns for the Redband parrotfish (Figure 5) show strong similarity over most of the first two years. In the third year, there is a trend of

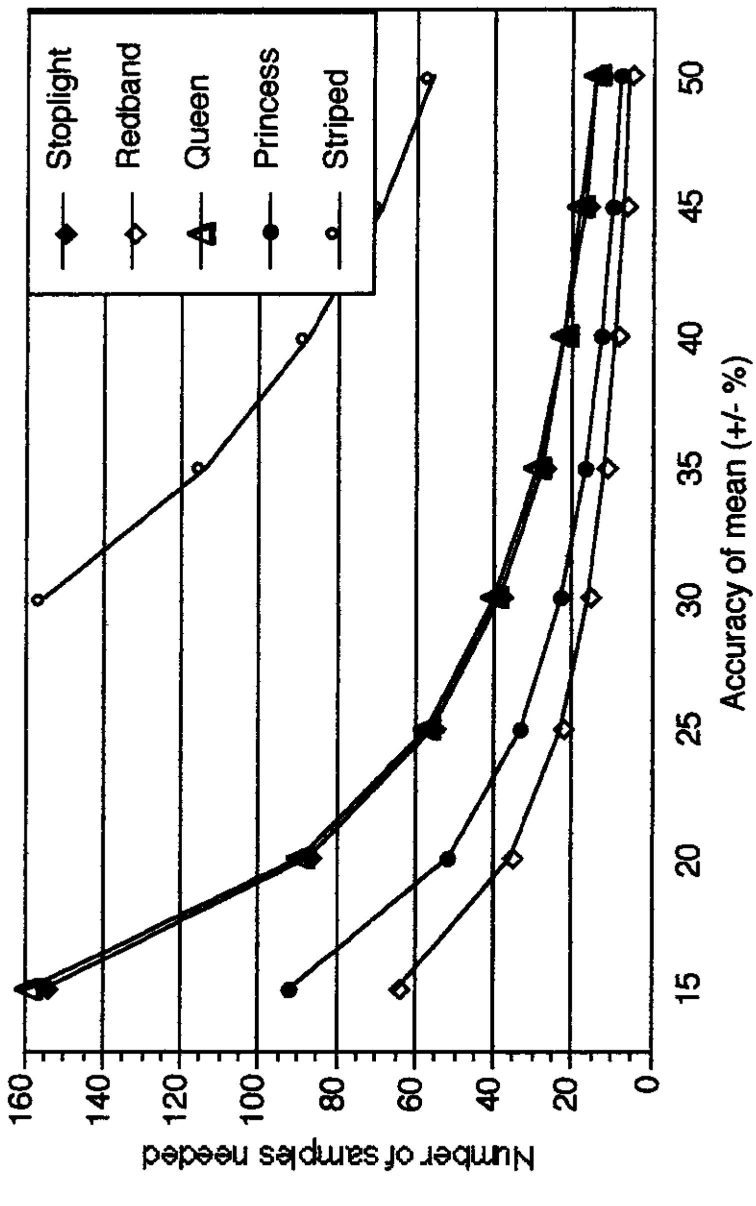

Figure 3. Power analysis for five species of parrotfish with total monthly sample size N = 32.

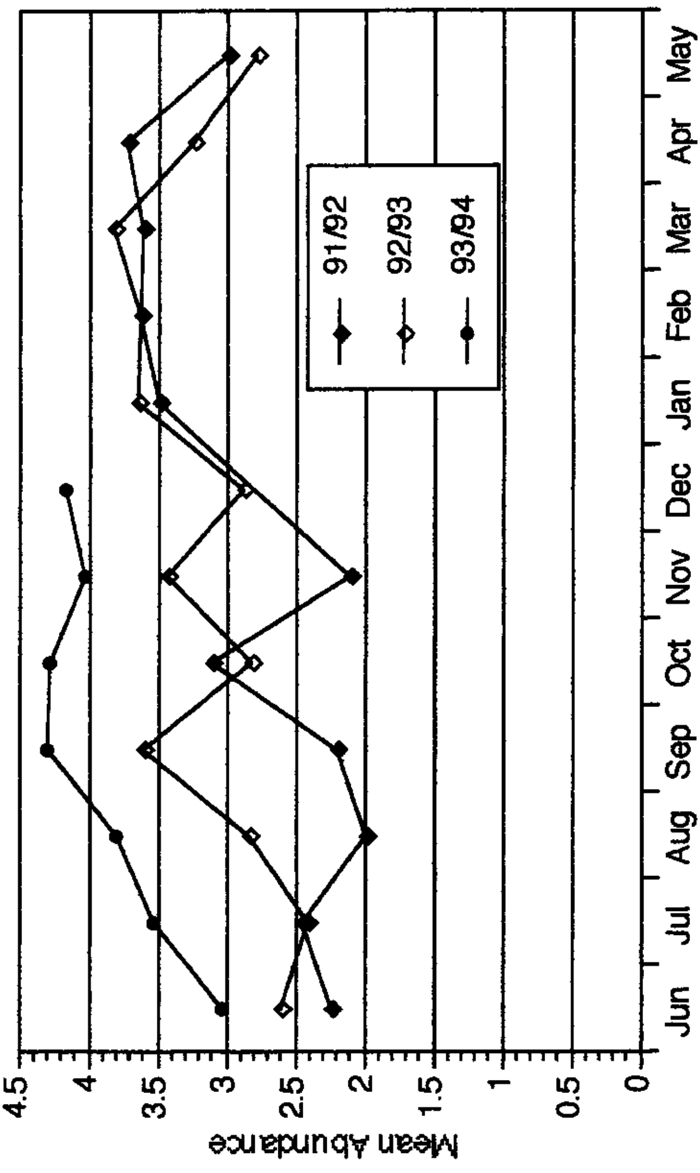

Figure 4. Mean abundance of Princess parrotfish (10+ cm FL) over 31 month period.

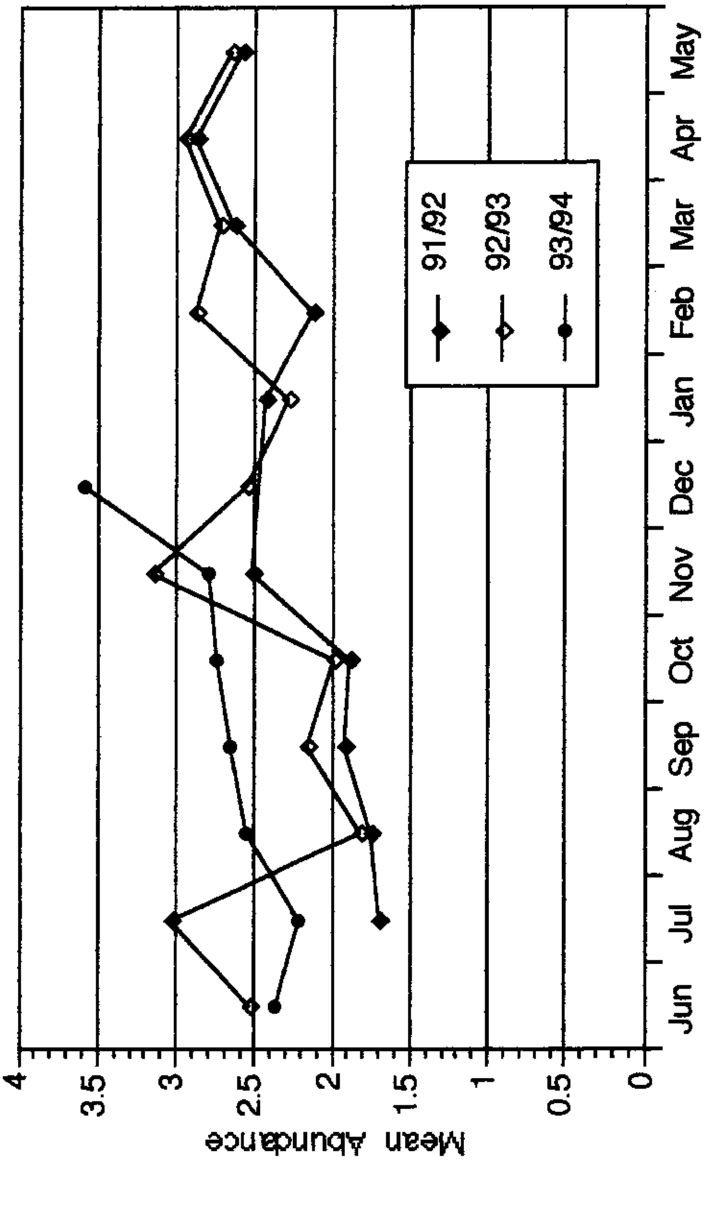

Figure 5. Mean abundance of Redband parrotfish (10+ cm FL) over 31 month period.

generally higher abundance values but it is not as marked as in the Princess parrotfish. An F_{max} test performed on these abundance data indicated homogeneity of variances ($F_{max} = 2.29$). The ANOVA analysis showed that the second and third year abundance estimates were significantly different ($F = 2.159$, $p = 0.0038$).

In contrast to the previous two species, the Queen parrotfish did not present as clear a trend of increasing abundance in the third year (Figure 6). Some monthly abundance estimates oscillated downward in the second year while others were strikingly similar in the same month. It is difficult to explain the declines in abundance in some months of the second year in the absence of fishing mortality. They may be the result of species-specific movement patterns or simply a sampling artefact. In any event, it is the long term trends in abundance which are of significance and that is the rationale for comparing annual trends rather than shorter time periods. An F_{max} test on this data set indicated that there was heterogeneity of variances ($F_{max} = 3.817$) and thus the data were transformed using log (x + 1) to meet ANOVA assumptions. The analysis indicated that the second year was significantly different from the third year ($F = 2.343$, $p = 0.0014$).

The Stoplight parrotfish provided the strongest example of similarity in abundance patterns in year over year comparisons (Figure 7). Many monthly values are tightly clustered or fall within a narrow range. There was no evidence of increased abundance in the third year. In fact, the abundance values appeared to remain very similar from year to year. An analysis showed that the variances were heterogeneous ($F_{max} = 3.089$) and the data were transformed (log x + 1) prior to the ANOVA which showed no significant differences between years.

As parrotfishes were taken almost exclusively with fish pots before the ban, there was an expectation that the populations might exhibit a relatively rapid recovery when they were no longer subjected to fishing mortality. Because of their abundance and biomass on Bermuda's reefs, they may be an important prey group for larger predators such as groupers. But as the stocks of the larger grouper species have been seriously depleted (Luckhurst, in press), predation pressure from benthic predators may be low. Given their rapid potential growth rate (Randall, 1962), there was speculation that the stocks might show a faster rate of recovery than the data indicates. However, growth rates of scarids in Bermuda's sub-tropical marine environment have not yet been determined. An examination of the size structure of the samples is being conducted to provide further insights into the dynamics of the growth of these stocks following the ban. It is possible that spawning stock biomass levels were lower than was assumed when the fish pot ban went into effect, so that there has been a lag phase of 2 - 3 years before significant increases in abundance were observed, *e.g. S. taeniopterus*. This may have been due to low recruitment levels or possibly a density-dependent factor influencing spawning dynamics. More

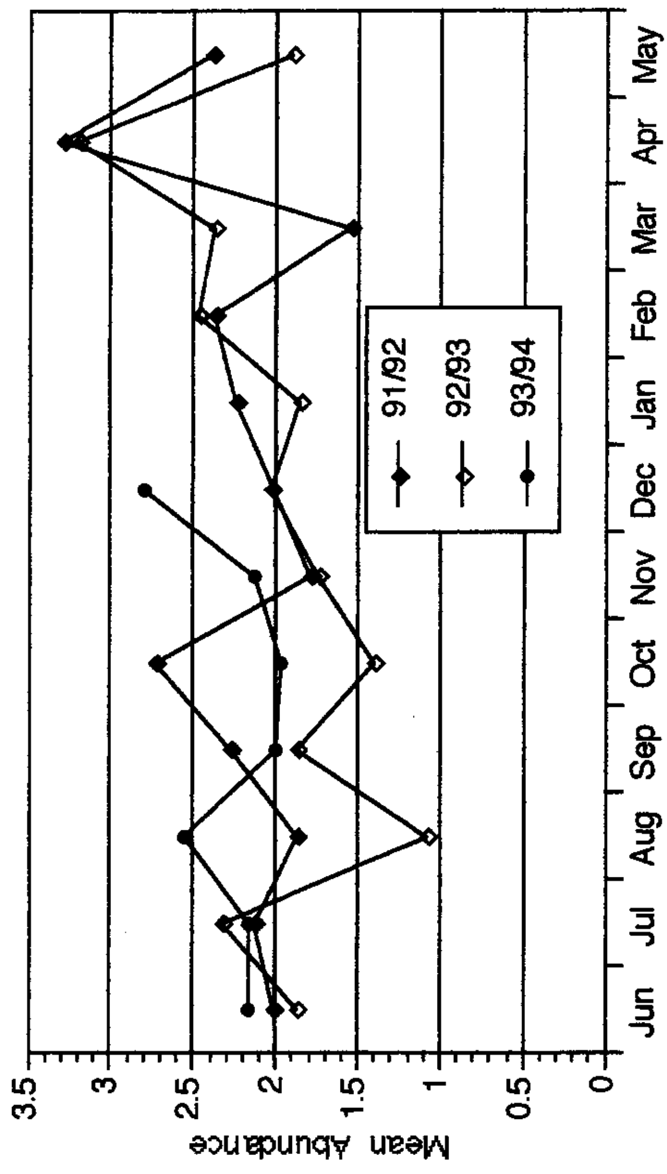

Figure 6. Mean abundance of Queen parrotfish (10+ cm FL) over 31 month period.

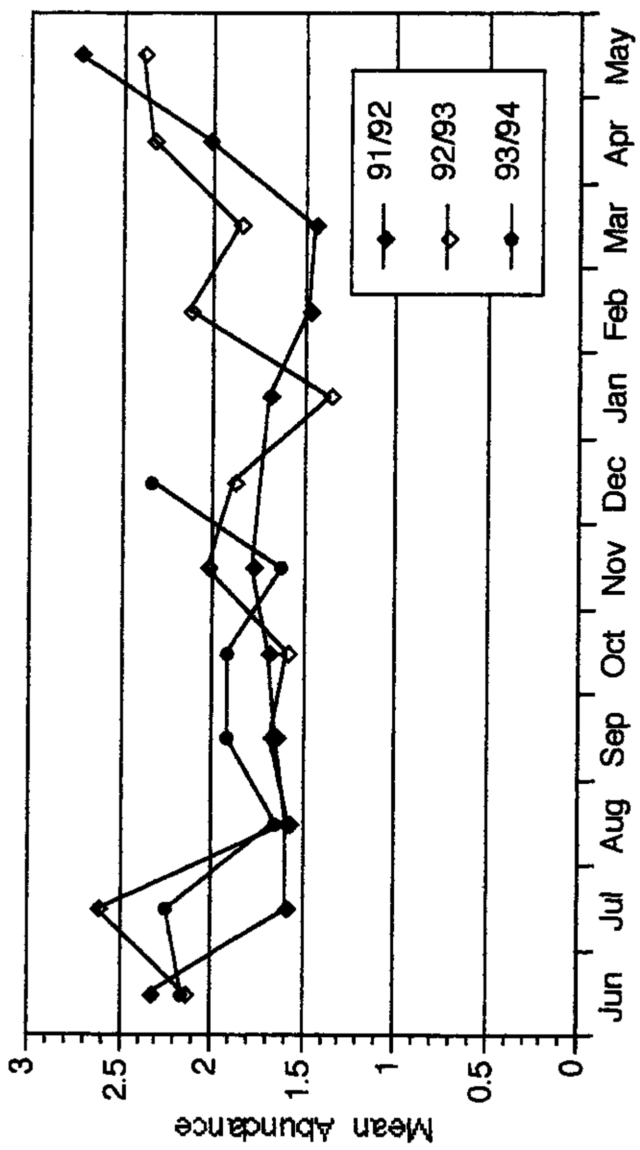

Figure 7. Mean abundance of Stoplight parrotfish (10+ cm FL) over 31 month period.

detailed information on the reproductive biology and behaviour of these species is required to address these issues.

In complex, multi-species reef fish assemblages, there are many interactions which may potentially influence these observed abundance patterns. This study has given an indication of the time frame which may be required to detect significant changes in population levels following sustained fishery exploitation and provides further evidence of the difficulties inherent in attempting to make assessments of multispecies fishery stocks in coral reef habitats. It lends support to the importance of long term monitoring of reef fish stocks as an essential element in evaluating the effectiveness of various fishery management and conservation measures.

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