Estimating multi-species trends in reef fishes from a large volunteer generated data set: A new tool for management

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ABSTRACT

Coral reefs are subject to major anthropogenic impacts worldwide and sites in decline are prime candidates for management and restoration. In assessing trends, it is imperative to have data from a wide area, over several years, and for many species. We assessed trends in 50 common coral reef fishes at 21 sites throughout the Florida Keys National Marine Sanctuary, based on volunteer surveys for the Reef Environmental Education Foundation (REEF) from 1993-1999. Analytical techniques were modified from those applied to the Breeding Bird Survey to detect sites with multi-species declines (ordered logistic regression followed by probit-normal analysis). Our results identify a subset of reef sites where trends were relatively poor for most fish species. At East Sambo in particular, a shift in fishing pressure may be reducing the density of fishes. No clear differences in trends were evident where fishing was prohibited in 1997 relative to other fished sites throughout the Florida Keys, although the expectation is that fish should increase in the future. As volunteer-generated data continue to accumulate, they will provide increasingly useful indicators of community level changes.

Keywords Reef fish, Multi-species trends, Reef Environmental Education Foundation, Marine reserves, Florida Keys, National Marine Sanctuaries

Introduction

Effective management of coral reefs requires information on species distributions and how these distributions change in time and space (Ginsburg 1993). This information allows managers to focus on sites where biological values are particularly high or particularly threatened. This need is exacerbated by mounting evidence that coral reefs are in decline worldwide and are sensitive to a variety of anthropogenic and natural disturbances (Ginsburg 1993, Connell 1997).

Scientists are too few to be able to generate synoptic data on reef communities at all or even most reef sites within a region. The difficulty of monitoring at appropriate scales has been noted previously (Johannes 1998) and is a common theme in management pertaining to marine resources (e.g. Baird et al. 2000). One solution is to use volunteers to help collect information on natural communities or resources. Dubbed "citizen science", it has become a widespread alternative for scientists and resource agencies that need information, but lack sufficient resources for monitoring and research.

There are considerable challenges to interpreting volunteer generated information on natural systems. Typically, volunteers involved in citizen science range dramatically in skill level from first time novices to experts who have skills rivaling the scientists or managers organizing and implementing the programs. Additionally, volunteer monitoring programs are rarely balanced in their effort, since volunteers have strong preferences for specific study sites. Thus, synthesizing volunteer generated data must necessarily involve a method that is robust to noisy and patchy data (Sauer et al. 1994).

In this paper we developed a method for calculating multi-species trends in reef fish populations. We applied the method to a large data set collected by volunteers in the Florida Keys, Florida. The non-profit organization Reef Environmental Education Foundation (REEF) began a program to monitor reef fishes in the Caribbean and Gulf of Mexico based on volunteer data collection in 1993. Between 1993 and 1999, more than 4,000 REEF surveys were conducted in the Florida Keys.

A variety of agencies are involved in the management and protection of the Florida Keys reefs. The sites evaluated in this study all fall under the jurisdiction of the National Oceanic and Atmospheric Administration (NOAA), through the National Marine Sanctuary (NMS) Program. In 1975 and 1981, respectively, Key Largo NMS and Looe Key NMS were established. This designation resulted in the prohibition of spearfishing, but not hook-and-line or trap fishing. In November 1990, the United States Congress passed the Florida Keys National Marine Sanctuary and Protection Act that designated the entire reef tract from Key Largo to the Dry Tortugas as the Florida Keys National Marine Sanctuary (FKNMS). The FKNMS comprises approximately 9,500 km^2 of coastal and oceanic water and submerged lands. As part of the comprehensive FKNMS Management Plan, the area was organized into five management zones: Wildlife Management Areas (WMA), Ecological Reserves (ER), Sanctuary Preservation Areas (SPA), Existing Management Areas (EMA), and Special Use/Research Only Areas (SU/RO). These zones aim to protect the biological diversity and integrity of the marine environment in the Keys. On July 1, 1997, the FKNMS Management Plan, which included a large-scale marine zoning plan became effective and closed 23 areas (eighteen SPAs, four SU/ROs, and one ER) to all extractive use (NOAA 1996). The EMAs included the Looe Key and Key Largo NMS sites.

To analyze this large data set, we adapted techniques used to analyze data from breeding bird surveys carried out by volunteers for decades in North America (James et

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al. 1996). The analysis ranked sites throughout the Florida Keys based on trends among the 50 most common reef fish species found in the region. These species constitute 14.4% of all reef fish species observed by REEF volunteers in the FKNMS. Sites were ranked according to: 1) the number of species at a given site that exhibited trends in abundance below the median trend for that species Keys-wide, and 2) the number of species at each site that exhibited trends in abundance that were in the bottom 25% (1st quartile) or top 75% (4th quartile) of all trend estimates for each species. Highly ranked sites where a large majority of species had below average trends in abundance over time, or relatively large changes in abundance (whether increases or decreases), represent a potential management concern. We considered highly ranked sites in the context of regional reserve design and anecdotal information regarding the changes in the demography of reef fish assemblages. Such analyses may provide insight into the efficacy of management decisions. However, other factors such as absolute abundances and size structure also need to be incorporated in prioritizing sites for management.

Methods

REEF data and data selection criteria

The REEF Fish Survey Project is an ongoing volunteer monitoring effort in the tropical western Atlantic. REEF has maintained a publicly-accessible database of fish sightings and relative abundance information since 1993, when the project began. By the end of 1999, the REEF database contained over 19,000 surveys from over 1,700 sites. Our analysis is based on REEF data collected beginning in 1993 and ending in 1999 in the Florida Keys (REEF geographic zone 34). During this time, volunteers have conducted 4,431 unique surveys at 119 sites throughout the Keys (REEF 2000).

Volunteer REEF surveyors used the Roving Diver Technique (RDT) visual survey method (Schmitt and Sullivan 1996). During RDT surveys divers swam freely throughout the dive site and recorded every observed species. At the conclusion of each survey, each recorded species was assigned one of four $\log_{10}$ abundance scores [single (1); few (2-10); many (11-100); and abundant (>100)]. The length of each survey was variable, typically ranging from 30-60 minutes. The species data along with survey time, depth, temperature, and other environmental information were then transferred to a REEF scansheet. These sheets were returned to REEF and optically scanned. The data were then run through a series of custom-written quality control programs (Schmitt et al. 1998) and entered into a Web-accessible database (http://www.reef.org).

The flexible nature of the RDT method and the patchy distribution of effort (both spatially and temporally) make the REEF data noisy above and beyond community and observer variability. The first step in our analysis was to eliminate certain surveys and sites from the data set to reduce variation in survey methods. Surveys were excluded if they were collected during night dives (after 9PM and before 6AM), or if they lasted less than 20 minutes or longer than 80 minutes. Sites were removed from the data set if they did not have at least five surveys from at least four different years. These data selection criteria eliminated 1,998 surveys from our analysis, leaving a total of 2,433 surveys from 21 different sites (Fig. 1). Eight of the sites were from Key Largo (REEF zone code 3403), four were from Islamorada (REEF zone code 3404), three were from Marathon (REEF zone code 3405), and six were from Key West (REEF zone code 3408). Six different buoys within The Elbow site off of Key Largo had at least five surveys from at least four different years. Each buoy is a different permanent mooring for watercraft on the Elbow. The site level analysis described below does not consider these buoys as separate sites. To reduce observer variability and to circumvent problems associated with analyzing data on species with very low sighting frequencies, we removed all but the 50 most frequently sighted species from our analysis (Table 1). All of the data selection cri-teria were implemented in the statistical package JMP (Version 3.2.2, SAS Institute Inc.).

Data analysis

The data analysis involved three steps: 1) conduct ordinal logistic regressions (OLRs) on the abundance of each species at each site over time, 2) convert the slopes obtained from the OLRs into binary data, and 3) conduct a probit-normal analysis on the binary data to determine if there were any significant differences in multi-species trends among sites.

Abundance scores were analyzed as ordered categorical variables. For a given survey, the score equaled 0 if a species was not sighted or identified, or else 1 (single), 2 (few), 3 (many), or 4 (abundant). To estimate a trend for a given species at a given site, we conducted OLRs that treated the year in which a survey was recorded as an independent continuous variable, and the abundance code as the dependent categorical variable. The cumulative probability of a species being at or below a given abundance code (response level) was modeled by a logistic regression curve. The model fit r-1 curves with different intercepts but the same slope, where r was the number of response levels. The curves were fitted by maximum likelihood estimation techniques. OLRs were carried out on each species at each site in Matlab (version 5.3, The Mathworks Inc.) using the OLR routine in StatBox 4.1 (Smith 1999), and then a text file was generated that contained a matrix of slope values resulting from the analysis.

Table 1 The 50 most frequently sighted reef fish species in the Florida Keys according to the REEF Fish Survey Project database. The trend value is the slope term for the ordinal logistic regression curve that models the cumulative probability of a species being at or below a given abundance code over the 1993-1999 timeframe. The percent sighting frequency (SF) is calculated by determining what percent of all surveys conducted in the Florida Keys reported a given species.

Rank	Species	Trend	SF (%)	Rank	Species	Trend	SF (%)
1	Blue Tang *Acanthurus coeruleus*	0.20	89.9	26	Trumpetfish *Aulostomus maculatus*	-0.07	56.4
2	Stoplight Parrotfish *Sparisoma viride*	0.19	86	27	Bermuda/Yellow Chub *Kyphosus sectatrix/incisor*	0.21	55.6
3	Yellowtail Snapper *Ocyurus chrysurus*	0.26	83.7	28	Schoolmaster *Lutjanus apodus*	0.14	54.9
4	Bluehead *Thalassoma bifasciatum*	0.38	82.3	29	Graysby *Epinephelus cruentatus*	0.18	53.4
5	Sergeant Major *Abudefduf saxatilis*	0.17	82.1	30	Threespot Damselfish *Stegastes planifrons*	0.26	53.2
6	French Grunt *Haemulon flavolineatum*	0.17	80.6	31	Blue Chromis *Chromis cyanea*	-0.03	52.8
7	Bicolor Damselfish *Stegastes partitus*	0.12	79.6	32	Yellow Goatfish *Mulloidichthys martinicus*	0.30	52.7
8	Bluestriped Grunt *Haemulon sciurus*	0.24	77.3	33	Striped Parrotfish *Scarus croicensis*	0.43	52.7
9	Ocean Surgeonfish *Acanthurus bahianus*	0.20	74.9	34	French Angelfish *Pomacanthus paru*	-0.04	51.7
10	Foureye Butterflyfish *Chaetodon capistratus*	0.13	73.1	35	Neon Goby *Gobiosoma oceanops*	0.14	50.7
11	Porkfish *Anisotremus virginicus*	0.19	72.8	36	Cocoa Damselfish *Stegastes variabilis*	0.30	49
12	White Grunt *Haemulon plumieri*	0.25	71.6	37	Queen Parrotfish *Scarus vetula*	0.29	47.9
13	Yellowtail Damselfish *Microspathodon chrysurus*	0.09	71.3	38	Gray Snapper *Lutjanus griseus*	-0.08	47.8
14	Spotfin Butterflyfish *Chaetodon ocellatus*	0.10	70.4	39	Clown Wrasse *Halichoeres maculipinna*	0.34	47.3
15	Redband Parrotfish *Sparisoma aurofrenatum*	0.44	69.4	40	Puddingwife *Halichoeres radiatus*	0.32	47.2
16	Yellowhead Wrasse *Halichoeres garnoti*	0.23	68.2	41	Spotted Goatfish *Pseudupeneus maculatus*	0.10	46.9
17	Great Barracuda *Sphyraena barracuda*	0.35	67.7	42	Doctorfish *Acanthurus chirurgus*	0.03	46.7
18	Gray Angelfish *Pomacanthus arcuatus*	0.23	66.3	43	Brown Chromis *Chromis multilineata*	0.30	45.9
19	Bar Jack *Caranx ruber*	0.16	65.5	44	Butter Hamlet *Hypoplectrus unicolor*	0.32	45.7
20	Sharpnose Puffer *Canthigaster rostrata*	0.09	59.3	45	Queen Angelfish *Holacanthus ciliaris*	0.00	45.2
21	Spanish Hogfish *Bodianus rufus*	0.16	59.2	46	Spanish Grunt *Haemulon macrostomum*	0.17	44.4
22	Rock Beauty *Holacanthus tricolor*	-0.09	59.2	47	Banded Butterflyfish *Chaetodon striatus*	0.25	42.8
23	Hogfish *Lachnolaimus maximus*	0.19	58.6	48	Mahogany Snapper *Lutjanus mahogoni*	0.15	42.3
24	Slippery Dick *Halichoeres bivittatus*	0.29	57.5	49	Redfin Parrotfish *Sparisoma rubripinne*	0.33	41.4
25	Harlequin Bass *Serranus tigrinus*	0.13	56.8	50	Bridled Goby *Coryphopterus glaucofraenum*	0.15	41.3

Table 2 Proportion of 50 fish species with below-median and dramatic trends at sites in FKNMS. Sites are listed in geographic order (from east to west). All sites with NT following have been no-take areas since 1997. The indented sites represent different buoys on The Elbow.

Site		Below Median Binary Matrix	1st and 4th Quartile Binary Matrix
Carysfort Reef	NT	0.28	0.3
The Elbow	NT	0.08	0.6
Anchor Chain	NT	0.28	0.36
City of Washington	NT	0.06	0.56
Mike's Wreck	NT	0.12	0.68
South Ledges	NT	0.34	0.38
The Fingers	NT	0.18	0.68
South South Ledges	NT	0.24	0.48
Key Largo Dry Rocks	NT	0.76	0.38
Little Grecian		0.54	0.42
Grecian Rocks	NT	0.84	0.56
Benwood Wreck		0.68	0.26
French Reef	NT	0.44	0.16
Molasses Reef	NT	0.94	0.82
Conch Reef	NT	0.48	0.2
Davis Reef	NT	0.4	0.4
Crockers Wall		0.46	0.62
Hens and Chickens	NT	0.34	0.36
Coffins Patch	NT	0.66	0.46
Samantha's Ledge		0.14	0.58
Sombrero Reef	NT	0.04	0.58
Eastern Sambo	NT	0.86	0.68
Middle Sambo		0.74	0.82
Western Sambo	NT	0.2	0.42
Eastern Dry Rocks	NT	0.34	0.6
Rock Key	NT	0.46	0.28
Sand Key	NT	0.32	0.5

Because there was unequal survey effort among sites we focused on the magnitude rather than statistical significance of trends in abundance. This is because significance improves with sample size (Pattengill-Semmens and Semmens 1998). We developed two matrices where each column was a site and each row a species (James et al. 1996). Elements in these matrices were binary (0,1) based on trends of each species at each site. The first binary matrix reflected only below-median slope values for each species across all sites (each slope value was converted to a 1 if it was below the median slope value for that species, or else 0). Hereafter this matrix is referred to as the below-median binary matrix. The second binary matrix approximated the first and fourth quartiles of slope values for each species across all sites (the five largest and five smallest slopes for each species at all sites were converted to a 1, and the rest were made 0). Hereafter this matrix is referred to as the 1st and 4th quartile binary matrix. With these binary matrices we next addressed the questions "which sites have the most species with below-median trends in abundance?" and "which sites have the most species with relatively large changes in abundance (positive or negative)?" A probit-normal model was applied to the two binary matrices to formally test for significance in overall geographic variation in multi-species trends (James et al. 1996).

We conducted a separate probit-normal analysis on multi-species trends from the six buoys at the Elbow Reef site to determine if there was significant variation among assemblages within a site. For this separate analysis we recalculated trends at each of the Elbow Reef buoys separately (N = 512). Two new 50 x 6 binary matrices were developed in the manner described above. Binary values for each species at each buoy were assigned based on the median values and quartile ranges that emerged from the 21-site analysis.

The SAS (version 8.0, SAS Institute Inc.) procedure NLMIXED fits nonlinear mixed models, and was used to construct the probit - normal model of the form

$$y_{ij} = t_i + \alpha_{ij} + e_{ij}$$

where i indexed treatment (each species) and j indexed each site. The t_i represented species means, the α_{ij} represented random site effects assumed to be independent, identically distributed $N(0,s_i^2)$, and the e_{ij}

represented the independent, identically distributed residual errors. We let x_{ij} be the binary value for the ith species at the jth site. The generalized linear mixed model became:

$$x_{ij} \mid \alpha_{ij} \sim \text{Binary}(p_{ij}), \text{ where } p_{ij} = \Phi(t_i + \alpha_{ij})$$

NLMIXED fitted separate models to the below median binary matrix and the 1st and 4th quartile binary matrix using likelihood-based methods, and provided maximum likelihood estimates of the 50 fixed species effects, and the single random site effect parameter.

The intent of this analysis was to determine the significance of the site-effect parameter (i.e. do multi-species trends differ among sites more than would be expected by chance?). There were no differences among species in the probit-normal analyses because we normalized all data to the species-specific median trend.

Results

Multi-species trends varied significantly among the 21 sites analyzed in this study (Table 2). The probit-normal analysis indicated a random site effects term p-value of 0.0096 and 0.0139 for the below-median binary matrix and the 1st and 4th quartile binary matrix, respectively (Table 3). Multi-species trends did not vary significantly among buoys on Elbow Reef (p-value of 0.2708 and 0.2638 for the below-median binary matrix and the 1st and 4th quartile binary matrix, respectively).

There did not appear to be any relationship between the geographic location of the sites and their performance given our binary matrix criteria (Fig. 1). That is, sites where fish abundances appeared to be increasing or decreasing were scattered throughout the region. Sixteen of the 21 sites analyzed were designated as no-take areas (SPA, ER, or RO) by the FKNMS in 1997. The remaining sites are also in the Sanctuary and have some limitations to the types of harvest allowed, but are not strict no-take areas. The low sample size of these limited-take sites coupled with their high variability in multi-species trends rendered any comparison of no-take and limited-take sites statistically insignificant.

The results from the analysis of the two different binary matrices were complementary, such that most sites with a high or low number of species trends below-median values also had a high number of species trends in the 1st and 4th quartiles. The eastern sites Molasses and Grecian Rocks and the western sites Middle Sambo and Eastern Sambo scored particularly high percentage values on both criteria (high proportion of species with below-median trends, and a high proportion of species with dramatic positive or negative changes over time). Sombrero Key off the lower middle Keys had a low proportion (0.04) of species with trends below the median, but these were evidently not dramatically below median trends because the site had only a moderate proportion (0.58) of species with trends in the 1st and 4th quartile.

Discussion

When translated into binary data, trends in abundance for multiple reef fishes differed significantly among sites in the FKMNS. We used two methods to translate OLR slope values into binary data: one method highlighted species at each site that exhibited below-median slope values, and one method highlighted species at each site that changed dramatically over the survey period (whether up or down). Our results distinguish between sites based on the proportion of species declining in abundance, and based on the proportion of species exhibiting dramatic changes in abundance.

Table 3 Site effects parameter in the probit-normal analysis of multi-species trends in reef fishes. The probit-normal model was applied to both the below median binary matrix and the 1st and 4th quartile binary matrix. Results indicated significant differences in multi-species trends among sites, and insignificant differences among buoys at the site The Elbow.

	Estimate	S.E.	DF	t-Value	Pr > |t|
Comparison of Sites					
Below Median Binary Matrix	1.6994	0.5932	20	2.86	0.0096
1st and 4th Quartile Binary Matrix	0.5606	0.2079	20	2.70	0.0139
Comparison of Buoys at The Elbow					
Below Median Binary Matrix	0.6837	0.5525	5	1.24	0.2708
1st and 4th Quartile Binary Matrix	0.2697	0.2143	5	1.26	0.2638

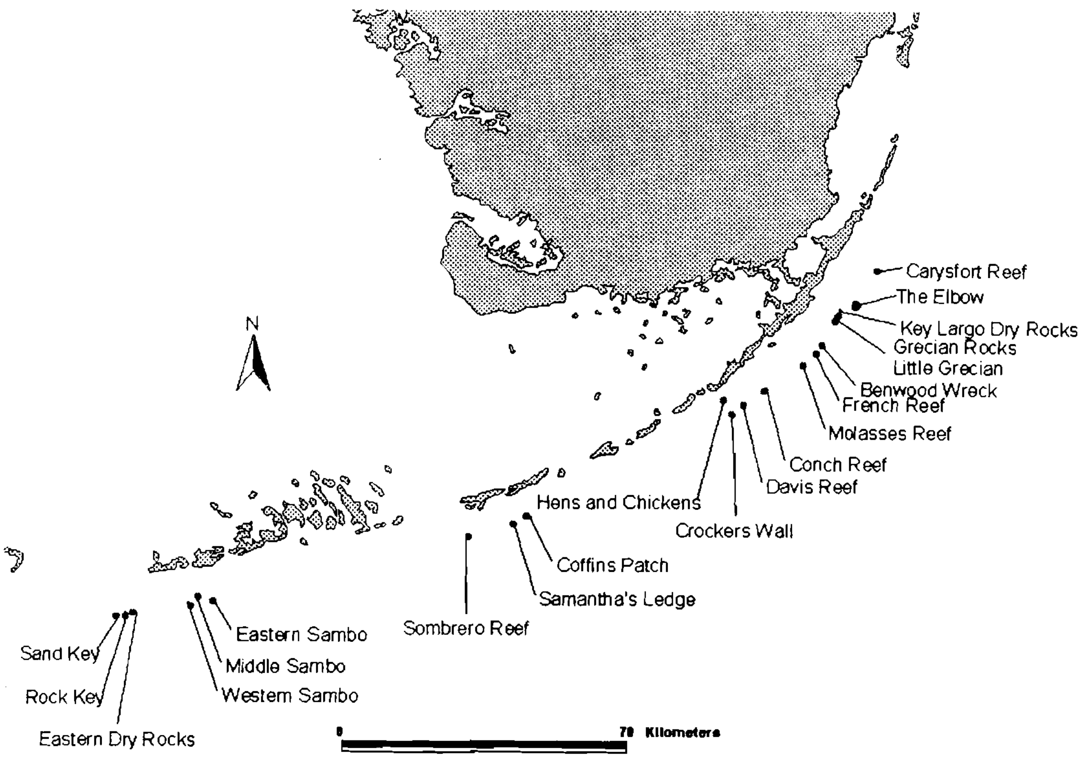

Fig. 1 A map of the Florida Keys, Florida (REEF Zone 34). Each dot represents a site included in this analysis.

Molasses Reef and Grecian Rocks both had a remarkably high proportion of species with below-median trends (0.94 and 0.84, respectively). Among experienced REEF volunteers in the Florida Keys region, there is general consensus that these apparent declines may be due to improvements in reef fish assemblages. Molasses and Grecian Rocks are among the most heavily visited reefs in the Florida Keys. In the early and mid-1990s, the reef fish assemblages at these two sites were dominated by juveniles and had few large predatory fishes. In 1997 both of these sites were established as SPAs, and since that time all forms of fishing on the reef have been banned. Before 1997 they were heavily fished recreationally. The sites continue to be very popular dive destinations, and the constant presence of dive boats on the reefs serves to deter "cheating" on the no-take policy by recreational fishers. During the late 1990s schools of large predatory snappers and grunts were more common on the reefs, and this coincided with a decline in the numbers of smaller fishes. It seems that the establishment of these sites as a no-take area may have resulted in a precipitous decline in the abundance of reef fish. However, given the apparent forces driving this community change, it is clear that a high proportion of below-normal population trends is not necessarily a cause for management concern.

Based on corroborative evidence, the high proportion of below-median trends on Eastern Sambo (0.84) represents a potential management concern. Eastern, Western, and Middle Sambo are sites off Key West. Western Sambo was designated as an Ecological Reserve in 1997, which prohibited harvest of any sort over an expansive area (3,084.1 ha). Middle Sambo was not given any special designation, and harvest such as sport fishing is allowed on the reef. Eastern Sambo is a small (27.7 ha) Research Only reserve immediately adjacent to Middle Sambo that was protected from all harvest and recreational activity in 1997. Historically, all of the Sambo sites were popular among sport fishers, but since 1997 the efforts of recreational fishers from the lower Keys have become focused on Middle Sambo. Increased fishing pressure may be the cause of Middle Sambo's dramatic declines: it had a high proportion of species with trends in abundance below the median, and a high number of species that changed dramatically in abundance over the survey period. Western Sambo showed no consistent pattern in multi-species trends over the same period. It is not clear what factors are behind the striking multi-species trends at Eastern Sambo (86% of species had below-median trends, and 72% showed dramatic changes in abundance), especially given that the site has the highest protection afforded any site throughout the Florida Keys. Why would a site with so much protection exhibit such apparent shifts in community composition, and have so many species with below median trends? It is possible that the small size of the Eastern Sambo SU/RO Reserve, coupled with its close proximity to and increased fishing levels at Middle Sambo, have affected fish communities on Eastern Sambo. Any fish that "spill over" from the small reserve are likely to be harvested. This suggests that FKNMS resource managers should focus effort on determining whether the size and placement of the Eastern Sambo SU/RO has compromised the intended harvest protection for reef fish.

The success of the probit-normal approach in distinguishing sites with below and above normal trends is evident at Elbow Reef. The seven sites at Elbow Reef are within a 90 ha area, and because they are part of the same local reef tract a portion of the species included in this analysis are likely to move relatively freely between these sites (Kramer and Chapman 1999). All of the Elbow sites show similar multi-species patterns with 6-28% of species having below-median trends. This result suggests that our method of analysis was conducted at the appropriate scale to capture significant differences among assemblages.

Overall Trends in Reef Fishes

The results of our analysis imply that most species increased in abundance over the survey period throughout the Florida Keys (Table 1). We suspect these increases are due in part to a bias in the REEF data. Divers using the RDT method are instructed not to report species identifications they are unsure of. As many REEF divers have become better at reef fish identification since 1993 when the REEF program began, it is likely that they have recognized and reported more species over time. Our results appear to reflect this bias, in that a large majority of the 50 species included in this analysis had positive median population trends. However, because we standardized our site comparison analysis to the median trend of each species, this bias should not have affected the results pertaining to differences in multi-species trends among sites.

Prioritizing Sites Based on Multi-Species Trends

This across-site comparison of multi-species trends in reef fishes generates an objective categorization of sites of special concern. However, the complex and interacting processes structuring reef communities insure that a simplistic interpretation of the results (such as "sites with a high proportion of species trends below the median are doing poorly") may not be prudent. In the case of Molasses and Little Grecian, the increase in size of predatory fishes may have caused an increase in top - down community structuring on the reef. However, the release of fishing pressure could lead to overall increases in abundance on reefs where top-down interactions among fishes are relatively unimportant.

The composition of reef fish communities is affected by interactions between climate, benthos, consumers, resources, oceanography, and other factors, many of which are highly variable (Doherty and Williams 1988, Thresher 1991, Williams 1991). Given this complexity, it is ill-advised to have rigid notions about what the results of an analysis such as this imply for reef health or the efficacy of management actions. Rather, the results from this analysis should be used as a means to identify potentially anomalous sites for further investigation. Sites with striking results should be considered in light of other information such as overall abundances, diversity, and size structure. Sites where concerns remain should be investigated further to determine what mechanisms led to the results, and whether or not these mechanisms represent a management concern. For example, the results of our analysis indicate that Eastern Sambo SU/RO should be scrutinized further. If fishes in Eastern Sambo are regularly caught outside the reserve boundaries, reserve design for this location may need to change, and may alter designs for other locations in the Florida Keys.

We anticipate that as volunteer-generated data accumulate in the Florida Keys, an increasingly clear picture will emerge of which sites have communities that are changing rapidly, versus sites that sustain relatively consistent reef fish assemblages. Similar analyses in the future will thus provide coral reef managers with an increasingly powerful management tool to identify sites of management concern. However, given the complexity of reef communities, to be used effectively, these analyses must be interpreted in concert with other forms of information available to management.

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