NOAA Technical Report NMFS 41 July 1986

A Stationary Visual Census Technique for Quantitatively Assessing Community Structure of Coral Reef Fishes

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA TECHNICAL REPORT NMFS

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ABSTRACT

A new method is described and evaluated for visually sampling reef fish community structure in environments with highly diverse and abundant reef fish populations. The method is based on censuses of reef fishes taken within a cylinder of 7.5 m radius by a diver at randomly selected, stationary points. The method provides quantitative data on frequency of occurrence, fish length, abundance, and community composition, and is simple, fast, objective, and repeatable. Species are accumulated rapidly for listing purposes, and large numbers of samples are easily obtained for statistical treatment. The method provides an alternative to traditional visual sampling methods.

Observations showed that there were no significant differences in total numbers of species or individuals censused when visibility ranged between 8 and 30 m. The reefs and habitats sampled were significant sources of variation in number of species and individuals censused, but the diver was not a significant influence. Community similarity indices were influenced significantly by the specific sampling site and the reef sampled, but were not significantly affected by the habitat or diver.

INTRODUCTION

Interest in visual and video methods for censusing reef fishes has greatly increased in recent years because of the inadequacy of some traditional sampling techniques and the need for reliable, nondestructive, fishery-independent sampling methods. Various methods and problems of visual sampling have been reviewed recently by Russell et al. (1978), Sale (1980), Sale and Douglas (1981), DeMartini and Roberts (1982), and Sale and Sharp (1983). The main objectives in conducting reef fish censuses are to:

1) compare fish populations between reefs and other habitats, and

2) quantitatively monitor reef fish composition and relative or absolute abundance over time.

Censusing fishes is difficult in coral reef environments because of the structural complexity of the habitat and the mobility, diversity, and abundance of reef fishes (Russell et al. 1978). Total counts for reef fishes are usually possible only on small patch reefs where populations are small enough to count in an hour or less. Counting all individuals is impossible on larger reefs with more diverse and abundant fish populations. At present, no census methods have been universally accepted for censusing reef fishes on large reefs.

DeMartini and Roberts (1982) and Sale and Sharp (1983) provide reviews of common visual census methods. We found that the most commonly used methods, belt-transect and rapid visual census techniques, suffered from several problems which rendered them inadequate for sampling coral reef fish community structure. Six of the most important problems were:

1) No method allowed a diver to simultaneously collect adequate data on species composition, abundance, frequency of occurrence, and biomass from reefs with diverse and abundant fish populations;

2) some methods attempted to deal with complexity by dealing only with a small group or "core species" and eliminated much of the visible fauna from consideration;

3) methods requiring extensive use of transect lines were unacceptably cumbersome, time consuming, or simply impossible to use on some local reefs due to complex habitat features, governmental regulations, or accidental interference from other divers;

4) few methods were adequate for sampling small restricted areas, such as certain reef microhabitats and areas damaged from ship groundings;

5) some methods could not deal quantitatively with different habitat types and habitat heterogeneity (patchiness) characteristic of Caribbean reefs; and

6) all methods suffered from several recognized or unrecognized biases that were likely to significantly affect census results. Some biases have been documented, but most have been either ignored or superficially investigated (Sale 1980; Sale and Douglas 1981; Sale and Sharp 1983).

We attempted to overcome these and other sampling difficulties by developing and testing a new visual census technique, using stationary divers to quantitatively sample fishes in diverse coral reef communities. Here we describe the method, evaluate it under field conditions, and report statistical characteristics of collected data. In a separate paper (in prep.) we qualitatively evaluate advantages and disadvantages of the method compared to commonly used transect and rapid-search methods based on experience and available data.

This study has three objectives:

1) Describe the stationary sampling method developed to meet specific sampling criteria;

2) test the sampling methodology to examine intrinsic and extrinsic factors that could influence the numerical values of collected data;

3) describe statistical characteristics of collected data so that appropriate sampling strategies and analytical methods can be used in future studies.

METHODS

Stationary Sampling Methodology

A restricted stationary sampling method (SS) was developed to provide quantitative data on reef fish community structure based on the following criteria:

1) All observable species should be included in each census on the assumption that no basis was available for *a priori* excluding species prior to collecting data;

2) the method should require minimum setup time and equipment manipulation;

3) diving time should be used as efficiently as possible for collecting data;

4) data should be able to generate estimates of species composition, abundance, frequency of occurrence, and biomass;

5) the method should minimize experimental, observer, and behavioral bias; and

6) sampling should include larger economically and ecologically important species which frequently avoid divers (Bohnsack 1982).

The sampling methodology is described in detail below.

The selected stationary sampling technique was based on censuses taken at randomly selected points using open-circuit SCUBA (Fig. 1). The distance between sampling points was based on a number of swimming kicks determined from a table of random numbers. Homogeneous habitats were sampled using a predetermined pattern of random directions and distances. Stratified habitats were sampled at random points while progressing at an angle across the gradient. To avoid decompression problems, the sampling progression usually went from deeper to shallower water.

At each sampling point we initially recorded all species observed in 5 min within an imaginary cylinder extending from the surface to the bottom within a radius of 7.5 m (24 ft) from the observer. Average visibility was generally greater than 12 m. The sampling radius was estimated by tape measure.

Each sample began by facing seaward and listing all species observed in the pre-set radius within the field of view. New sectors or field of view were scanned and new species listed by rotating in one direction. This was continued and new species were listed as observed for 5 minutes. No statistical data on the observed species were recorded at this time with one exception: a few species in moving schools were counted when first observed in the sampling cylinder. From experience we knew that these particular species were unlikely to remain in the sampling area. By counting schools when first observed, we avoided counting the same individuals more than once in case the school reappeared, and we obtained an average abundance for highly mobile species in multiple schools.

Next we recorded statistical data for the species listed in the initial 5-min sampling period; all other observed species were ignored. The estimated number of individuals and the minimum, maximum, and mean estimated length for each observed species were recorded using the methodology described below. We always worked systematically up the list from the bottom to avoid overlooking a species and to avoid bias caused by a tendency to count each species when it is particularly conspicuous or abundant. Thus, actual counts for particular species were made at random times even though delayed after the initial observation. For many species, only a few individuals appeared within the sampling radius during the initial 5-min listing period. These individuals were easily remembered and data were recorded from memory. Species that were always present in the sampling radius were counted, one at a time, after the 5-min listing period by starting at one point and rotating 360° until the entire area was scanned. When large schools were present, it was sometimes necessary to count by 10's, 20's, 50's, or even 100's.

Fish fork lengths in cm were estimated by comparing fishes to a ruler attached perpendicular to the far end of a 1-m rod held out from the diver (Fig. 2). This device helped avoid underwater magnification problems in estimating fish sizes.

We found the organization of the data sheet and procedures for recording data were critical to the success of the method. Time was kept to the nearest second with the aid of an underwater stopwatch attached to the top of an aluminum clipboard. Data were recorded on plasticized paper (Fig. 3). Scientific names were abbreviated by using the first three letters of the genus and the first four letters of the specific name. After all fish census data were recorded, data on depth and bottom features within the sampling radius were taken.

Method Evaluation

The SS methodology was evaluated by experimental and descriptive methods. We experimentally evaluated the influence of variations of habitat, field conditions, and the sampling protocol on the SS method. A statistical description of one reef fish community was also made to help evaluate the SS method and to aid other investigators in designing sampling strategies for specific research questions. To simplify the discussion, details of specific analysis methods are described with appropriate results.

Experimental Methods—Various factors that could affect SS data were examined. The applicability of the SS method in various habitats was examined using different habitats found in Looe Key National Marine Sanctuary (lat. 24°32′N, long. 81°24′W), Florida, U.S.A. Habitats were compared using mean number of species and mean number of individuals as dependent variables. Effects of sampling duration, radius, and visibility were examined using the Looe Key Reef forereef. The forereef zone had the most complex topography (Shinn et al. 1981) which, in our opinion, was an ideal location to evaluate a sampling method because it was the most difficult environment to sample. The effect of sample duration on the number of species and individuals censused was evaluated at several randomly selected sites in July 1979. Data were collected from 7.5-m radius samples while noting 1-min intervals. The effect of different sampling radii was evaluated on 3 August 1980 at one randomly selected site using 5-min samples collected in random order with radii of 1, 2, 3, 4.5, 6, 7.5, and 9 m. Effects of visibility on collected data were analyzed for samples taken from 1980 to 1985 by regressing number of species and individuals censused against estimated visibility. Visibility was the estimated distance at which a diver could be seen.

An experiment was conducted to examine sources of variation between sites, habitats, reefs, and divers. Two divers (JAB and SPB) collected SS data from the forereef of three different reefs: Looe Key Reef (LKR) and Molasses Reef (MR, lat. 25°01′N, long. 80°23′W), Florida, and Carrie Bow Cay Reef (CBC, lat. 16°48′N, long. 88°05′W), Belize, Central America. Divers sampled paired sites by sequentially alternating between the two sites until each had been sampled twice by each diver. On each reef, half the sites selected were atop spur formations (spur habitat) and half were

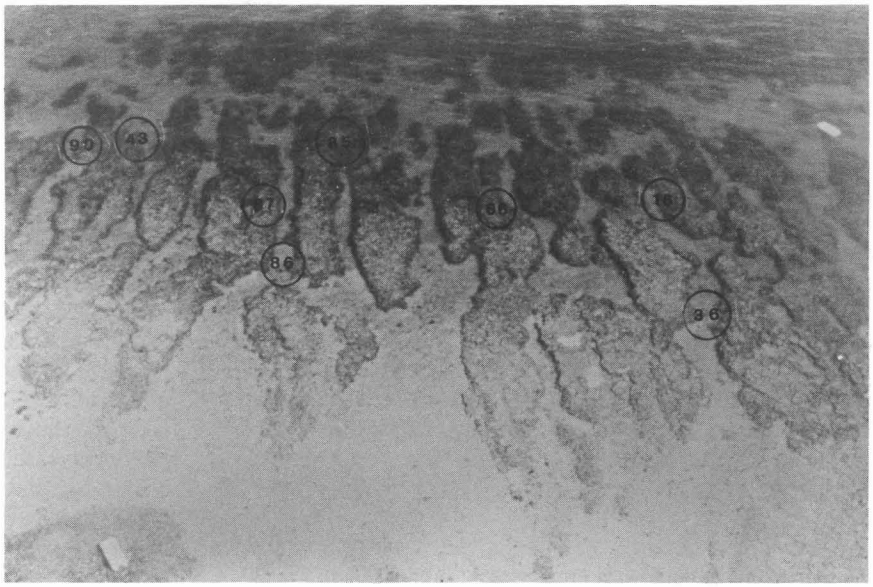


Figure 1.—Aerial view of Looe Key Reef forereef showing approximate areas included in representative, randomly selected, stationary samples.

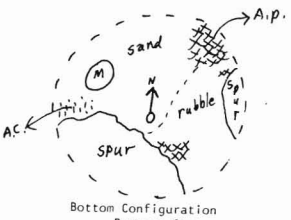
Figure 2.—A stationary diver collecting data. A ruler attached to the end of a meter stick was used to reduce magnification errors in estimating fish lengths.

Figure 3.—A sample data collection sheet. Species codes are listed on the left as observed. The wavey line below the species codes is used to mark the end of species observed in 5 min. "N" is the total number of individuals censused per species. Mean, minimum, and maximum fork lengths are directly recorded for most species. For some species, individual lengths are recorded and additions for total individuals and calculations of mean lengths are done later in the laboratory. The fishing index is the number of pieces of loose fishing gear noted in the sampled area. The sketch of features in the sampling area shows the diver's location in the middle. Percent cover is the estimated surface area viewed by the diver.

Location Looe Key Forereef
Date 1/14/84
Visibility 15 m
Temperature 29.5°C
Time started 10:05
Time ended 10:27

Fishing Index 2
Depth 4m

Species Codes	N	LENGTH Mean	Minimum	Maximum
Abu saxa	15	11	8	13
Tha bifa	56	5	2	10
Pom part	132	4	1	6
Hal macu		6, 5, 8, 11, 7, 8		
Hae auro	32	14	12	16
Aca coer		15@14, 2@20,		
Pom paru			28	31
Sca croi	12	8	4	12
Spa viri		42		
⋮				
Hae flav		15		



Bottom Configuration
Percent Cover

30% Spur Formation
25% medium rubble
10% Acropora palmata
2% A. cervicornis
3% Montastrea Head
Rest = Sand 30%

between spur formations (groove habitat). Specific site locations within each habitat were selected randomly. To get worst-case estimates of variance, divers estimated the sampling radius and made no attempt to compare results or specific procedures during the experiment.

Numbers of species and individuals were analyzed by 3-way analysis of variance using SPSS (Nie et al. 1975) with diver, habitat, and reef as the independent variables. Similarity between divers was examined further by correlating cumulative abundance estimates for each species with data from all three reefs.

Similarity coefficients (Bray-Curtis Index) were calculated and analyzed for all pairwise sample comparisons in the above experiment from the two reefs with the most data, MR and LKR (Brower and Zar 1977). Data from CBC were not used because of a lack of replicate samples. Similarity coefficients, PS, were defined as:

$$PSij = \sum_{n=1}^{s} min\,(p_{ij})$$

where $\min(p_{ij})$ is the lowest proportion of individuals in samples i and j, and s is the total number of species in samples i and j. The similarity coefficient has a minimum value of 0.00, where the two samples have no species in common, and a maximum value of 1.00, where both samples have the same species in common and the same numbers of individuals for each species. Bloom (1981) found this index most accurately reflected true similarity. For clarity, details on analysis methods for similarity coefficients are provided with the results.

Descriptive Methods—Statistical characteristics of an observed reef fish community were described for the LKR forereef because it was representative of complex reef environments and it was the most intensively sampled reef. Patterns of abundance, frequency of occurrence, size, and dispersion were described. An evaluation of adequate sample size was made based on performance curves of cumulative species and Spearman rank correlation coefficients (Zar 1974).

RESULTS AND DISCUSSION

General Comments on Stationary Sampling Methodology

The SS method was evaluated under a variety of field conditions and found to be extremely effective for censusing reef fishes. Stationary sampling is similar to traditional quadrat sampling in that censusing is restricted to a small increment of space and time. It differs in this study in that the observer remained in the middle of a circular quadrat. Stationary sampling is similar to strip transect sampling only in that it is the shortest possible transect (i.e., one where the observer does not move). Instead of censusing continuously over a strip transect, censusing with the SS method is accomplished by accumulating a series of independent samples.

Data on species composition, frequency of occurrence, abundance, and average fish length were collected simultaneously. We found that a stationary diver could easily record data and keep track of events that a moving diver would find difficult or impossible. Experience with other divers showed that the methods were easily learned and reliable data could be obtained after minimal training. As with any visual sampling method, divers must be experienced with the local fauna. Equipment required was minimal and no time was wasted in preparation prior to collecting data. For example, the effort, expense, and time required to deploy transect lines and make up data sheets were avoided.

Dive time was used efficiently and large numbers of samples were accumulated rapidly for statistical analysis. Depending on depth and reef complexity, we collected four to seven samples and approached 2 hours bottom time per standard 72 ft^3 SCUBA cylinder. Long bottom times were possible because a stationary diver consumed much less air than a swimming diver. This is an important consideration, especially at remote sites. We averaged 9 samples/diver/day (minimum 6, maximum 12). The maximum number of samples collected per day was limited by cold endurance in winter and mental fatigue in the summer.

A major attribute of the SS method is that very small areas can be censused. Thus, sampling can easily be restricted to one zone or habitat. This is particularly useful for sampling specific microhabitats or small sites, such as damaged reef areas. Stratified sampling designs can be used where each sample must be in a particular habitat. Statistical problems caused by lengthy transects crossing different habitat patches or zones are eliminated. The effects of bottom heterogeneity can be examined for randomly collected samples by multiple regression techniques. If necessary, the same sampling point locations can be found again for repeated sampling.

Like other visually oriented sampling methods, the SS method is not suitable for use in heavy surge, strong currents, deep depths, and very poor visibility. Although a diver could conceivably be attached to an anchor in strong currents, to do so in strong wave surge could result in an embolism. Decompression problems limit the usefulness of the method at deep depths. We did not attempt to sample sites deeper than 20 m for this reason.

Unlike other methods that census only a few target species or color forms, a diver must be able to visually distinguish all species potentially present. The availability of good identification guides for many regions reduces the problem of species identification. However, we found that behavioral information was also important.

The described data sheet and protocol for its use were designed to avoid bias and to prevent counting individuals more than once. Preprinted data sheets with listed species names were tried but abandoned, mainly because divers wasted a lot of time looking for the proper line to record data. Preprinted data sheets also tended to bias observers by reminding them to look for particular species. The proper position on each diver's data sheet (Fig. 3) was conveniently marked with a thumb. Much of the data could be recorded without actually looking at the data sheet so that more time was spent searching the sampling area. With preprinted data sheets, efficiency was directly influenced by familiarity with a particular version of a data sheet, independent of an observer's familiarity with the fauna, such that any changes to the species list caused confusion. Also, the large number of species potentially present made a standard form unmanageable. Using different lists in different regions also created confusion and reduced recording efficiency.

Experimental Evaluations of Influencing Factors

Habitat—We found that the SS method could be used in all tested habitats ranging from flat sand to complex, high relief, spur-and-groove formations. The average number of species and individuals censused during a sample was roughly proportional to habitat complexity (Figs. 4, 5). In general, more time was required to census fishes in structurally complex, versus simple, habitats. In flat sand and sea grass habitats, a sample could usually be completed in 6 min. The complex forereef environment required the longest sampling time (average 20 min, minimum 15, maximum 32).

Sampling Duration—The number of species detected per sample increased slowly after the initial 5 min of sampling and varied with habitat, with more species being found in more complex, forereef habitats than in simpler, lagoon rubble habitats (Fig. 5, top). The rate at which new species were observed at one site tended to level off after 5 min of sampling effort. Species observed after the initial 5-min sampling period usually represented only one or a few individuals, so that additional sampling time was a negligible contribution to the cumulative number of individuals. Doubling the sampling time to 10 min only added 1% to 3% more individuals in five test samples (Fig. 5, bottom).

Five minutes was selected as the standard sampling time for listing species present, because it was considered the minimum period adequate to carefully scan the sampling area in complex habitats and because longer periods increased the bias toward detecting highly mobile species. Longer time intervals also increased confusion in distinguishing between individuals within the sampling area and those that were continually moving in and out of the sampling area.

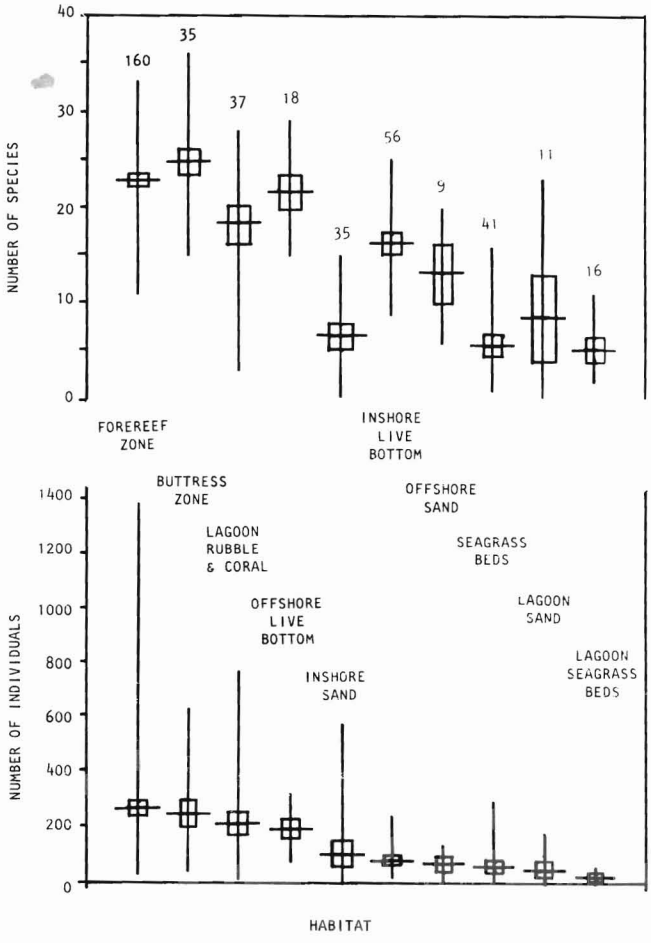


Figure 4.—Mean numbers of species (top) and individuals (bottom) censused per sample in various habitats of Looe Key National Marine Sanctuary. Boxes show 95% confidence limits, vertical lines show ranges, and numbers indicate the number of samples in each habitat. Subjective rankings of habitat complexity from most to least complex were: forereef, buttress, live bottom, lagoon rubble and coral, seagrass beds, and sand flats. Bohnsack et al. (in press) provides more detailed descriptions of sampled habitats.

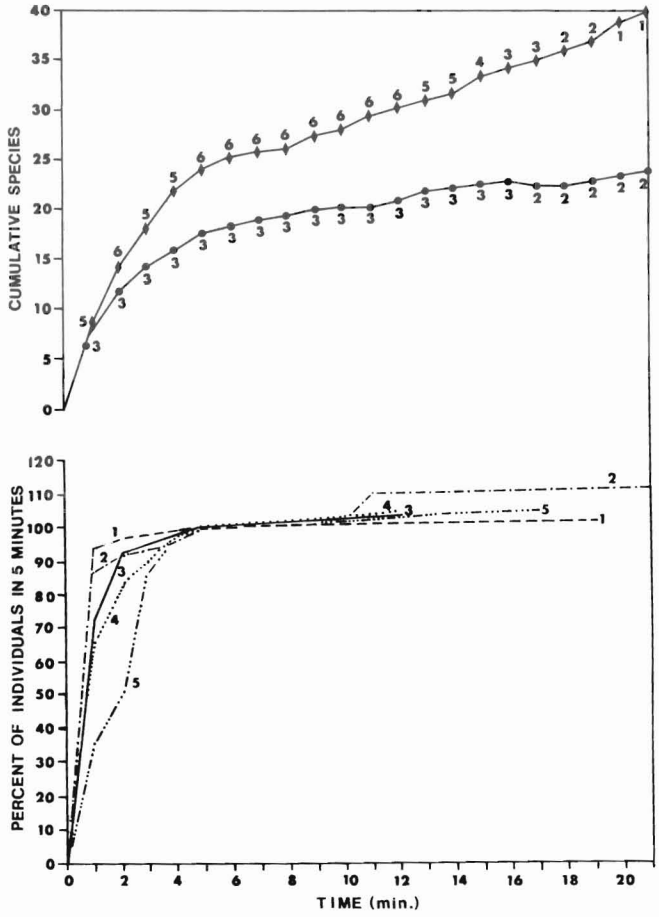


Figure 5.—Effects of sampling time on cumulative observed species and individuals at randomly selected forereef sites. (Top) Cumulative species observed over time from one spot. Numbers show sample size. (Bottom) Percent of individuals represented by species counted per minute during five censuses. Data were standardized by having 100% equal the number of individuals observed in 5 min. 100% represents 640, 381, 172, 235, and 135 individuals for each numbered sample, respectively.

Sampling Radius—We examined the effects of sampling radius on the number of species, number of individuals, and density of individuals censused. The number of species censused per sample was approximately asymptotic to the radius searched, while the number of individuals censused was approximately a linear function of the radius searched (Fig. 6). Due to time limitations, only one sample could be replicated; however, results are assumed to be reliable based on the high precision obtained from replication of the 7.5-m radius sample. Individuals were not counted in the 9-m radius sample because some small individuals could not be identified at that distance.

On a theoretical basis, a wide search diameter should be much more effective at detecting species than a short search diameter based on search theory (Cox 1983). A small increase in search width will initially result in a large increase in the probability of detecting a target species. However, there eventually comes a period of saturation when even a large increase in search width will have a small effect on the probability of species encounter. Results (Fig. 6) empirically support this prediction.

The asymptotic function of number of species versus distance sampled (Fig. 6) is also expected, based on the fact that the number

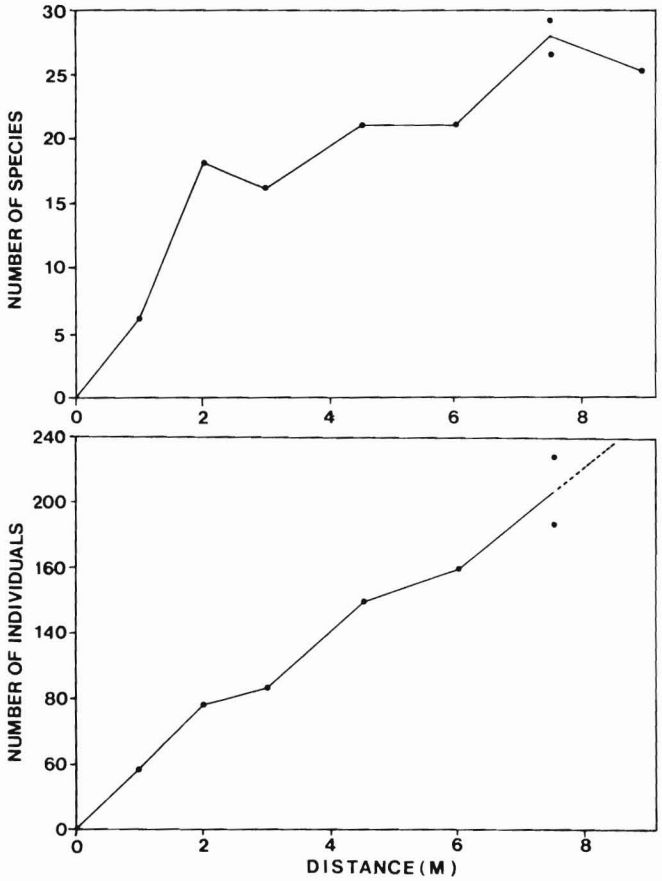


Figure 6.—Effects of sampling radius on the censused number of species (top) and individuals (bottom) in 5-min samples at the same site. Individuals were not counted in the 9-m sample because some individuals could not be identified with certainty.

of observed species is generally a logarithmic function of the number of individuals sampled (MacArthur and Wilson 1967). However, in theory the expected number of individuals censused should be proportional to the area sampled and should increase as a function of the square of the sampling radius. The fact that it did not is explained by the fact that all individuals were not observed and that detection is less likely at greater distances (Sale and Sharp 1983). To further investigate this relationship, we examined the effects of sampling radii on density.

The effects of sampling radius on density estimates were investigated by calculating density indices for the 15 species occurring at five or more radii. Density indices were obtained by dividing observed number of individuals by the basal area of each respective sampling cylinder. Density indices were plotted against sampling radius for each species (Fig. 7). Absolute density (individuals/m^2) was considered the 1-m intercept of linear regressions made from the linear portions of each curve (Sale and Sharp 1983). A density correction factor was calculated for each species so that when multiplied by the 7.5-m density index, the absolute density would be obtained (Sale and Sharp 1983). Calculated correction factors ranged between 1.85 and 7.79 (Fig. 7).

Density indices for 14 of the 15 species were inversely related to the length of the sampling radius (Fig. 7). The remaining species (*Scarus croicensis*) showed no clear density pattern, probably because it occurred by chance in infrequent and highly mobile schools. Regressions of density indices versus sampling radii were approximately linear if data from 1-m and 2-m radii were ignored (Fig. 7). Results for the 14 species suggested that samples taken at radii of 2 m or less may give an unacceptably biased view of community structure. Ten of the 14 species showed very low density indices at sampling radii of 1 m or 2 m. The most parsimonious explanation for these low observed values is that these species avoided approaching the observer. However, these low densities could be artifacts of the small area sampled using short radii. Four of the 14 species showed a curvilinear, negative exponential relationship with high density indices observed from the shortest radii. However, these density estimates at short radii would probably be unrealistically high if extrapolated over large areas. A school of *Haemulon aurolineatum* happened to swim through the 1-m sampling area during the census. The high densities at short radii for the three remaining species were most likely the result of a high proportion of sand substrate, their preferred habitat, in these samples. Although these species could have been attracted to the diver, this is unlikely based on our knowledge of their normal behavior. We occasionally observed some wrasses (particularly *Halichoeres*) initially attracted to the disturbed area at the feet of the diver. However, by the time they were counted after the initial 5-min sampling period, they usually had returned to what appeared to be their ambient density.

These results show that abundance values collected using the SS method are indices of abundance and not absolute abundance estimates. Ideally, observed density should not change with sampling radius if fishes are uniformly distributed and the habitat is uniform. Obviously, not every individual of every species was seen. Density indices declined with longer sampling radii because individuals further away from an observer were less likely to be detected. Individual size, behavior, coloration, and physical bottom features within the sampling area could have had the effect of hiding some individuals from the viewer.

The possibility that detection was related to mean species size was examined by correlating calculated correction factors with mean size using the Spearman rank order correlation coefficient (Zar 1974). Correction factors were not correlated with average species size ($p > 0.05$). This lack of correlation indicated that additional factors besides size influenced observed abundances and the detectability of different species.

Abundance data can be calibrated with other sampling statistics such as fishery landings or catch per unit effort. Also, correction factors can be applied to estimate absolute abundance and density, as discussed previously. However, absolute measures are not necessary in most comparative studies assuming that biases are consistent for each species. This should be especially true when samples are collected in the same manner from similar habitats. We did not examine the possibility that our observed density correction factors were unique to the sampling site and could vary greatly from site to site. We therefore recommend caution in applying correction factors between habitats.

Based on the above results and theoretical considerations, a radius of 7.5 m (24 ft) was chosen as the standard sampling radius. This distance maximized the number of species and individuals that could be conveniently censused in a reasonable time. It allowed observation of small cryptic species, as well as large shy species, that were often present but avoided closely approaching a diver. The latter group was especially important to sample because it included many of the larger commercially and ecologically important species.

Although desirable, the use of a tape measure to estimate the sampling radius was not always necessary. The sampling radius could be accurately estimated to 0.5 m with practice and with only

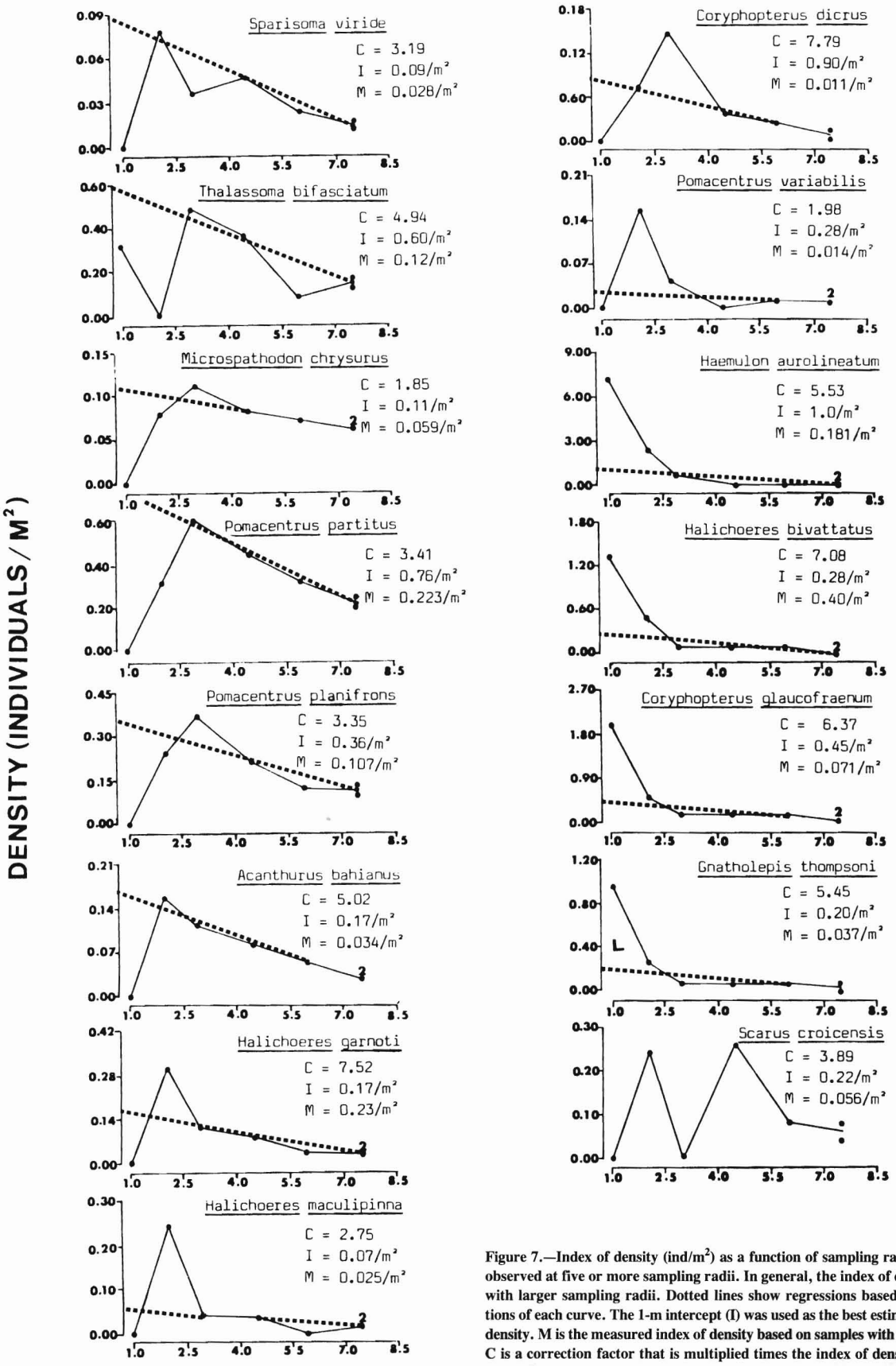


Figure 7.—Index of density (ind/m^2) as a function of sampling radius for species observed at five or more sampling radii. In general, the index of density declines with larger sampling radii. Dotted lines show regressions based on linear portions of each curve. The 1-m intercept (I) was used as the best estimate of absolute density. M is the measured index of density based on samples with a 7.5-m radius. C is a correction factor that is multiplied times the index of density (M) to give estimated absolute density (I). Low-density estimates for many species at 1 and 2-m radii were assumed to be caused by individuals avoiding close approach to the observer. See text for details.

periodic calibration. We found that a diver stationary on the bottom could accurately estimate distance much easier than could a moving diver. Based on our tests of different sampling radii (Fig. 6), minor errors in estimating the 7.5-m radius are unlikely to have significant effects on the number of species and individuals censused. Comparisons of density estimates from different sampling radii (Fig. 7) showed that values for most species were stable for sampling radii beyond 3 m, again suggesting that calculated density indices would be somewhat insensitive to minor errors in estimating the sampling radius.

The sampling radius should be constant for comparative purposes. However, a smaller sampling radius could be used in areas with consistently poor visibility, if the areas compared were sampled with the same radius and under the same conditions. Correction factors could be applied to compensate for reduced visibility.

Visibility—Effects of visibility on sample data were examined by regressing number of species and individuals observed versus ambient visibility (Fig. 8). Estimated ambient visibilities during the study varied between 4.5 and 30 m and had no significant effect ($p > 0.05$) on total number of species or individuals censused.

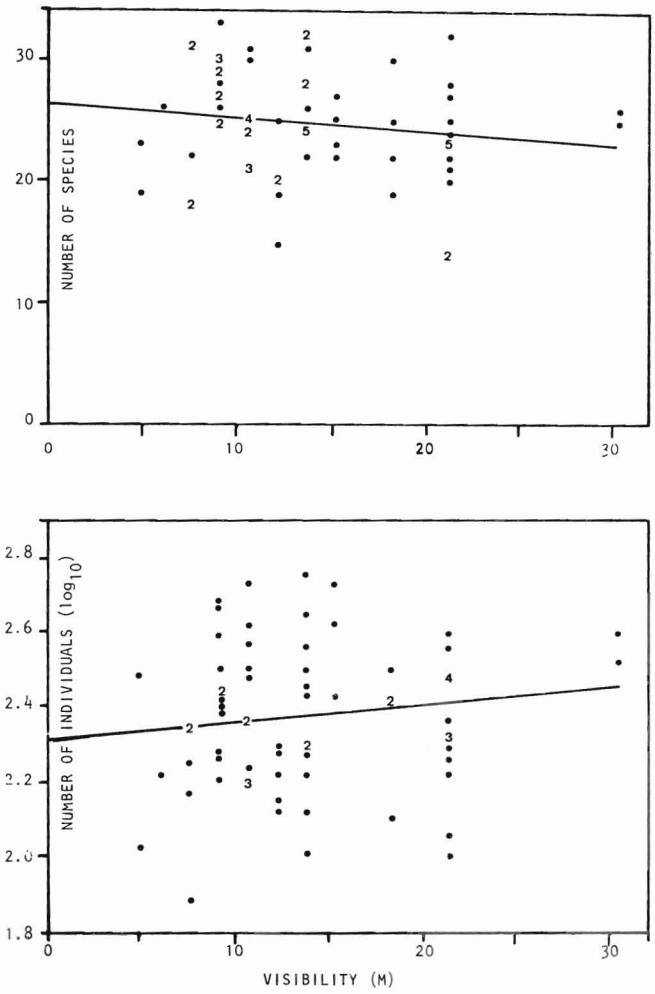


Figure 8.—Regressions of the observed number of species ($p > 0.05$, top) and individuals ($p > 0.05$, bottom) on visibility. Regression statistics: For species, $Y = 26.2 - 0.0338\ X$, $r^2 = 0.007$; For individuals, $Y = 2.31 + 0.00142\ X$, $r^2 = 0.003$.

Table 1.—Three-way analysis of variance on the effects of different reefs, habitats, and divers on number of species and individuals censused. The distribution of 36 samples among reefs was 16 (Molasses Reef), 12 (Looe Key), and 8 (Carrie Bow). An equal number of samples (18) was taken in each habitat (spur and groove) by each diver (diver 1 and 2).

Source of Variation	df	SS	MS	F	Significance
Number of species					
Main effects	4	595	149	3.57	$p < 0.05$
Reef (R)	2	296	148	3.55	$p < 0.05$
Diver (D)	1	64	64	1.55	ns
Habitat (H)	1	235	235	5.64	$p < 0.05$
2-Way interactions	5	171	34	0.82	ns
R × D	2	34	17	0.40	ns
R × H	2	133	66	1.59	ns
D × H	1	4	4	0.10	ns
3-Way interactions (R × D × H)	2	53	27	0.63	ns
Explained	11	818	74	1.78	ns
Error	24	1,001	42		
Total	35	1,819	52		
Number of individuals					
Main effects	4	1,012,476	253,119	8.15	$p < 0.001$
Reef (R)	2	516,146	258,073	8.31	$p < 0.002$
Diver (D)	1	66,650	66,650	2.15	ns
Habitat (H)	1	429,680	429,680	13.84	$p < 0.001$
2-Way interactions	5	229,120	45,824	1.48	ns
R × D	2	51,939	25,970	0.84	ns
R × H	2	145,438	72,719	2.34	ns
D × H	1	31,743	31,743	1.02	ns
3-Way interactions (R × D × H)	2	22,522	11,261	0.36	ns
Explained	11	1,264,119	114,920	3.7	**
Error	24	744,983	31,041		
Total	35	2,009,102	57,403		

However, only a few samples were collected at visibilities less than 8 m. We anticipate that lower visibilities would have a significant effect at some point. Samples collected under different visibility conditions might perhaps be compared using nonparametric methods. We suspect, but do not show, that rank/order relationships probably would not be altered significantly for most species even with greatly reduced visibilities.

Sources of Variation—A 3-way analysis of variance showed that the combined effects of reef, diver, and habitat were significant for species richness ($p < 0.05$) and individual abundance ($p < 0.01$) (Table 1). Significant sources of variation for individuals were the reef sampled ($p < 0.01$) and the habitat ($p < 0.01$), but different divers had no significant effect ($p > 0.05$). Significant sources of variation for observed species richness were also the reef ($p < 0.05$) and habitat sampled ($p < 0.05$). Again, different divers had no significant effect ($p > 0.05$). No significant interactions ($p > 0.05$) between sources of variation were found for any of the parameters. These results suggest that differences between divers was the least important factor influencing collected data in this study.

A more detailed comparison of variation between different divers was done by correlating cumulative abundance data obtained from the above experiment. Abundance estimates were significantly correlated ($r^2 = 0.863$, $p < 0.01$) although regression showed that one diver tended to provide slightly higher abundance estimates (Fig. 9). The observed slope (0.853 ± 0.0992, 95% CI) was significantly

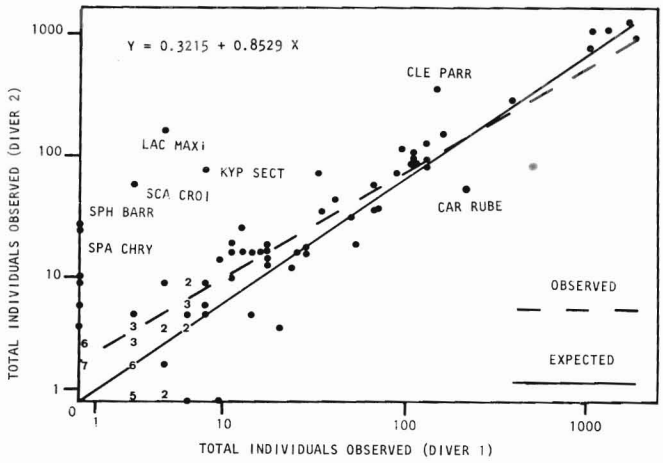


Figure 9.—Correlation of cumulative abundance estimates for 103 species by two divers sampling the same sampling sites ($r^2 = 0.963$, $p < 0.01$, 18 samples/diver). Numerals indicate multiple data points atop one another. The observed slope (0.853) differed significantly ($p < 0.05$) from an expected slope of 1.0, indicating that diver 2 provided slightly higher abundance estimates for low and moderately abundant species. Coded names show highly mobile species that occurred unpredictably in large schools. These species accounted for the greatest differences in abundance estimates between divers. Uncoded species names can be found in Table 3.

Table 2.—Four-way analysis of variance on the effects of different reefs, habitats, sites, and divers on similarity coefficients for paired samples. The distribution of 28 samples among reefs was 16 (Molasses Reef), and 12 (Looe Key). An equal number of samples (14) was taken in each habitat (spur and groove) by each diver (diver 1 and 2). See text for details.

Source of Variation	df	SS	MS	*F*	Significance
Main effects	7	6,292,355	898,908	3.05	$p < 0.025$
Reef	2	2,676,832	1,338,416	4.54	$p < 0.025$
Diver	2	450,165	225,082	0.76	ns
Habitat	2	118,013	59,007	0.20	ns
Site	1	953,217	953,217	3.23	$p < 0.10$
Explained	7	6,292,354	898,907	3.05	$p < 0.025$
Error	20	5,899,400	294,970		
Total	27	12,191,755	451,546		

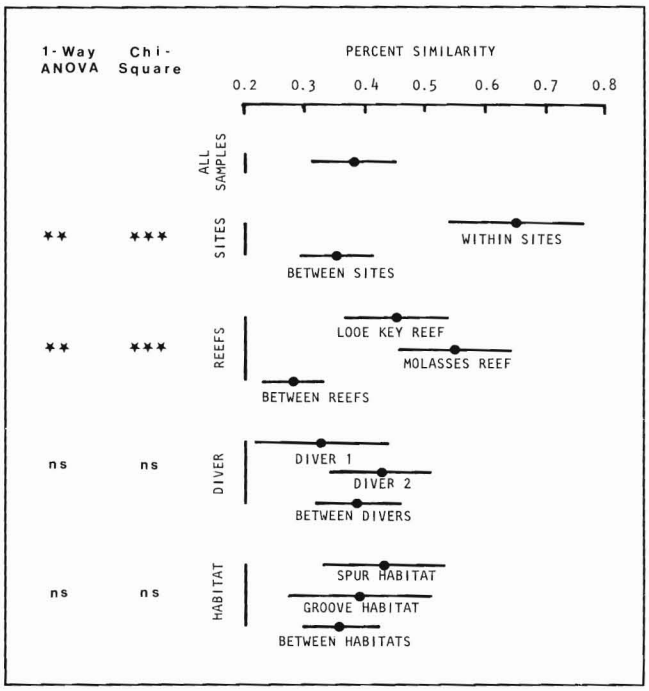


Figure 10.—Mean and 95% confidence limits of similarity coefficients as a function of sampling variables. Similarity coefficients were independently tested using chi-square and 1-way ANOVA analyses for differences within and between sites, reefs, divers, and habitats. Results showed that actual sample site and reef significantly influence similarity values, while habitat and diver were not significant influences. See text for details. Results from 4-way ANOVA are provided in Table 2. Key: ** = $p < 0.01$, *** = $p < 0.001$, ns = not significant.

different ($p < 0.05$, *t*-test) from a slope of 1.00 expected if perfect agreement between divers occurred. The major differences in abundance estimates between divers tended to be for highly mobile schooling species whose presence in samples is a chance occurrence.

Similarity coefficients were analyzed by three methods. First, similarity coefficients were analyzed as dependent variables by 4-way ANOVA (Sokal and Rohlf 1981) using coded independent variables representing site, diver, habitat, and reef. Codes reflected whether the two samples were

1) taken from the same or different sites;
2) taken by diver 1, diver 2, or both divers;
3) taken from Looe Key Reef, Molassas Reef, or both reefs; and
4) taken from groove habitats, spur habitats, or both habitats.

A total of 378 coefficients were produced from 28 samples. Degrees of freedom and mean squares were corrected to reflect the actual sample size ($n = 28$) rather than the implied sample size ($n = 378$). Because it is not clear whether similarity coefficients meet all the assumptions of ANOVA, specifically that of being normal and independent variables, two other analyses were also done. In the second analysis, similarity coefficients were assigned to 0.1-unit categories. Frequency distributions of similarity coefficients for each parameter were then compared to the total distribution using chi-square tests. In the third analysis, each variable was independently tested using 1-way ANOVA. Because independent tests for each of the four parameters increases the type-1 error, an alpha of 0.01 was used to reject each null hypothesis in the chi-square and 1-way ANOVA analyses in order to keep the overall type-1 error level less than 5% (i.e., $1 - [0.99]^4$).

Results from all three methods (Table 2, Fig. 10) showed that correlation coefficients were significantly influenced by the actual site and reef sampled ($p < 0.05$) but were not significantly influenced by the diver or habitat ($p > 0.05$). Many factors can influence collected SS data, including reef heterogeneity; natural variation of individuals moving in, out, and around the sampling area; methodological errors; and differences between divers. The high similarity values for samples from the same site indicate that the SS data reflect the actual biota present. The fact that the reef sampled was a major influence on collected data indicates that the method will be effective for comparing different reefs. The position of the diver on or between spurs had a surprisingly minor effect on collected data. This is apparently because the same biota were being censused, although from different perspectives.

Any good sampling method should reflect the biota as much as possible and should be least affected by differences between observers. Differences between divers was the least important factor affecting numbers of species, individuals, and similarity coefficients among the tested sources of variation in this study (Figs. 9, 10). This conclusion does not imply that inter-observer variability is not a potentially significant factor in other studies using the SS

or other visual methods, especially if divers are not adequately trained. Ideally, for comparative studies the same divers should collect data from all the sites. However, we suggest that the method is robust, and valid comparisons can be made with results taken by different divers. Improved precision between divers could probably be achieved by comparing data periodically, by using measured sampling radii, and by reducing slight differences in protocols for scanning and counting individuals.

Accuracy and Precision—The described rigorous sampling protocol was used to improve precision, avoid bias, and to prevent counting individuals more than once. Results presented above (Figs. 9, 10) show good precision and repeatability between and within observers for the same sampling site. However, it is impossible to evaluate with certainty the accuracy of the method because there is no way to know the true abundance and distribution of any species on a reef. Accuracy, although desirable, is not as critical when using relative abundance comparisons or rank/order statistics, because they are less sensitive than parametric statistics to less-than-major inaccuracies. Nevertheless, the SS method may have improved accuracy because many sources of observer bias (see Sale and Sharp 1983) were reduced or eliminated. For example, stationary divers eliminated biases caused by moving divers

1) swimming at different speeds,
2) swimming at different distances from the substrate,
3) searching at different distances down a transect, and
4) looking in particular hiding places based on special personal knowledge about the expected fauna.

In addition, a circular sampling area has the minimum border for the area sampled. This reduces potential edge effect errors caused by deciding whether an individual is inside or outside the sampling area. Such errors are more likely in narrow strip transects because the ratio of border to area sampled is much greater.

We observed, but did not quantify, that stationary sampling reduces bias resulting from some species being attracted to or repelled by moving divers. For example, the yellowtail snapper, *Ocyurus chrysurus*, usually congregated around a moving diver but quickly lost interest in a stationary diver and returned to what appeared to be normal densities by the time they were counted. Some shy species, such as the graysby, *Epinephelus cruentatus*, hid and were often overlooked by moving divers during transect surveys. However, they appeared to habituate to the stationary diver and could be censused by the end of a 5-min sample. Moving divers would probably overestimate abundance of yellowtail and underestimate abundance of graysby.

Statistical Description of Collected Data

Detailed descriptive statistics are provided for reef fishes based on stationary sampling data from the forereef at Looe Key Reef (Table 3, Fig. 11). Knowledge of statistical characteristics of census data collected from reef environments is important for evaluating the census method, for designing future sampling strategies, and for selecting appropriate analytic methods for answering specific research questions. Although many studies have reported sampling methods for examining the community structure of coral reef fishes, few have reported assumptions or statistical characteristics of the resulting data.

Descriptive Community Parameters—A total of 117 species were observed in 160 random samples collected between June and September 1983 (Table 3). Species were plotted according to ranked abundance, frequency of occurrence, and mean fork length (Fig. 11). The approximate linear decline of ranked $\log_{10}$ abundances (Fig. 11, top) is typical of many undisturbed, highly diverse communities (Brower and Zar 1977; Hubbell 1979). Species ranked according to frequency of occurrence (Fig. 11, center) showed a smooth decline from a few common species to many rare species (Fig. 11, center). This pattern is also typical of highly diverse tropical communities and implies that large numbers of samples are probably necessary to statistically describe the rarer species. Mean fish lengths varied by two orders of magnitude (Fig. 11, bottom; Fig. 12) which indicates that total biomass varied greatly

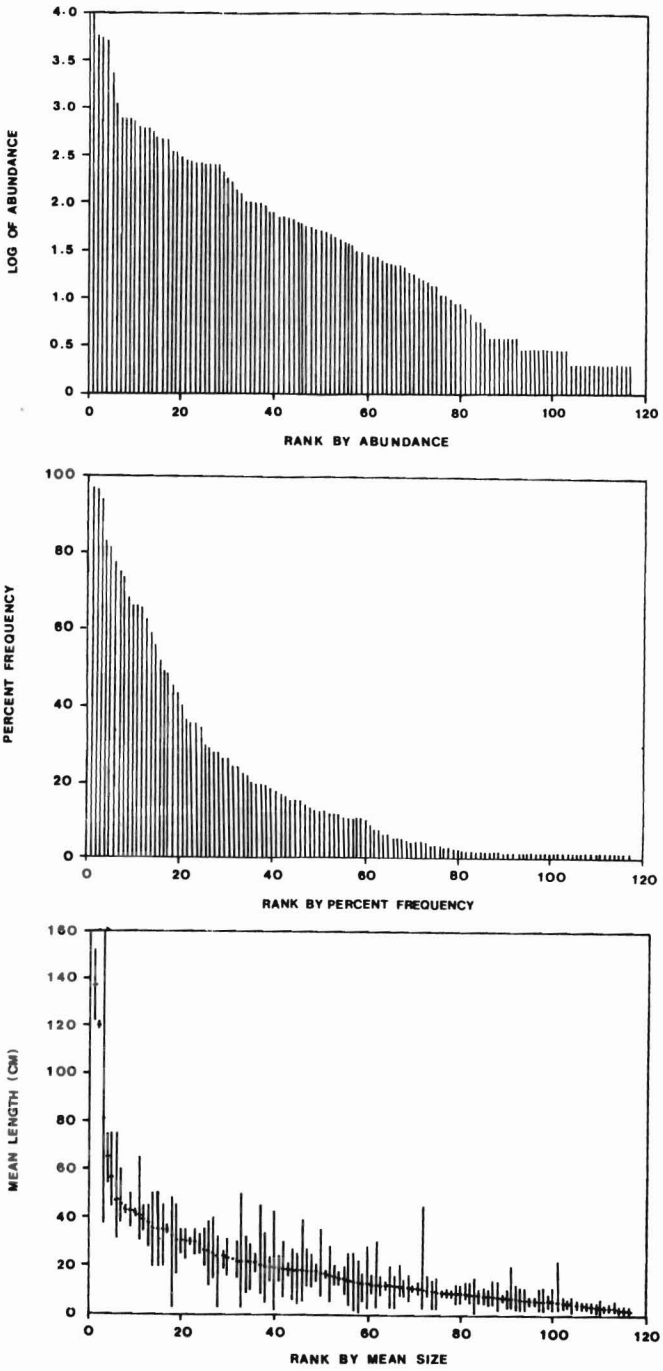


Figure 11.—Patterns of total abundance (top), frequency of occurrence (center), and estimated fork lengths (bottom) for 117 species observed in 160 samples on the forereef of Looe Key Reef in 1983. Estimated lengths show mean individual lengths and range of minimum-to-maximum length for each species. Details are provided for each species in Table 3.

Table 3.—Summary of data collected from the forereef of Looe Key Reef between June and September 1983. Scientific names are according to Robins et al. (1980).

Species	Total abundance	Mean individuals per sample	Frequency (N = 160)	Percent frequency	Length (cm) Mean	Min.	Max.	Variance/ mean ratio	K	
Abudefduf saxatilis	5174	32.3375	124	77.50	9.69	3	15	83.17	0.31730	+
Acanthurus bahianus	492	3.0750	117	73.13	11.84	3	20	12.49	0.73415	*
Acanthurus chirurgus	39	0.2438	26	16.25	18.35	6	27	1.64	0.28730	+
Acanthurus coeruleus	263	1.6438	105	65.63	12.05	3	30	4.29	0.88935	**
Aluterus schoepfi	2	0.0125	2	1.25	23.5	16	31	154.88	10000.00000	
Aluterus scriptus	6	0.0375	6	3.75	42.67	36	50	1.71	10000.00000	
Amblycirrhitus pinos	1	0.0063	1	0.63	9	9	9	2.56	2208.14351	
Anisotremus surinamensis	1	0.0063	1	0.63	30	30	30	40.96	2208.14351	
Anisotremus virginicus	18	0.1125	13	8.13	18.15	4	25	2.28	0.36213	+
Aulostomus maculatus	19	0.1188	17	10.63	35.59	20	50	1.21	1.11383	+
Balistes capriscus	2	0.0125	1	0.63	35	35	35	1.28	-	
Bodianus rufus	158	0.9875	89	55.63	21.85	9	32	1.31	2.32183	+
Calamus bajonado	23	0.1438	18	11.25	35.22	20	50	1.00	0.35476	+
Calamus calamus	15	0.0938	11	6.88	21.91	15	30	1.54	0.54051	+
Cantherhines pullus	13	0.0813	11	6.88	11.56	3	16	1.77	0.28672	+
Canthidermis sufflamen	5	0.0313	4	2.50	39.5	35	45	2.05	0.06289	+
Canthigaster rostrata	27	0.1688	20	12.50	3.58	2	5	1.52	0.30974	+
Caranx bartholomaei	22	0.1375	7	4.38	47.1	32	75	11.64	0.02269	+
Caranx ruber	453	2.8313	56	35.00	17.15	8	35	26.91	0.13562	+
Chaetodon capistratus	260	1.6250	104	65.00	8.32	1	15	1.42	10000.00000	**
Chaetodon ocellatus	79	0.4938	42	26.25	11	6	16	262.48	10000.00000	**
Chaetodon sedentarius	3	0.0188	2	1.25	12	9	15	0.85	10000.00000	
Chaetodon striatus	59	0.3688	35	21.88	10.29	8	16	1.56	10000.00000	**
Chromis cyaneus	213	1.3313	72	45.00	7.08	2	14	2.70	10000.00000	**
Chromis insolatus	1	0.0063	1	0.63	2	2	2	2.56	2208.14351	
Chromis multilineatus	779	4.8688	47	29.38	8.35	5	13	64.41	0.08608	+
Chromis scotti	29	0.1813	6	3.75	5.83	2	11	17.30	0.01464	+
Clepticus parrai	98	0.6125	9	5.63	11.33	8	20	23.51	0.01569	+
Coryphopterus dicrus	36	0.2250	19	11.88	2.84	2	4	2.56	0.12328	+
Coryphopterus glaucofraenum	183	1.1438	44	27.50	2.83	2	5	5.05	10000.00000	**
Coryphopterus personatus	2338	14.6125	31	19.38	2.07	1	3	407.43	0.03611	+
Diodon hystrix	1	0.0063	1	0.63	43	43	43	2.56	2208.14351	
Diplectrum formosum	16	0.1000	1	0.63	3	3	3	16.00	10000.00000	
Echeneis naucrates	3	0.0188	3	1.88	8.67	5	12	0.85	10000.00000	
Epinephelus cruentatus	82	0.5125	69	43.13	16.24	6	28	1.12	10000.00000	
Epinephelus guttatus	1	0.0063	1	0.63	23	23	23	2.56	2208.14351	
Equetus acuminatus	1	0.0063	1	0.63	9	9	9	2.56	2208.14351	
Equetus punctatus	1	0.0063	1	0.63	12	12	12	2.56	2208.14351	
Gnatholepis thompsoni	58	0.3625	20	12.50	4.25	3	5	3.58	0.36250	**
Gobiosoma oceanops	62	0.3875	31	19.38	2.39	2	3	2.64	0.22515	+
Haemulon album	27	0.1688	2	1.25	21.5	18	25	24.27	10000.00000	*
Haemulon aurolineatum	5444	34.0250	77	48.13	13.15	1	22	152.78	0.12675	+
Haemulon carbonarium	351	2.1938	19	11.88	17.94	12	27	164.10	0.02830	+
Haemulon chrysargyreum	463	2.8938	17	10.63	13	6	17	55.29	10000.00000	**
Haemulon flavolineatum	256	1.6000	109	68.13	14.65	9	20	2.25	1.43209	*
Haemulon macrostomum	52	0.3250	30	18.75	24.36	3	32	5.96	0.22267	+
Haemulon melanurum	2	0.0125	2	1.25	17	17	17	1.28	10000.00000	
Haemulon parrai	53	0.3313	5	3.13	24	19	26	19.32	10000.00000	
Haemulon plumieri	136	0.8500	64	40.00	19.32	14	24	8.30	0.39304	**
Haemulon sciurus	299	1.8688	56	35.00	21.88	3	50	18.12	0.16065	**
Halichoeres bivittatus	620	3.8750	78	48.75	5.62	3	11	23.23	0.24358	+
Halichoeres garnoti	636	3.9750	132	82.50	6.67	3	20	4.65	1.14524	+
Halichoeres maculipinna	733	4.5813	119	74.38	5.75	2	11	14.31	0.63636	**
Halichoeres poeyi	1	0.0063	1	0.63	11	11	11	2.56	2208.14351	
Halichoeres radiatus	107	0.6688	54	33.75	10.87	3	45	2.39	0.53628	+
Hemipteronotus novacula	1	0.0063	1	0.63	-	-	-	2.56	9556.93451	
Hemipteronotus splendens	1	0.0063	1	0.63	7	7	7	2.56	10000.00000	
Holacanthus bermudensis	8	0.0500	7	4.38	29	25	33	1.28	0.20907	+
Holacanthus ciliaris	13	0.0813	13	8.13	21.58	10	29	0.79	10000.00000	
Holacanthus tricolor	37	0.2313	27	16.88	14.08	4	25	1.73	0.69275	+
Holocentrus ascensionis	7	0.0438	6	3.75	17.17	14	20	1.46	0.14711	+

Table 3.—Continued.

Species	Total abundance	Mean individuals per sample	Frequency (N = 160)	Percent frequency	Length (cm) Mean	Min.	Max.	Variance/ mean ratio	K	
Holocentrus rufus	25	0.1563	16	10.00	16.13	13	20	1.64	0.14419	+
Hypoplectrus gemma #	3	0.0188	3	1.88	8	7	10	0.85	10000.00000	
Hypoplectrus unicolor	3	0.0188	3	1.88	4	3	5	0.85	10000.00000	
Inermia vittata	31	0.1938	2	1.25	8	5	11	23.87	10000.00000	*
Kyphosus sectatrix	357	2.2313	29	18.13	26.15	12	38	39.27	0.05324	+
Lachnolaimus maximus	30	0.1875	24	15.00	26.73	20	35	1.37	0.55925	+
Lactophrys bicaudalis	2	0.0125	2	1.25	8.5	8	9	1.28	10000.00000	
Lactophrys triqueter	4	0.0250	4	2.50	7.5	4	14	5.76	10000.00000	
Lutjanus analis	3	0.0188	3	1.88	45.7	38	60	0.85	10000.00000	+
Lutjanus apodus	129	0.8063	23	14.38	19.7	14	24	9.60	0.05795	+
Lutjanus griseus	100	0.6250	24	15.00	30.55	17	45	20.07	0.06840	+
Lutjanus mahogoni	9	0.0563	3	1.88	18.67	16	21	4.55	0.01004	+
Lutjanus synagris	254	1.5875	17	10.63	17.71	12	25	25.20	10000.00000	
Malacanthus plumieri	2	0.0125	2	1.25	11	9	13	1.28	10000.00000	
Malacoctenus triangulatus	3	0.0188	3	1.88	6	5	7	0.85	10000.00000	
Megalops atlanticus	2	0.0125	2	1.25	137	122	152	1.28	10000.00000	
Microspathodon chrysurus	787	4.9188	130	81.25	10.02	3	14	6.30	1.01558	+
Monacanthus tuckeri	2	0.0125	1	0.63	6	6	6	1.28	-	
Mulloidichthys martinicus	290	1.8125	38	23.75	18.83	7	30	15.57	0.08938	+
Muraena miliaris	2	0.0125	2	1.25	30	25	35	1.28	10000.00000	
Mycteroperca bonaci	5	0.0313	5	3.13	41.5	31	65	0.51	10000.00000	
Ocyurus chrysurus	1107	6.9188	150	93.75	20.68	9	45	15.55	1.08759	**
Odontoscion dentex	72	0.4500	28	17.50	12.32	9	16	6.97	0.12053	+
Ophioblennius atlanticus	24	0.1500	14	8.75	5.64	3	8	2.67	0.10137	+
Ophstognathus aurifrons	8	0.0500	3	1.88	5	3	7	2.88	10000.00000	
Pempheris schomburgki	274	1.7125	7	4.38	8	5	10	157.90	0.00836	+
Pomacanthus arcuatus	51	0.3188	42	26.25	30.21	23	35	1.25	7.13701	+
Pomacanthus paru	21	0.1313	17	10.63	30.44	25	35	1.10	0.39529	+
Pomacentrus diencaeus	103	0.6438	19	11.88	8.63	5	12	7.18	10000.00000	**
Pomacentrus fuscus	596	3.7250	58	36.25	6.32	4	12	20.45	0.14125	*
Pomacentrus leucostictus	14	0.0875	9	5.63	3.13	1	6	1.65	0.13835	+
Pomacentrus partitus	5694	35.5875	154	96.25	3.82	2	5	23.78	1.49706	**
Pomacentrus planifrons	814	5.0875	83	51.88	6.21	2	11	13.29	0.26525	*
Pomacentrus variabilis	72	0.4500	20	12.50	6.31	2	11	9.10	0.06327	+
Priacanthus cruentatus	2	0.0125	2	1.25	15.5	14	17	1.28	10000.00000	
Pseudupeneus maculatus	17	0.1063	7	4.38	11.29	8	14	2.41	10000.00000	
Scarus coelestinus	10	0.0625	9	5.63	38.89	28	45	1.02	0.39468	+
Scarus coeruleus	48	0.3000	21	13.13	35.1	20	45	9.01	0.09504	*
Scarus croicensis	560	3.5000	94	58.75	5.59	2	22	7.68	0.44184	*
Scarus guacamaia	10	0.0625	8	5.00	32.6	3	48	2.30	10000.00000	
Scarus taeniopterus	67	0.4188	46	28.75	12.37	3	28	1.87	0.71533	+
Scarus vetula	42	0.2625	24	15.00	20.61	5	34	2.19	0.19084	+
Scomberomorus cavalla	1	0.0063	1	0.63	120	120	120	2.56	2718.89497	
Scomberomorus maculatus	1	0.0063	1	0.63	42	42	42	2.56	2208.14351	
Serranus baldwini	2	0.0125	2	1.25	4	4	4	1.28	10000.00000	
Serranus trigrinus	44	0.2750	36	22.50	6.94	3	10	0.93	1.85613	+
Sparisoma aurofrenatum	256	1.6000	99	61.88	13.75	2	25	2.25	1.14195	+
Sparisoma chrysopterum	62	0.3875	32	20.00	17.96	6	39	62.80	0.21978	+
Sparisoma rubripinne	94	0.5875	44	27.50	25.14	15	40	2.72	0.30405	+
Sparisoma viride	262	1.6375	105	65.63	19.52	2	43	2.82	1.32677	+
Sphoeroides spengleri	1	0.0063	1	0.63	5	5	5	2.56	2208.14351	
Sphyraena barracuda	69	0.4313	39	24.38	81	39	160	3.71	0.29199	*
Synodus intermedius	1	0.0063	1	0.63	9	9	9	2.56	7109.71622	
Thalassoma bifasciatum	9558	59.7375	156	97.50	4.46	1	7	72.42	0.89184	+
Trachinotus falcatus	3	0.0188	3	1.88	56.7	45	75	0.85	10000.00000	
Tylosurus crocodilus	2	0.0125	2	1.25	65	55	75	1.28	10000.00000	

Now considered a color form of H. unicolor.
+ fits negative binomial distribution ($p > 0.05$)
* reject negative binomial fit ($p < 0.05$)
** reject negative binomial fit ($p < 0.01$)

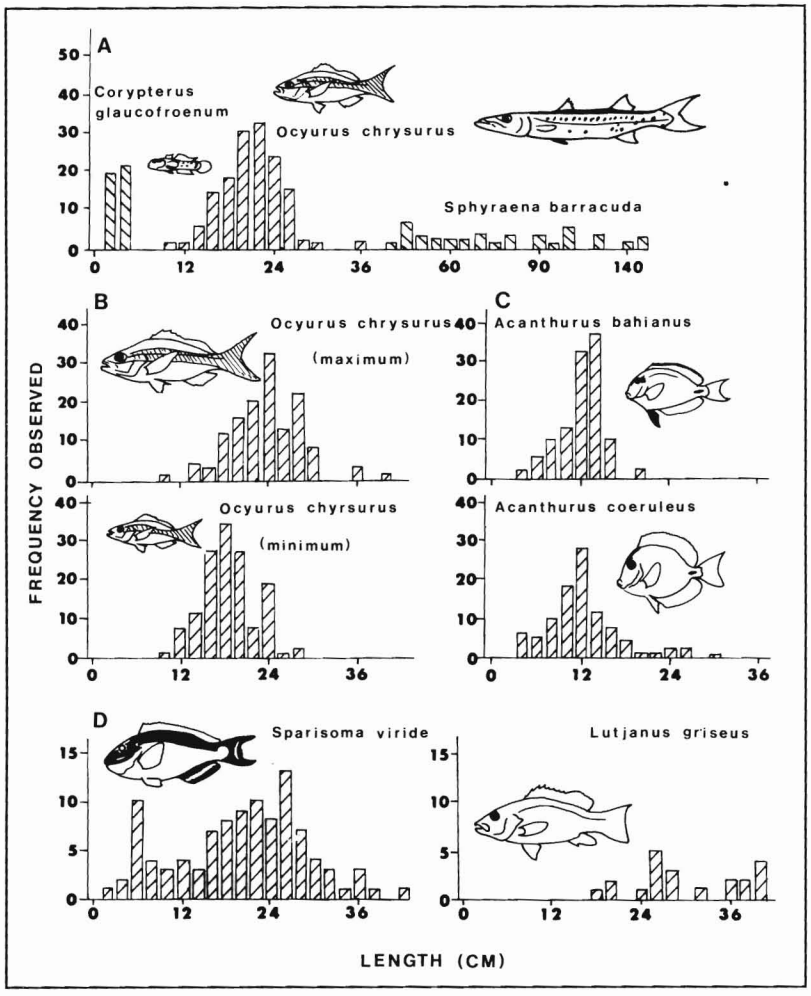


Figure 12.—Length/frequency histograms of selected species showing size distributions of individual species based on stationary sampling data. A. Mean lengths per sample for representative small, medium, and large species; B. Comparison of minimum and maximum lengths for *Ocyurus chrysurus*; C. length/frequency composition of two species with taxonomic, morphological, and ecological similarities; D. comparison of two similar-sized reef species in which one is found on reefs at all sizes while the other recruits only as a young adult.

between species. Clearly, community analyses based only on mean abundance may be misleading in terms of the biological importance of various species.

A major attribute of the SS method is that data are collected simultaneously on species composition, abundance, frequency of occurrence, and individual lengths for all visually detectable species. Thus, data on all major community parameters can be collected practically with this one method. Size distributions can be determined for individual species based on length data (Fig. 12). An index of biomass could be obtained from length data for each species by multiplying abundance estimates by weight based on empirically derived, species-specific length-weight relationships (Russell et al. 1978). Mean length data could be used directly to compare average stock sizes between habitats, reefs, and over time. Minimum lengths may be useful indicators of recruitment size for sampled habitats, while maximum lengths may be useful indicators of fishing pressure.

Abundance patterns from census data are characterized by high variance (Table 3). The SS method relies on ability to easily obtain large numbers of samples. Goodall (1970) noted in systems with naturally high variance that variance can be reduced more effectively by more intensive sampling than by improved precision. Also, for statistical purposes and for the same effort, many small samples are usually preferable to a few large samples. In general, confidence interval width for any parameter is narrowed with more samples.

Dispersion Patterns—Dispersion patterns, examined on the basis of variance-to-mean ratios (Pielou 1969; Brower and Zar 1977), showed that 105 out of 117 species (90%) censused on the Looe Key forereef were clumped, and 12 species (10%) were randomly distributed among samples (Table 3). No species were distributed uniformly. Among clumped species, 48 species did not differ significantly ($p > 0.05$) from a negative binomial distribution (Table 3). A total of 51 species had k values greater than 1000 which implies a Poisson distribution. Two species were rejected from the negative binomial curve fit program. The distributions of the remaining four species were significantly different ($p < 0.05$) from a negative binomial distribution but had low k values.

Most species exhibited clumped dispersion patterns due to schooling and the habitat heterogeneity of the forereef environment. This high variance between individual samples probably reflects true distributions on a reef in space and time. This suggests that nonparametric procedures may be most appropriate for analyzing raw data, although transformations and combining samples will normalize data in many cases and allow use of parametric procedures. The fact that many species fit a negative binomial distribution is important because it implies that mean abundances may not be the best criteria for comparing populations. Bannerot and Austin (1983) have suggested that statistics such as "k" or the negative probability of zero would be more sensitive measures for comparing populations with data fitting a negative binomial distribution.

Adequate Sample Size—The number of samples necessary for an adequate sample was examined by plotting performance curves (Fig. 13). Increases in cumulative species slows rapidly with additional samples (Fig. 13, top). An average of six samples included species representing 90% of the total individuals censused in 160 samples. Spearman rank correlation coefficients (Zar 1974), based on number of species in various numbers of independent randomly selected samples, were also plotted versus cumulative sample size. Correlations increased rapidly with sample size until leveling off around a value of 0.8 with 20 or more lumped samples (Fig. 13, bottom). No significant correlations were found for comparisons of one and two samples ($p > 0.05$) but all comparisons were significantly correlated with four or more lumped samples ($p < 0.05$), and very highly correlated with eight or more samples ($p < 0.001$). These results suggest that 8 to 20 samples may be sufficient for some purposes. However, adequate sample size depends on the statistical characteristics of a specific parameter, the acceptable chance of error, and the degree of resolution desired. The number of samples necesssary for a study can be estimated by usual statistical procedures (see Elliott 1977; Green 1979). More detailed comments on data analysis and community structure analysis are beyond the scope of this paper.

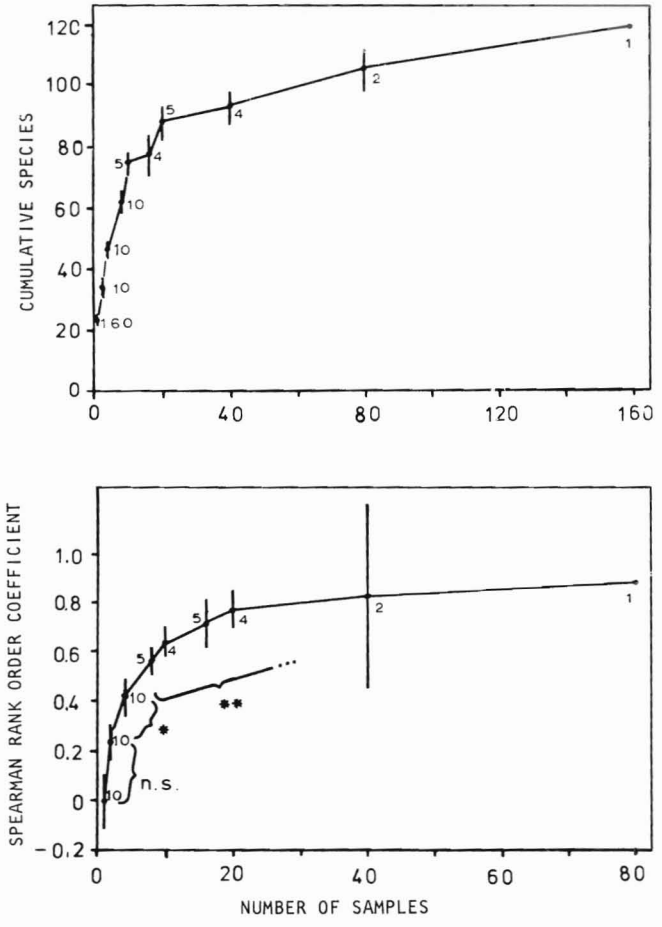


Figure 13.—Mean cumulative species (top) and mean Spearman rank correlation coefficients (bottom) for lumped samples. Vertical lines show 95% confidence limits. Numbers show sample sizes. Significance of Spearman rank correlation coefficients are indicated in the bottom figure (n.s., not significant; * = $p < 0.05$; ** = $p < 0.01$).

CONCLUSIONS

Stationary sampling is a new and valid method for sampling reef fish community structure even in diverse environments with abundant reef fish populations. It offers a standardized means of comparing reef fish communities and reduces many of the inadequacies of traditional visual sampling methods. It also offers many desirable features worth considering for reef fish sampling programs. Quantitative data are provided on frequency of occurrence, fish length, abundance, and community composition. The method is simple, fast, objective, repeatable, and easy to use. Species are accumulated rapidly for listing purposes, and large numbers of samples can be easily obtained for statistical treatment. Although we sampled for all observable species, the method can be modified to count specific taxa or groups of interest, such as commercial species, grunts, herbivores, or single species.

Despite the major advantages of stationary sampling, the method will not solve all sampling problems. As noted, the method is not suitable for use under certain environmental conditions. As with most visual methods, crevice-dwelling, cryptic, and very secretive species are probably not effectively sampled. Extremely intense sampling efforts would be required to detect all rare species. Finally, the SS method was designed to evaluate community structure: it may be inefficient, as presented, for studies concerned only with one, or a few, species or genera.

ACKNOWLEDGMENTS

We thank D. E. Harper, D. B. McClellan, and D. L. Sutherland of the Southeast Fisheries Center, National Marine Fisheries Service, NOAA, for contributing to the preparation of the manuscript, and G. Beardsley, B. Bohnsack, S. Bortone, D. G. Lindquist, J. Witzig, and an anonymous reviewer for critical comments and suggestions. Support for field operations was provided by I. Hooper (Newfound Harbor Marine Institute), C. R. Robins (Division of Biology and Living Resources, Rosensteil School of Marine and Atmospheric Science, University of Miami), and Klaus Rutzler (Smithsonian Institution). Research was supported in part by NOAA Postdoctoral Research Awards No. NA80AAD00108 and NA81AAD00102 from the Office of University Affairs; the Cooperative Institute for Marine and Atmospheric Studies, University of Miami; and the Sanctuary Programs Division, Office of Ocean and Coastal Resource Management, NOAA. Initial concepts were developed from funding by the Lerner Fund for Marine Research (American Museum of Natural History) and the Florida Sea Grant College Program with support from the Office of Sea Grant, NOAA, U.S. Department of Commerce, Grant No. NA80AA-E-00038.

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