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## QUANTIFICATION OF REEF FISH ASSEMBLAGES: A COMPARISON OF SEVERAL *IN SITU* METHODS

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**ABSTRACT:** On two coral reef biotopes off St. Croix in the U.S. Virgin Islands a total of 41 *in situ* visual assessments of reef fish assemblages were conducted using six different methods. These methods included: transect, quadrat, random count, cinetransect, cineturret, and still photography. The dependent variables (numbers of species and species diversity) were examined for possible influence by the independent sample variables (time of day, amount of observation time, reef site, and census method). Cluster analyses indicated that all methods gather data which allow community separation based on the sample variables. However, methods which tend to produce more "information" in terms of more species and numbers of individuals tend to recognize these sample variables more distinctly. Census assessment methods strongly influenced the dependent variables. It is suspected that the amount of time employed for each method may be the most important feature influencing *in situ* reef fish assemblage assessments.

Because of their diversity, reef fish assemblages have often served as a heuristic data source to test and formulate various ecological and evolutionary hypotheses including: stochastic/deterministic derivation of faunal composition (Dale 1978, Helfman 1978, Sale 1978, Sale 1980, Sale and Dybdall 1975, Smith 1978, Smith and Tyler 1975, and Talbot, Russell and Anderson 1978); species area relationships (Molles 1978); community succession and colonization (Sale and Dybdall 1975, Smith and Tyler

1975, and Talbot *et al.* 1978); and species diversity determinants (e.g., Helfman 1978 and Slobodkin and Fishelson 1974). Additionally, *in situ* data on reef fish communities have served to evaluate community responses to natural and artificial changes in the biotope (Bortone 1976 and Simpson 1977).

However, accurate and precise evaluation of species composition and abundance has been extremely difficult owing to the complexity and numerous inherent attributes of reef fish life histories such as: activity patterns (Hobson 1973, 1974); temporal variation in abundance (Talbot *et al.* 1978 and Thompson and Schmidt 1977); territoriality (Reese 1973 and Warner and Hoffman 1980); mixed-species schooling

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and heterotopic behavior (Ehrlich and Ehrlich 1973); migration (Bakus 1967, Bardach 1959, and Hobson 1972); and cryptic habits (Tyler and Böhlke 1972). Moreover, spatially irregular biotopes and high physical relief preclude the use of conventional surface-tended collection methods such as trawling and dredging to quantitatively sample reef fish assemblages (Bardach 1959).

Additionally, much of the high variation in population estimates currently observed may be due to the variety of methods used to assess these assemblages (Goldman and Talbot 1976). These methods have included special collecting techniques such as explosive charges (Goldman and Talbot 1976 and Talbot and Goldman 1972), ichthyocides (Smith 1973 and Talbot and Goldman 1972), photographic techniques such as underwater television (Smith and Tyler 1973a, 1973b), motion picture photography (Alevizon and Brooks 1975), and still photography (Simpson 1977). A variety of *in situ*, visual census methods have also been used such as transects (Bardach 1959, Brock 1954, Chave and Eckert 1974, Jones and Chase 1975, and McCain and Peck 1973); quadrats (Hastings 1979); patch counts (Molles 1978, Smith and Tyler 1972, and Talbot *et al.* 1978); point diversity (Slobodkin and Fishelson 1974); species-time, random count (Jones and Thompson 1978 and Thompson and Schmidt 1977); and estimated relative abundance (Bortone 1976, Chave and Eckert 1977, Gilligan 1980, Hastings, Ogren, and Mabry 1976, and Smith *et al.* 1975). Each of these methods has its own inherent positive and negative biases with regard to the types of individuals, species, and families present, as well as biases caused by a plethora of varying physical parameters. This suggests that methodological attributes alone may be

responsible for much of the problem in establishing a reliable data base with regard to community assessment, population dynamics, and standing biomass (Goldman and Talbot 1976 and Lundälv 1971).

Although the accuracy of most of these methods has never been adequately verified (Ehrlich 1975) there have been several attempts at utilizing multiple methods to further substantiate or add to a faunal analysis. Simpson (1977) used qualitative observations, still photography, and video recordings to evaluate a fish assemblage associated with an oil platform. Bardach (1959) studied a natural Caribbean reef using transects, rotenone ichthyocide, and mark (tag)-and-recapture. Jones and Chase (1975) used transects and a modified random count technique on the reefs off the coast of Guam. Chave and Eckert (1974) employed quadrats, transects, and estimated relative abundance to quantify relative fish abundance off Hawaii. Smith and Tyler (1972) used rotenone ichthyocide and patch counts to estimate reef fish populations in the Virgin Islands. Talbot and Goldman (1972) surveyed the fish fauna associated with the Great Barrier Reef using explosive charges and ichthyocides. Hastings (1979) and Hastings *et al.* (1976) combined estimated relative abundance with quadrat counts to assess fish communities in the Gulf of Mexico. Brock (1982) compared visual transect census data with rotenone collections off Hawaii. In addition DeMartini and Roberts (1982) compared visual transect data with the species-time, random count method. Kimmel (1985) developed a modification of the species-time, random count technique and compared his results with reef fish population data gathered by other methods.

Through the use of saturation diving in conjunction with the underwater diving facility Hydrolab (NULS-1), we were afforded an opportunity to employ several *in situ* methods of reef fish quantification at a single reef environment at two different reef biotopes, both diurnally and nocturnally, and within a relatively brief period of time (six days). We employed six methods (i.e., species-time, random count; transects; quadrats; linear cinetransects; circular cine-transects or cineturret; and still photography) generally according to descriptions in previous research publications. Our purpose here is to compare each of these methods as to how they describe the ichthyofauna of the reef environment and to assess the effects these methods may have in conjunction with physical parameters, in quantifying reef fish assemblages.

## DESCRIPTION OF THE STUDY AREA

The two reef biotopes surveyed were on the East and West sides of the entrance to Salt River Bay located along the north side of St. Croix, U.S. Virgin Islands. The East Wall reef has a slope of 10-20° and is composed mainly of coral cobble and boulders. In contrast, the West Wall reef is very steep and often vertical with many overhanging ledges and large coral formations. Minimum daytime underwater visibility was 7-25 m during the 27 Oct. - 1 Nov. 1978 study period. Surface waves were 0.5-1.0 m high and the bottom current was generally northerly at approximately 20 cm/sec. or less.

A 100 m transect line, marked at 10 m intervals, was placed along the 15 m depth contour on both East and West Wall reefs. On the East reef this transect traversed the 10-20° reef slope but on the West reef the transect was located along

the reef crest. Below the crest the reef was usually vertical.

## METHODS OF ASSESSMENT

### Transect

This method, with only slight modification, was conducted similarly to that of other authors; i.e., a diver swam slowly along one side of the transect line and counted all the fish, by species, which occurred in front of the diver and within 2m of one side of the line. We followed the procedure of Brock (1954) in counting fishes: if part of a school passed in front of the diver, members of the entire school were counted; schools or individual fish which crossed the transect behind the diver or recrossed in front were not counted or recounted during the census. Species names were prelisted on an opaque sheet of white plastic, roughened with sandpaper so graphite pencil could be used to mark abundance. A total of 24 transect surveys was conducted: 8 day and 4 night on the East Wall and West Wall. A diver required approximately 20-30 min. (generally 20 min. at night and 30 min. during the day) to traverse the entire 100 m transect and record species abundance. SCUBA was used throughout the entire study and handheld "divers" lights were used to facilitate all night surveys regardless of method. A total of 200 m<sup>2</sup> (100 m x 2 m) was surveyed during each transect census.

### Quadrat

Ten 2 m x 2 m quadrats were designated at 10 m intervals along the 100 m transect line. A diver took a position 5 m from the line and counted, by species, all fishes which were in or passed through an imaginary 2 m x 2 m x 2 m cube during a 10 min. time period (Slobodkin and Fishelson 1974). During

the 9th min. the observer moved close to the 4m<sup>2</sup> area to search for cryptic, secretive or diminutive fishes. Criteria for including or excluding schools or individuals were as in the transect method. The data from the 10 quadrats were summed per 100 m transect to constitute a census. The East Wall was surveyed twice diurnally and once nocturnally using the quadrat method. The West Wall was surveyed only once each diurnally and nocturnally. The total area observed per quadrat method was 40 m<sup>2</sup> (4 m<sup>2</sup> x 10). The total sample time per quadrat method was 100 min. (10 min. x 10).

#### **Random count**

The "species-time, random count" method developed by Thompson and Schmidt (1977) and Jones and Thompson (1978) was duplicated in the study area. Over the general region of the 100 m transects (no farther away than water clarity would allow, and no shallower than 10 m due to the saturated diving technique employed at Hydrolab) a diver slowly swam "randomly" over the reef for 50 min. Fish species were recorded as to whether they were initially observed during the first 10 min. time interval, second, third, fourth or fifth. A species was listed only once per sample. Later during analysis, a species was given an abundance score value of 5 if it was observed during the first 10 min. interval, 4 during the second, etc. Each 50 min. survey period was repeated 8 times during the day to compensate for individual survey variation (Jones and Thompson 1978). Time permitted only two surveys at night. A total diurnal sample time of 400 min. (50 min. x 8) was used to obtain relative abundance data for the East and West Walls; total nocturnal sample time was 100 min. (50 min. x 2) (5 x 8). The "number of individuals" used as a sample parameter for method com-

parisons was the sum of the abundance score for a species recorded either at the East or West Wall reefs, diurnally or nocturnally. The maximum abundance score was 40 for any species seen at either the East or West Walls in the daytime, and 10 for any species observed at night. Because of the "random" swim technique involved in this method, no measure of the surface area sampled was feasible.

#### **Linear Cinetransect**

Each 100 m transect was surveyed with a motion picture camera in the manner described by Alevizon and Brooks (1975). A diver swam slowly with the handheld underwater movie camera and exposed the film while slowly panning 2-3 m on either side of the transect line. It was necessary to expose two rolls of film (15 m each roll, super 8, high speed Ektachrome) to survey each transect. Both East and West Wall reefs were surveyed day and night using the cinetransect method. Total film exposure time for each transect was approximately 5 min. Each roll of developed film was subsequently reviewed by SAB and RWH at least three times with stop, slow motion, and reverse projection. All individuals seen on the film were identified (when possible) and counted. Any fishes appearing on the films which could not be identified because of poor focus or other reasons were excluded from the sample. An underwater movie light was used for filming at night.

#### **Cineturret (Circular Cinetransect)**

An additional motion picture technique was employed as suggested by A.W. Ebeling (pers. comm.). In this method, film was exposed while a diver slowly turned the handheld movie camera 360° parallel to the reef face. Exposure time was controlled at 2 min.

per revolution. Each 100 m transect was sampled by cineturret at three locations (0 m, 50 m, and 100 m) along its length. Therefore each cineturret sample was the sum of the data from three rolls of film totaling 6 min. of exposure. East and West Wall reefs were each surveyed diurnally. Developed films were examined as in the cinetransect method.

### Still Photography

At each 10 m interval along the 100 m transect a 35 mm (high speed Ektachrome, with strobe illumination) color transparency was exposed along each of the four compass coordinates (north, south, east, and west). The camera was handheld at a height of 1 m above the substrate and aimed-and-focused at a point 2 m away on the substrate. The developed slides were examined by SAB and RWH for species identification and abundance. Lists were compiled for 100 m transects based on 40 slides (10 stations, 4 frames at each station) taken diurnally on both East and West Wall reefs. Sample time was arbitrarily estimated at 1 minute for the 40 slides.

### Statistical Procedures

Comparisons were made among the methods as well as the associated independent sample variables (i.e., day-night, East Wall reef - West Wall reef, observation time). Dependent variables used in comparison were: number of species per sample, number of individuals (or scored abundance), and species diversity ( $H'$  calculated according to Pielou 1966).

Independent variables were used to determine which were significant contributors to variation in the dependent variables. Statistical methods used to make this assessment were: simple and multiple regression, step-wise multiple

regression, correlation, and analysis of variance and covariance. Additionally, Spearman rank correlation coefficients were used in a non-parametric comparison of the dependent variables. These analyses were conducted using the SAS statistical program package (SAS, 1979).

Four phenograms depicting the relationship among samples were generated using cluster analyses according to Sneath and Sokal (1973) with UPGMA clustering algorithm of the NT-SYS program package (Rolf, Kispauh and Kirk 1973).

A total of 41 samples was considered as OTUs compared (OTUs = Operational Taxonomic Units). The "characters" used to generate the data matrices were either the presence/absence of species per sample using the coefficient of Jaccard or the standardized number of individuals (or scored abundance) using the average distance coefficient, the Pearson product — moment correlation coefficient, and the Spearman Rank correlation coefficient.

Many authors have made various transformations on species abundance data (e.g. Barnes 1952, and Alevizon and Brooks 1975). Generally one would prefer to transform the species abundance data so that any correlation coefficient between the mean and variance is 0. We attempted several log, square root, and arcsine transformations on our data to remove the relationship between variance and mean but to no avail. Plots of the residuals clearly indicated a 4th order relationship that was never eliminated regardless of the transformation employed. Several explanations may be offered for this feature of our data but the most influential factor is probably the difference in social behavior of the various species (Taylor 1971) and the fact that species are not randomly distributed

within habitats (Gilligan 1980). Most other factors which affect the relationship of variance and mean can be predicted or described mathematically (and therefore corrected for). However, our observations indicated that social aggregation of individuals varied considerably among species. For example, some species are solitary while others may form negatively binomial (or Poisson), positively binomial, normal aggregations, or even intermediates of these. Additionally they may alternatively take on different aggregation patterns depending on temporal or physical circumstances (Sale 1978). Since the aggregation features are not predictable or consistent within some species, any simple transformation to remove the relationship of variance and mean would be purely accidental. We therefore have chosen to make our comparisons with cluster analyses based on only standardized abundance data (the abundance for each species was subtracted from the mean abundance for that species and divided by the standard deviation; see Sneath and Sokal 1973).

## RESULTS

A total of 41 *in situ* census samples was made during the study period resulting in a total of 126 reef associated fish species being recorded along with their relative abundance. These species abundance data for each census (Table 1) served as the basis for the data matrices used in all intra-and inter-methodology comparisons. A summary of the dependent and independent variables recorded for each census is present in Table 2. We made: 24 transect; 4 random count, 5 quadrat, 2 still photographic, 4 cinetransect, and 2 cineturret census samples. Twenty-one census samples were taken on the East

Wall reef, and 20 on the West Wall reef. Twenty-seven of the census samples were made diurnally while 14 were made nocturnally.

The highest number of species recorded was 90 observed in census sample WDR1 (West Wall reef, diurnal, using the random count method) and the fewest species recorded were 8 observed in census sample WNL1 (West Wall, nocturnal using the cinetransect method).

The purpose of this study was to evaluate and compare the census methods implemented. Therefore, two procedures were employed to accomplish these objectives. The first of these procedures employed several cluster analyses which served to determine the relationship patterns among the dependent variables and the potential influence that the independent variables may have on these relationships. Regression analysis permitted the assessment of the significance and degree of influence the independent variables have, accounting for variations in the dependent variables.

The dependent variables examined here were the number of species and the species diversity recorded for each census. The independent variables were place (East or West Wall reefs), time of day (day or night), observation time, and census method (transect, quadrat, random count, cinetransect, cineturret, or still photography).

## CLUSTER ANALYSIS

An analysis of samples using clustering techniques permits a visual examination of the similarities (or dissimilarities) based on the association or correlation among the dependent sample variables. Four separate types of cluster techniques were employed

**Table 1.** Alphabetically listed reef fish species and their relative numerical abundance (or score) for each sample. Sample letter-code designations are as follows: place - E = east wall reef, W - west wall reef; time of day - D = day, N = night; method of observation - T = transect, R = species time/random count, Q = quadrat, P = still photography, L = cinetransects (linear), U = cineturret (circular). Numbers following the code letter indicate repetitive samples.

	EDT1	EDT2	EDT3	EDT4	EDT5	EDT6	EDT7	EDT8	ENT1	ENT2	ENT3	ENT4	WDT1	WDT2	WDT3	WDT4	WDT5	WDT6	WDT7	WDT8	WNT1	WNT2	WNT3	WNT4	EDR1	ENR1	WDR1	WNR1	EDQ1	EDQ2	ENQ1	WDQ1	WNQ1	EDP1	WDP1	EDL1	ENL1	WDL1	WNL1	EDU1	WDU1	
<i>Abudefduf saxatilis</i>	-	-	-	-	-	-	-	-	1	1	-	-	-	1	3	1	1	1	-	1	-	-	-	-	13	5	38	10	-	-	1	5	1	-	-	-	-	-	-	-	-	-
<i>Acanthurus bahianus</i>	5	23	10	5	13	13	7	8	7	7	3	3	1	-	-	-	-	-	-	-	-	-	-	1	40	10	11	-	-	16	-	-	-	-	-	-	-	-	-	-	-	-
<i>Acanthurus chirurgus</i>	5	3	2	3	5	4	3	2	-	-	-	-	2	1	2	3	5	-	2	2	-	-	-	-	39	3	24	-	2	12	-	-	-	1	-	2	-	-	-	-	-	2
<i>Acanthurus coeruleus</i>	4	2	4	2	7	2	-	1	3	4	2	2	3	-	-	-	-	-	1	1	4	1	5	-	29	7	35	9	-	-	2	-	-	-	-	7	1	1	1	3	1	
<i>Aetobatus narinari</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<i>Amblycirrhitus pinos</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	5	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	
<i>Anchoa</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	1	-	-	-	-		
<i>Anisotremus surinamensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Anisotremus virginicus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Apogon binotatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	9	3	5	-	-	1	-	-	-	-	-	-	-	-	-	-	-		
<i>Apogon lachneri</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	31	19	20	31	-	4	5	10	-	-	2	11	-	-	-	-	-	1	-	-		
<i>Apogon maculatus</i>	-	-	-	-	-	-	-	1	2	1	1	-	-	-	-	-	-	-	-	-	5	4	2	-	9	-	5	-	1	-	-	-	-	-	-	-	-	-	-	-	-	
<i>Apogon robbinsi</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Apogon</i> sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	1	-	-		
<i>Apogon</i> sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Apogon townsendi</i>	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	16	10	14	3	9	15	10	-	1	-	6	-	-	-	-	-	-	3	-		
<i>Aulostomus maculatus</i>	-	-	-	-	-	1	-	-	1	2	-	-	1	1	1	-	-	-	-	1	1	2	33	7	30	4	1	-	1	3	-	-	-	-	-	-	2	-	-	-	-	
<i>Bodianus rufus</i>	-	-	-	-	1	1	-	1	-	-	-	-	2	8	3	1	2	4	5	4	-	-	-	11	-	28	-	2	-	4	-	1	-	-	-	-	-	-	-	-	-	
<i>Bothus lunatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Calamus</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Cantherhines pullus</i>	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Canthigaster rostrata</i>	1	3	1	1	-	2	1	-	-	-	-	-	5	4	3	4	3	9	5	6	-	-	-	34	-	35	-	4	1	-	9	1	-	-	-	-	-	-	-	-		
<i>Caranx latus</i>	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Caranx ruber</i>	-	-	-	-	-	-	-	1	-	-	-	-	2	-	-	-	7	-	1	-	-	-	-	28	-	23	-	-	6	-	1	-	-	-	-	-	-	-	-	-		
<i>Cephalopholis fulva</i>	2	7	7	8	4	8	7	4	-	2	-	-	1	1	1	-	2	4	-	1	-	-	1	40	5	37	-	1	9	1	2	-	2	-	1	-	-	-	1	-		
<i>Chaetodon capistratus</i>	-	2	1	1	-	-	-	-	-	-	-	-	1	7	4	5	4	2	6	3	4	-	-	17	8	40	7	-	-	7	-	-	-	-	-	-	3	-	-	-		
<i>Chaetodon striata</i>	2	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32	4	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Chromis cyanea</i>	5	4	9	5	8	4	7	8	-	-	-	-	28	69	100	21	32	88	44	29	-	-	-	38	-	40	-	4	1	-	47	-	3	18	7	-	19	-	-			
<i>Chromis multiineata</i>	-	-	-	-	-	-	-	1	-	-	-	-	35	155	390	50	55	231	123	41	-	1	1	-	32	-	40	8	-	-	87	-	-	23	-	-	-	98	-	-		
<i>Clepticus parrai</i>	-	-	-	-	-	-	-	-	-	-	-	-	4	28	54	1	11	70	9	-	-	-	-	1	18	-	35	-	-	2	-	-	-	-	-	-	-	-	-	-		
<i>Coryphopterus glaucofraenum</i>	2	3	4	-	7	1	2	1	-	-	-	-	1	-	-	1	1	-	-	-	-	-	-	31	-	18	-	6	-	2	-	1	-	-	-	-	-	-	-	-		
<i>Coryphopterus hyalinus</i>	-	-	-	-	-	-	-	-	-	-	-	-	199	204	90	160	285	290	313	212	-	-	-	17	-	40	-	2	2	-	351	-	-	19	-	-	75	-	-			
<i>Coryphopterus lipernes</i>	-	-	-	-	-	-	-	-	-	-	-	-	2	2	-	-	-	-	-	-	-	-	-	-	33	-	-	-	1	-	-	4	-	-	-	2	-	-	-	-		
<i>Decapterus</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Diodon holacanthus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Diodon hystrix</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	24	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Emmelichthys atlanticus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	5	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Epinephelus adscensionis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Epinephelus cruentatus</i>	-	-	-	-	1	-	1	-	1	-	-	-	1	-	-	-	-	1	-	1	-	1	-	6	-	28	8	1	-	-	1	1	-	1	-	-	-	-	-	-		
<i>Epinephelus guttatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17	3	8	-	1	-	-	-	-	-	-	-	1	-	-	-	-		
<i>Epinephelus striatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Equetus lanceolatus</i>	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-		



EDT1	EDT2	EDT3	EDT4	EDT5	EDT6	EDT7	EDT8	ENT1	ENT2	ENT3	ENT4	WDT1	WDT2	WDT3	WDT4	WDT5	WDT6	WDT7	WDT8	WNT1	WNT2	WNT3	WNT4	EDR1	ENR1	WDR1	WNR1	EDQ1	EDQ2	ENQ1	WDQ1	WNQ1	EDP1	WDP1	EDL1	ENL1	WDL1	WNL1	EDU1	WDU1
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	6	5	-	-	1	-	-	-	-	-	-	-	-	-
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-	2	8	-	-	2	2	-	-	-	-	-	56	48	51	57	56	22	43	51	-	-	-	28	40	-	1	-	-	47	3	-	10	-	-	-	20	-	-	4	
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-	-	-	-	1	1	-	1	-	-	-	-	1	3	2	2	-	1	1	-	-	-	-	16	1	23	-	-	-	1	-	-	-	-	-	-	-	-	-	-	
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6	10	5	1	12	10	10	1	-	-	2	-	1	1	1	-	1	2	1	-	2	1	-	37	9	39	8	3	4	-	3	-	3	1	5	-	-	-	-	-	
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1	-	-	1	-	-	-	-	2	-	1	-	-	-	-	-	-	1	-	-	-	1	-	16	5	22	5	4	1	1	-	-	-	1	1	-	2	-	-	-	
-	-	-	1	-	1	-	-	-	-	-	1	-	-	1	-	-	1	-	-	1	-	33	7	36	6	3	3	-	-	-	-	-	-	-	-	-	-	-	-	
25	56	13	39	30	30	26	64	-	-	-	-	4	1	5	6	9	1	5	3	-	-	-	18	40	-	28	-	17	20	-	2	-	3	-	-	2	-	1	-	
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	
1	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
1	-	-	-	-	-	1	-	-	-	-	-	2																												

Table 1. (Continued)

and each of these will be described separately below.

### Jaccard Coefficient of Association

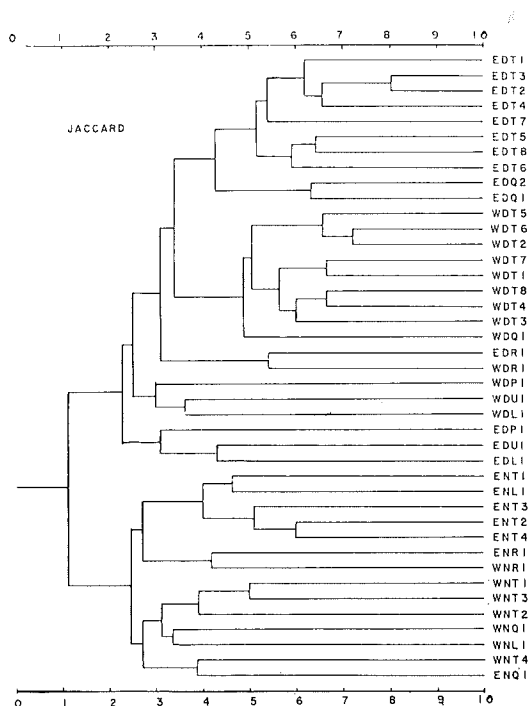
The phenogram in Fig. 1 depicts the relationship among the samples based on the Jaccard coefficient of association using the presence/absence of species recorded for each sample.

Two major clusters are formed at the 0.2 level of association based on the

time of day (diurnal and nocturnal). Within each of these clusters there was a general grouping of samples based on time of day and place (i.e. the East Wall reef and West Wall reefs) respectively. Methods were generally responsible for the third level of clusters. There were several exceptions to this generalization with regard to sample grouping by method for the third level of clusters. The random count method correctly aligned

**Table 2.** Summary of sample data. Sample letter-code designation as in Table 1.

Station Code	No. of Species	No. of Individuals	Species Diversity (H')	Observation Time	Method	Place	Time of Day
EDT1	26	186	2.37	30	T	E	D
EDT2	22	273	2.20	30	T	E	D
EDT3	25	164	2.47	30	T	E	D
EDT4	18	194	2.01	30	T	E	D
EDT5	27	227	2.40	30	T	E	D
EDT6	31	226	2.34	30	T	E	D
EDT7	29	197	2.51	30	T	E	D
EDT8	24	245	2.19	30	T	E	D
ENT1	13	39	2.24	20	T	E	N
ENT2	13	36	2.36	20	T	E	N
ENT3	16	36	2.55	20	T	E	N
ENT4	11	23	2.26	20	T	E	N
WDT1	32	400	1.97	30	T	W	D
WDT2	29	592	1.96	30	T	W	D
WDT3	28	780	1.78	25	T	W	D
WDT4	26	358	1.92	25	T	W	D
WDT5	28	526	1.77	25	T	W	D
WDT6	26	788	1.80	25	T	W	D
WDT7	33	625	1.81	30	T	W	D
WDT8	24	390	1.69	30	T	W	D
WNT1	10	66	1.65	30	T	W	N
WNT2	11	51	1.70	30	T	W	N
WNT3	14	61	2.05	19	T	W	N
WNT4	12	58	1.52	19	T	W	N
EDR1	71	1448	4.01	400	R	E	D
ENR1	33	199	3.38	100	R	E	N
WDR1	90	1802	4.25	400	R	W	D
WNR1	31	188	3.33	100	R	W	N
EDQ1	28	102	2.86	100	Q	E	D
EDQ2	26	152	2.79	100	Q	E	D
ENQ1	13	17	2.43	100	Q	E	N
WDQ1	41	660	1.91	100	Q	W	D
WNQ1	12	29	1.97	100	Q	W	N
EDP1	11	42	1.83	1	P	E	D
WDP1	15	85	1.97	1	P	W	D
EDL1	11	76	1.68	5	L	E	D
ENL1	9	17	2.02	5	L	E	N
WDL1	16	247	1.71	5	L	W	D
WNL1	8	12	1.98	5	L	W	N
EDU1	9	31	1.27	6	U	E	D
WDU1	10	86	1.64	6	U	W	D



**Figure 1.** Cluster phenogram of the 41 samples using Jaccard's coefficient of association. The letter code for sample designation is as follows: E = East Wall reef, W = West Wall reef, T = transect, Q = quadrat, R = random count, P = still photography, L = cinetransect, and U = cineturret. Numbers represent replicate samples. The co-phenetic correlation coefficient is 0.92. The maximum association possible is 1.0 and minimum is 0.

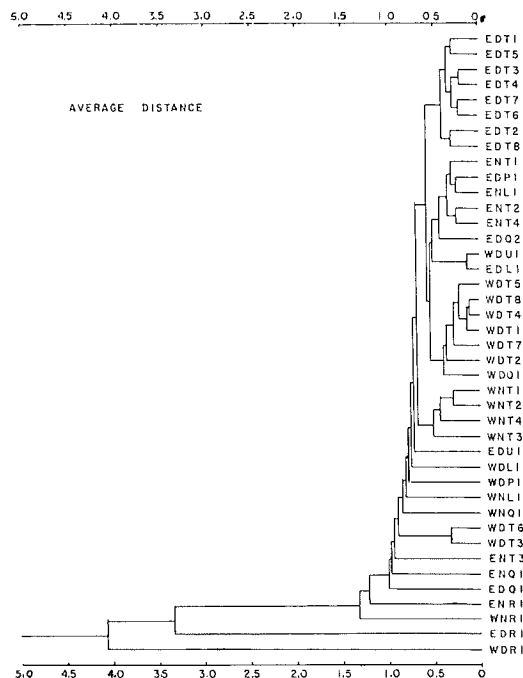
diurnally and nocturnally but tended to form clusters independent of the east and west reef samples. This can be attributed to the distinctly different fish assemblages which occur diurnally or nocturnally on a reef and the overall affinity that reef biotopes have based on a large total species list for a general reef area. Overall, the Jaccard's Association coefficient apparently produced strong intra-method associations partially based on the number of species generated per sample (Table 2).

There was an apparent indistinct association of samples obtained by photographic methods. This was possibly due to the paucity of species observed by each of these methods

(range = 8-16). Apparently the use of Jaccard's Association coefficient may seriously compromise some of the OTU's (samples) containing a reduced number of species. In the present case this was 6.3-12.7% of the total number of species (characters available for comparison).

### Average Distance

The phenogram representing the clustering of samples with regard to species abundance using the average distance coefficient (Fig. 2) indicates a considerably different relationship among the 41 samples being compared. This coefficient was used to depict a spatial relationship among the samples. This spatial relationship did form clusters associated with (in order) method, place, and time-of-day, most specifically for samples made using the transect method. Other methods did not



**Figure 2.** Cluster phenogram of 41 samples using average distance coefficients. The letter code for sample designation is as in Fig. 1. There is a possible minimum average distance of 0. The co-phenetic correlation coefficient = +0.99.

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**Table 3.** Correlation coefficients among the variables species, number of individuals, amount of observation time, and species diversity and their logarithms, where appropriate. Values recorded in the upper right half of the diagonal matrix are Spearman Rank correlation coefficients. Pearson product correlation coefficients are in the lower left half of the matrix. All correlation coefficients were significant at the .01 level.

No. of Species	Log No. of Species	No. of Individuals	Log No. of Individuals	Observation Time	Amount of Observation Time	Log Amount Diversity (H')	Species
No. of Species	—		.82		.67		.48
Log No. of Species	.92	—					
No. of Individuals	.91	.80	—		.42		.79
Log No. of Individuals	.77	.88	.81	—			
Amount of Observation Time	.86	.66	.77	.44	—		.56
Log Amount of Observation Time	.68	.69	.53	.46	.72	—	
Species Diversity (H')	.74	.66	.51	.31	.82	.67	—

seem to impart a distinct geometric association of the samples according to their ecological parameters. A notable exception (for other than transect data) were the samples made by the random count technique. An important positive feature of any method is the recognition of the distinctiveness of the samples. This can be done in geometric space. Therefore, methods which allow for distinctive separation in geometric space can be thought of as successful if it is a study objective to discriminate

census samples. The random count method, apparently through the large species lists generated and perhaps the unique feature of scoring relative abundance (even though standardized), permitted distinct graphic recognition and separation.

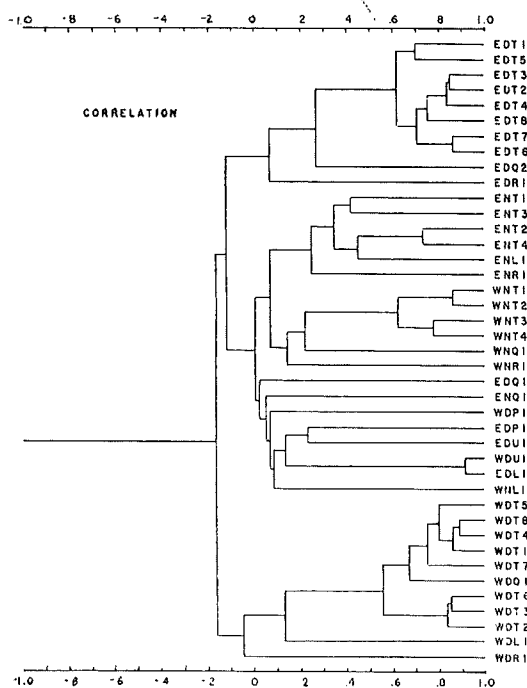
#### Pearson Product-Moment Correlation

A cluster phenogram based on the simple correlation matrix of samples by their respective species abundance (or score) was constructed (Fig. 3). Examina-

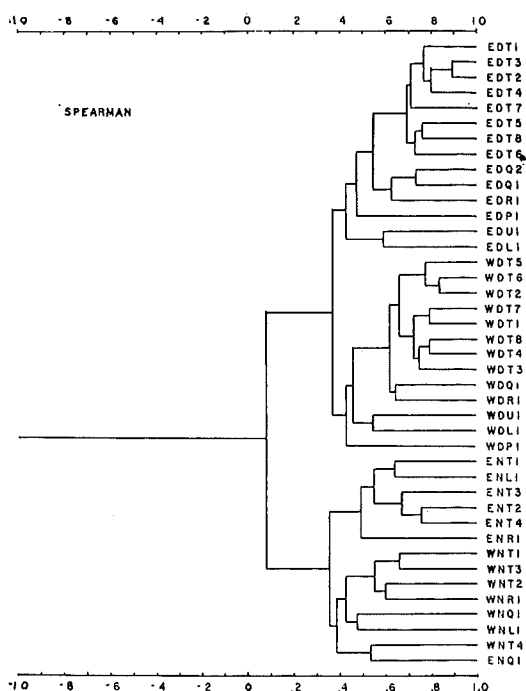
tion of the phenogram indicates that transect, random count, and quadrat methods tended to produce population estimate data which clustered together based on the two major independent variables: place and time-of-day. The clustering relationships among photography and cinematography samples formed a loose association cluster generally with little association based on the environmental parameters. This was evidenced by the cluster in Fig. 3 which includes with sample EDQ1, ENQ1, WDP1, EDP1, EDU1, WDU1, EDL1, and WNL1. With the exception of sample EDQ1 having 26 species all the other samples within the cluster consisted of only 8-15 species per sample.

### Spearman Rank Correlation Coefficients

A clustering phenogram was con-



**Figure 3.** Cluster phenogram of 41 samples using the Pearson product moment correlation coefficients. The letter code for sample designation is as in Fig. 1. The potential minimum-maximum values for correlation are -1 to +1. The co-phenetic correlation coefficient = +0.93.



**Figure 4.** Cluster phenogram of 41 samples using Spearman Rank correlation coefficients. The letter code designation is as in Fig. 1. The potential minimum-maximum values are -1 to +1. The co-phenetic correlation value = +0.92.

structed using the non-parametric Spearman Rank correlation coefficients based on the rank order of abundance of species within a sample to calculate the coefficients among samples (Fig. 4). We used this non-parametric approach as we are aware that the samples were not necessarily taken independently of each other as our presence on the reefs may have attracted or repelled certain species or individuals.

The phenogram produced by the inter-sample comparison of Spearman rank coefficients demonstrated a clear pattern of clusters composed of the congruent place and time-of-day variables regardless of sample method. The only exception was sample ENQ1 which aligned with samples that were from the West Wall reefs at night. We offer no explanation for this apparent discrepancy. We add, however, that the use of Spearman Rank correlation coefficients in

comparing methods requires fewer assumptions and seems to indicate that methods, regardless of what type, will tend to produce a rank order data base that discriminates between ecologically relevant parameters for reef biotopes such as place or type of reef and time-of-day.

## REGRESSION ANALYSIS

To examine the dependent variables in relation to their independent and associated dependent variables we have used multiple linear regression analyses. This will help determine the variables associated with producing the variability among the dependent variables. In this way it may be possible to determine the factors which may be necessary to control in future studies to obtain repeatable and reliable data on reef fish assemblages.

The dependent variables examined using regression analyses were again the number of species and species diversity. The independent variables were place, time-of-day, and method. Addi-

tionally we examined what effect amount of observation time might have had on the variation of the dependent variables.

Initially we determined the correlation relationship among all possible pairs of dependent variables and the independent variable, amount of observation time. This independent variable was chosen as a possible quantification aspect of an attribute of each method which would facilitate the regression analysis below. The correlation among these variables and their log transformed values can also indicate covariance (Fig. 3). Covariance among the dependent variables occurred because of the interrelationship between the number of species and the number of individuals. Predictably, the more individuals one records, the more likely one is to record additional species. Logically it would follow that the more time one employs to observe, the more individuals one will record. Although this point may seem overstated we will examine its importance to methods and their respective efficiencies below.

The multiple linear regression

**Table 4.** Multiple regression linear model of the independent variables: methods (each considered separately), number of individuals, day-night, time, East-West Wall reefs; on the dependent variable the number of species. The regression coefficient is 0.95 ( $R^2$ ) and is significant beyond the 0.0001 level. (\*\* = significant beyond the 0.01 level).

Model Parameter	Estimate	Standard Error of Estimate	T Value
Intercept	32.0626	± 4.3209	7.42**
Number of Individuals	0.0150	± 0.0051	2.96**
Methods			
Photography	-19.9632	± 5.0854	-3.93**
Quadrat	-13.5320	± 3.4798	-3.89**
Transect	-12.6875	± 3.9121	-3.24**
Cineturret	-23.6894	± 5.0431	-4.70**
Cinetransect	-18.1300	± 4.4085	-4.11**
Day-Night	- 8.8860	± 2.0743	-4.28**
Time	0.0603	± 0.0236	2.56**
East-West	- 0.2295	± 1.6010	-0.14

**Table 5.** Multiple regression linear model of the independent variables: methods (each considered separately), day-night, time, East-West Wall reefs; on the dependent variable  $H'$ . The regression coefficient is 0.89 ( $R^2$ ) and is significant beyond the 0.0001 level. (\*\* = significant beyond the .01 level).

Model Parameter	Estimate	Standard Error of Estimate	T Value
Intercept	3.3229	$\pm 0.2614$	12.71**
<b>Methods</b>			
Photography	-1.2391	$\pm 0.3071$	- 4.03**
Quadrat	-1.0215	$\pm 0.2044$	- 5.00**
Transect	-1.1346	$\pm 0.2322$	- 4.89**
Cineturret	-1.6989	$\pm 0.3040$	- 5.59**
Cinetransect	-1.3194	$\pm 0.2651$	- 4.98**
Day-Night	-0.0215	$\pm 0.0869$	- 0.25
Time	0.0025	$\pm 0.0008$	2.91**
East-West	-0.3667	$\pm 0.0735$	- 4.99**

models calculated, using each method separately, to predict the number of species ( $S$ ) and species diversity ( $H'$ ) are presented in Tables 4 and 5 respectively. Examination of these models indicates that methods were significant factors in explaining variation among the respective  $S$  and  $H'$  dependent variables. Likewise the amount of observation time was significant in explaining variation in these dependent variables. However, the variation in the numbers of species per sample was not explained by accounting for place (East or West). A significant difference between East and West reefs with regard to the number of species per

sample (22.19 and 24.75 respectively,  $P = .05$ ): however this independent variable is considered in conjunction with the other variables such as methods and amount of observation time, differences between East and West reefs were not significant.

Species diversity, similarly, was significantly affected by all variables (including place) except for day and night differences in this parameter. This agrees with a lack of significant difference which occurred between the mean species diversity per sample made diurnally and nocturnally (2.19 and 2.24 respectively).

**Table 6.** Analysis of variance (ANOVA) of the independent variables: number of individuals, methods (grouped), East-West Wall reefs, day-night and their interactions; as contributors to variation in the dependent variable, number of species. The regression coefficient ( $R^2$ ) is 0.97 and is significant beyond the 0.0001 level. (\*\* = significant beyond the 0.01 level).

Source	df	Type III Sum of Squares	F Value
Number of individuals	1	3.0530	0.26
Method	5	586.5180	9.94**
East-West	1	17.6276	1.49
Method x East-West	5	84.2806	1.43
Day-Night	1	249.6763	21.17**
Method x Day-Night	3	197.0505	5.57**
East-West x Day-Night	1	46.5953	3.95



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**Table 7.** Analysis of variance (ANOVA) of the independent variables: methods (grouped), East-West Wall reefs, day-night, and their interactions; as contributors to variation in the dependent variable H'. The regression coefficient ( $R^2$ ) is 0.96 and is significant beyond the 0.0001 level. (\*\* = significant beyond the .01 level; \* = significant beyond the 0.05 level).

Source	df	Type III Sum of Squares	F Value
Methods	5	12.0219	97.00**
East-West	1	0.0839	3.38
Method x East-West	5	0.9740	7.86**
Day-Night	1	0.1875	7.57*
Method x Day-Night	3	0.6064	8.15**
East-West x Day-Night	1	0.0158	0.64

It is apparent that methods, each considered separately, were responsible in accounting for variation in the dependent variables S and H'. Subsequently we were interested in knowing if methods, in general, as well as their interaction (with regard to application) with other independent variables, would be important in accounting for variation in the dependent variables S and H'. The results of this investigation using analysis of variance is presented in Tables 6 and 7 for S and H' respectively. These models generally indicate that methods and the interaction of methods with the variables, place and time-of-day, were significant in explaining variation in the census results for the dependent variables number of species and species diversity. The only notable exception was the method-place interaction. It would appear, therefore that methods were not biased in their application to either the East or West wall reefs.

Clearly, methods (both singly and collectively) were extremely important as they affect the results *in situ* of reef fish surveys or census studies with regard to the number of species and species diversity. To examine what specific aspect of method (as a variable) may be responsible for affecting the results of the survey, we could look to two quantifiable features inherent in the methods. The

first of these would be variation in results attributable to the amount of area surveyed. Although this is probably an important aspect of any methodology we were unable to accurately assess the amount of reef area surveyed for all methods. We therefore leave the question of area as an aspect of method that is responsible for variation in reef census results unresolved. A second component of method that we are able to analyze is amount of observation time.

As indicated in our previous multiple linear regression analyses, amount of observation time was one of the significant independent variables accounting for variation in the census results for both number of species per sample and species diversity. To examine for the effect of observation time on the results, we constructed another multiple linear regression model for S and H' (Tables 8 and 9 respectively) but eliminated methods and included observation time as one of the independent variables. The results of this analysis indicate that amount of observation time was indeed highly significant in accounting for variation in the census result of variables S and H'. This is even further substantiated by examining the results of a stepwise multiple linear regression analysis (10). This model indicates that amount of observation time was the second largest

**Table 8.** Multiple regression linear model of the independent variables: number of individuals, day-night; time, East-West Wall reefs; on the dependent variable the number of species (S). The regression coefficient is 0.91 ( $R^2$ ) and is significant beyond the 0.0001 level. (\*\* = significant beyond the 0.01 level).

Model Parameter	Estimate	Standard Error of Estimate	T Value
Intercept	14.9736	$\pm 1.4472$	10.35**
Number of Individuals	0.0228	$\pm 0.0050$	4.65**
Day-Night	- 4.0516	$\pm 2.1975$	1.84
Time	0.0796	$\pm 0.0185$	4.29**
East-West	- 1.8042	$\pm 1.8919$	0.95

contributor to variation in the number of species per sample after the number of individuals. We should point out, however, that both models using observation time in place of method produced multiple regression models with lower known  $R^2$  values indicating that methods have attributes other than amount of observation time which contribute to variation in the dependent census variables.

## DISCUSSION

In general all visual census methods produced some type of relative quantification of proportional abundance of species. Methods which produced the greatest amount of data or information with regard to number of species and abundance tended to produce less error or confusion in recognition of ecological parameters. Methods which produce the lowest numbers of species and numbers of individuals (and therefore less infor-

mation) apparently do not allow for the recognition and identification of assemblages of ecological significance. Methods which "see" the highest number of species may be the most useful in establishing or describing the fish fauna of reefs. Similarly, the discriminatory ability of methods to recognize the importance of ecological differences was greatest in those methods which produced the most information.

Maximum information can be expected to result from maximum observation or assessment time. Therefore, those methods which utilized more observation time produced more information in terms of numbers of species and individuals. One would suspect that the amount of area observed would also produce a high positive correlation with information. Unfortunately, in our study we were unable to estimate area accurately for enough methods to permit a reliable comparison.

The significance of the amount of

**Table 9.** Multiple regression linear model of the independent variables: day-night, time, East-West Wall reefs; on the dependent variable  $H'$ . The regression coefficient is 0.76 ( $R^2$ ) and is significant at or beyond the 0.0001 level. (\*\* = significant beyond the .01 level, \* = significant beyond the .05 level).

Model Parameter	Estimate	Standard Error of Estimate	T Value
Intercept	2.0099	$\pm 0.0848$	23.69**
Day-Night	0.1566	$\pm 0.1046$	1.50
Time	0.0060	$\pm 0.0006$	10.28**
East-West	-0.3630	$\pm 0.0988$	3.67**

**Table 10.** Stepwise multiple linear regression of all independent variables significant beyond the 0.05 level in estimating the number of species. The analysis included each of the methods considered separately.

Step	Variable Entered	R <sup>2</sup>	Model Parameter	Estimate	Standard Error of Estimate
1	Number of individuals	0.83	Intercept	12.4821	
			Number of individuals	0.0383	± 0.0028
2	Time	0.89	Intercept	12.2751	
			Number of individuals	0.0257	± 0.0036
			Time	0.0717	± 0.0155
3	Day-Night	0.91	Intercept	14.6515	
			Number of individuals	0.0202	± 0.0041
			Time	0.0882	± 0.0162
			Day-Night	- 4.8389	± 2.0341
4	Transect	0.92	Intercept	12.6888	
			Number of individuals	0.0157	± 0.0044
			Time	0.1114	± 0.0187
			Day-Night	- 5.8863	± 1.9970
			Transect	4.0219	± 1.8455

observation time is of utmost importance in standardizing the information derived from faunistic assemblage assessment; failure to recognize this feature has caused significant misinterpretation and subsequent erroneous hypothesis generation in the ecological literature (Connor and Simberloff 1978).

We recognize the overall importance of amount of observation time in influencing the results of *in situ* reef fish assemblage assessment. Nevertheless, a discussion is in order with regard to the features of methods which may allow for optimum methodological implementation once the amount of observation time is standardized. Each method had several positive and negative features, but only the major features will be considered here.

An overall influencing factor that has been cited by several authors as a special problem in *in situ* reef fish assemblage assessment is visibility. In our comparative study, visibility was high and consistent, and therefore, for com-

parative purposes, was not a significant factor, however, photographic methods in general would be more severely affected when used in low visibility circumstances. The random count technique would probably be the least affected by changes in visibility while other techniques (i.e., quadrat and transect) would suffer intermediately from the influence of visibility.

Our comparison of different methods of *in situ* reef fish assemblage assessment however reveals several features which may aid researchers in future studies. If a choice of implementing one or more assessment methods is available, the attributes of efficiency, time, or type of dependent variable parameter may dictate the type of method employed. For example, the random count technique as developed by Thompson and Schmidt (1977) and Jones and Thompson (1978) permits the accumulation of a higher number of species than do other techniques. However, the use such a technique for

the calculation of species diversity indices may be questioned because scored abundance is used instead of actual abundance. Future efforts should be directed toward converting "scored" abundances to "real" abundances to make the technique more applicable. If identification is a problem, those techniques which give permanent records on film or tape may be more useful except that we had some difficulty in identifying some species and individuals from photographs. Transect techniques in particular are influenced by identification problems as the effective observation time is reduced considerably by the presence of large numbers of difficult to identify organism.

Problems with identification, data recording, and observation are all critical to the acquisition of accurate reef fish census data. Currently we believe that the random count technique has the most potential of all those attempted here. Its limitation can be overcome by careful evaluation of census data under a variety of field conditions so that coefficients can be developed to effectively adjust the scored abundance data to more accurately reflect real abundance parameters. The random count technique accumulates large numbers of species owing to this being the method's main objective. Overall the random count method presents a challenge for each diver to record as many species as possible. This positive reward aspect of method implementation serves the observer as a work stimulus under sometimes difficult conditions. With *in situ* counting methods or film recording techniques the observer tends to treat the task of data gathering as a labor. While this is hardly a scientific reason for choosing one method over another, one must be aware of the advantages of a positive reward

technique when conducting census samples under less than ideal and sometimes apprehensive or stressful circumstances.

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