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Stephen A. Bortone
University of West Florida

Joseph J. Kimmel
University of Puerto Rico

Charles M. Bundrick
University of West Florida

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A COMPARISON OF THREE METHODS FOR VISUALLY ASSESSING REEF FISH COMMUNITIES: TIME AND AREA COMPENSATED

Stephen A. Bortone[1], Joseph J. Kimmel[2], and Charles M. Bundrick[3]

ABSTRACT: Reef fish assemblage survey results using Transect, Point, and Random *in situ* visual assessment techniques were evaluated and compared on a coral reef biotope off the southwestern coast of Puerto Rico. Parameters compared were: number of species, number of individuals, and species diversity (H'). No significant effect attributable to the time-of-day when the surveys were conducted was noted to occur. Variability in observations between divers was not noted for any of the dependent variables while conducting the Transect method. Divers using the Random technique recorded the highest number of species per survey, while the assemblage parameters recorded using Transect and Point methods were statistically similar for most dependent variables. Point surveys, however, had a higher and less variable species diversity. When the data were adjusted for amount of survey time and area it was determined that divers were more efficient in sampling numbers of individuals when using the Transect method.

Recently, an interest has developed in the underwater visual assessment of reef fishes (*e.g.*, Barans and Bortone 1983; Harmelin-Vivien *et al.* 1985). This interest is due to several reasons as natural reefs serve as important biotopes for testing evolutionary/ecological hypotheses (see Bortone *et al.* 1986 for a partial review). Additionally, to assess the relative "health" of natural reefs in terms of productivity, accurate community data are required. Furthermore, advances in the technology of artificial reef design (Buckley *et al.* 1985) depend on the development of accurate, quantitative data on fish community abundance and biomass (Bohnsack and Sutherland 1985).

Visually gathered reef fish abundance data avoids the substrate disrupting effects of traditional, surface tended collecting devices such as trawling (Bardach 1959). However, a plethora of problems make reef fish assemblage assessment by any general method difficult. These problems stem from the "... complexity and numerous inherent attributes of reef fish life histories ..." (Bortone *et al.* 1986:1) involving their behavior and their utilization of spatially irregular reef substrates. Additionally, there are logistical and analytical constraints inherent in each of the *in situ* visual techniques developed to date. These include difficulties in implementing some methods under less than ideal conditions such as poor visibility, strong currents, or especially irregular substrates. Some methods suffer from diver-related problems such as difficulties in manually recording data, accuracy of species identification, and diver fatigue. These problems, coupled with the previously mentioned behavioral aspects of the fauna such as secretive habits, schooling, and competitive interactions, illustrate the need to develop visual census techniques which permit accurate and efficient assessment of reef fish assemblages.

Many visual techniques for the assessment of reef fish assemblages have been implemented since Brock's (1954) pioneering study of Hawaiian fishes. Most of them have not been

[1]Biology Department, University of West Florida, Pensacola, FL 32514, U.S.A.

[2]Department of Marine Sciences, University of Puerto Rico, current address: Bureau of Marine Research, Florida Department of Natural Resources, 100 Eighth Avenue SE, St. Petersburg, FL 33701, U.S.A.

[3]Institute for Statistical and Mathematical Modeling, University of West Florida.

tested or verified for suitability and/or accuracy and often merely reflect a researcher's personal preference. Several recent studies have, however, attempted to objectively compare some methods (*e.g.*, Bortone *et al.* 1986, Brock 1982, DeMartini and Roberts 1982, Kimmel 1985, Sanderson and Solonsky 1986). These studies have used various visual methods to assess fish abundance and employed several analytical techniques to clarify some problems but there remains no clear consensus as to what method is the "best" for all or any specific set of conditions.

To help answer this methodological question, two observers compared six different methods under a variety of reef conditions (Bortone *et al.* 1986). The conclusion of that study was that all of the compared methods are roughly equivalent in their ability to qualitatively describe a fish assemblage. Methods that produce the most information (*i.e.*, number of species and number of individuals) tend to have less variance and more accurately associate environmental parameters with a particular assemblage. Also, the amount of sample time (and perhaps area) appears to be the most significant variable affecting the similarity of assemblage assessments, regardless of method. This suggests that, of the methods tested, those which produce the greatest amount of information in the least amount of time (or area surveyed) would be the most effective. Given that conventional scientific diving is monitarily expensive and constrained by depth-duration relationships, it is extremely important to develop techniques for *in situ* visual assessments which are efficient for these attributes. It is also imperative to know precisely how important the variables of time and area are to each method. This may allow future researchers to make adjustments or transformations in their data to permit accurate comparisons with other studies for which data were gathered using methods varying in the time or area surveyed.

The purpose of this study was to identify the significance of time and area among various visual assessment methods. This was accomplished by employing three different visual assessment techniques in a single location while recording the amount of time and area surveyed by each technique and by analyzing our data in ways that allowed us to evaluate the utility of the various visual methods for assessment of reef fish assemblages.

METHODS

Description of the Study Area

All visual surveys were conducted on the flat portion of a reef front called "El Palo" located 6.5 km SW of La Parguera, Puerto Rico. This reef area, along the southwestern coast of Puerto Rico, was chosen because it had a reasonable homogeneous, flat-bottom topography of hard coral, soft coral and sponge and had a bottom depth of 9-12 m. During the study period of 24 September to 3 October 1983 the water temperature was between 28.7 and 29.7 °C and visibility fluctuated between 10 and 15 m. Surface winds were generally out of the East at 10-15 knots (18.5-27.7 km/hr).

Within the study area, a grid system of transect lines was emplaced for spatial reference. The grid consisted of eight yellow polypropylene lines, each 100 m in length and anchored across the substrate to create a grid of nine squares, each side 33.3 m long (Fig. 1). The lines were in place at least 6 months prior to the study.

Visual Census Techniques

Transect method — A diver swam parallel to one side of a transect line at a distance of one meter while identifying and counting the number of individuals by species encountered within a zone two meters wide, parallel to the transect. Criteria for including fishes in our samples were consistent with Brock (1954) where: if only part of a school of fishes passed in front of the observer then the entire school was counted; individuals or schools which recrossed the transect or those passing behind the observer were not included in the sample. Observations were recorded with pencil on opaque plastic sheets roughened with sand paper. Divers noted the sample duration, time of day, and species abundance for each 33.3 m interval. A total of twenty-four, 33.3 m long transect surveys was conducted over the entire grid by each diver. The area surveyed per transect was 67 m² and the average amount of time per survey was 8.3 min. The total area surveyed by both observers using the transect method was 3216 m² and the total survey time for the entire grid was 400 min.

To make comparisons between divers, a single 33.3 m section of the transect was alternately surveyed by each diver. A total of 20 visual transect surveys (11 conducted by J. J. Kimmel and 9 by S. A. Bortone) were used to evaluate differences in survey data recorded between the two divers. Significant interaction effects between divers and methods (indicating the preference or ability to conduct one method over another by divers) was determined using ANOVA.

Point method — A diver took a position central to a corner of each quadrant of the grid and counted and recorded the number of individual fish by species for 12.5 min. While observing, the diver slowly rotated counterclockwise in a single sweep so that a circular area having an estimated radius of 5.6 m (18 ft.), with the diver at its focus, was surveyed. Criteria and methods for recording data were as described for the Transect technique. Alternate points in a "checker board" fashion were occupied by JJK and SAB, each diver making 18 surveys for a total of 36 point counts. The area surveyed with each Point was 98.5 m² while the total area surveyed by both observers with this method was 3546 m². Total time to survey the entire area with the Point method was 450 min. To compare inter-diver differences in survey data, one area of the grid was alternately resampled eight times by each diver.

Random method — The "species-time, random count" method developed by Thompson and Schmidt (1977) and Jones and Thompson (1978) was employed within the grid system. Each diver, swimming in an irregular or "ran-

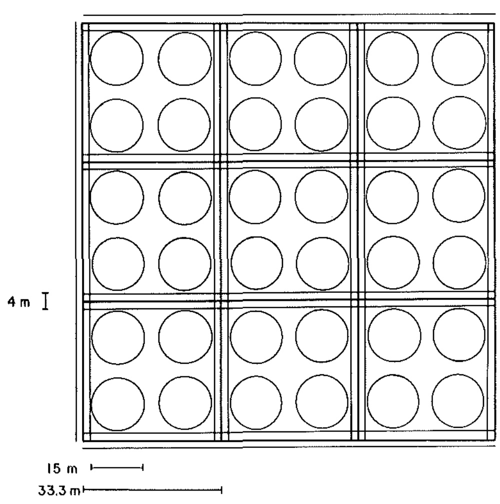

Figure 1. Diagram of the study grid. The heavy lines indicate the transect grid lines as positioned. The thinner lines paralleling them are the limits on either side of the line for the Transect method. Circles indicate the position and limits of the Point method. The Random method was conducted within the boundary of the outermost, heavy lines.

dom" pattern, censused fishes for a period of 50 min. "This 50 min period was broken up into five 10 min intervals and species were recorded as present in the interval in which they were first seen." (Kimmel 1985:25). "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." (Bortone *et al.* 1986:4). The survey was repeated 8 times (four for each diver) and the final "abundance" score was determined for each species by summing the scored abundance for each of the eight surveys. The maximum abundance a species could receive was 40. The total area surveyed was 80000 m^2 (8 surveys × 10000 m^2 grid area) and the total survey time for the random count method was 400 min.

Surveys using each of the three methods were conducted in a rotational sampling schedule to reduce possible introduction of bias due to the time of day, weather conditions, and method-method interaction. To test for diurnal effects, a sampling schedule was chosen so that alternate methods were used between 0945 and 1900 hrs. Surveys were assigned to four time intervals to detect diurnal bias when using Transect and Point methods.

Data Analysis

Log transformed data on species abundance data obtained using the Transect and Point methods and non-transformed scores from the Random technique were used to compare and contrast the survey results. Among the analyses performed were analysis of variance (ANOVA) and multiple linear regression on the dependent variables: number of species, number of individuals, and species diversity (H' calculated according to Pielou 1966). To further compare survey data obtained using the Transect and Point methods, randomly chosen surveys were combined to form larger data sets for each method. These pooled data sets were then used to compare the rate of species accumulation and fluctuations in species diversity. To account for the effect of time and area, additional sets of randomly chosen surveys were constructed to allow for the formation of a linear relationship between the variables time and area in successively larger sets. An analyses of covariance was then performed on these combined sets of surveys. All analyses were conducted using the SAS (SAS, 1985) statistical analysis programs.

RESULTS

Summaries of the survey effort and species abundance data used to compare the three visual reef fish assessment methods are presented in Tables 1 and 2. However, before a rigorous and realistic comparison of the three census techniques can be conducted, several variables which may account for considerable sample variation must be examined.

Time-of-Day

The results of an ANOVA analysis indicated that there were no significant differences among the dependent variables (*i.e.*, number of species, number of individuals, or species diversity) owing to the influence of the time-of-day during

Table 1. Summary of survey effort used in comparing the three visual techniques used for assessment of a Puerto Rican reef fish assemblage.

	Transect	Point	Random
No. of surveys	48	36	8
Area/survey (m^2)	67	98.5	10000
Total area (m^2)	3216	3546	80000
Time/survey (min)	8.33	12.5	50
Total time (min)	400	450	400

Table 2. Total abundance estimates for 76 reef fish species using three visual census assessment techniques. Values for the Random technique are scored abundance (maximum = 40).

Species	Transect	Point	Random
Abudefduf saxatilis	0	0	1
Acanthurus bahianus	250	296	40
A. chirurgus	5	2	2
A. coeruleus	100	91	40
Anisotremus virginicus	0	0	5
Aulostomus maculatus	5	8	15
Bodianus rufus	1	0	5
Calamus pennatula	0	2	2
Cantherhines pullus	2	0	23
Canthigaster rostrata	9	11	21
Caranx ruber	4	84	29
Chaetodon capistratus	20	27	39
C. striatus	10	9	34
Chromis cyaneus	0	0	15
C. multilineatus	0	0	20
Cryptotomus roseus	14	7	8
Dasyatis americana	0	0	2
Epinephelus adscensionis	1	0	1
E. cruentatum	14	7	21
E. fulvus	0	0	10
E. guttatus	8	5	14
E. striatus	1	0	1
Ginglymostoma cirratum	0	0	1
Gramma loreto	2	2	15
Gymnothorax funebris	0	0	3
G. moringa	0	1	0
Haemulon aurolineatum	0	0	5
H. chrysargyreum	2	5	21
H. flavolineatum	22	7	35
H. plumieri	4	2	28
H. sciurus	0	2	17
Halichoeres bivittatus	117	74	40
H. garnoti	0	1	3
H. maculipinna	39	28	26
H. poeyi	69	83	39
H. radiatus	17	20	36
Holacanthus ciliaris	1	0	9
H. tricolor	0	0	3
Holocentrus rufus	76	39	40
Hypoplectrus chlorurus	4	1	18
H. guttavarius	0	0	4
H. indigo	3	1	7
H. nigricans	1	0	0
H. unicolor	1	0	7
Lactophrys triqueter	0	1	3
Lujanus apodus	0	6	27
L. jocu	0	0	2
L. mahogoni	1	0	22
Microspathodon chrysurus	30	35	39
Monacanthus tuckeri	1	1	3
Mulloidichthys martinicus	4	5	33
Myripristis jacobus	1	1	3
Ocyurus chrysurus	16	24	31
Opistognathus aurifrons	1	0	13
Pomacanthus arcuatus	2	3	12
Pomacentrus diencaeus	3	2	7
P. partitus	274	225	40
P. planifrons	334	142	38
P. fuscus	206	103	39
P. variabilis	45	33	39
Pseudupeneus maculatus	6	10	26
Scarus coelestinus	3	1	12
S. croicensis	192	200	40
S. taeniopterus	9	3	3
S. vetula	9	6	28
Seriola dumerili	0	1	1
Serranus baldwini	0	1	0
S. tigrinus	1	1	0
Sparisoma atomarium	0	1	8
S. aurofrenatum	441	477	40
S. chrysopterum	17	20	14
S. rubripinne	8	8	14
S. viride	269	233	40
Sphyraena barracuda	0	0	3
Synodus intermedius	7	10	0
Thalassoma bifasciatum	111	91	40
CUMULATIVE NO. SPECIES	54	54	71

which the surveys were conducted (Table 3).

Diver Comparison

The results of a paired t-test (accounting for unequal variances) indicated that records taken by JJK and SAB differed significantly when using the Point method for the dependent variables: number of species and species diversity (Table 4). Likewise, when using the Random method, divers differed in the numbers of species as well as abundance scores recorded (note: it is not possible to calculate the species diversity index when using the Random generated data). Transect assessment results, however, indicated no significant differences between divers for these same parameters.

Significant differences between reef fish assemblage parameters determined by divers occurred for the dependent variables: number of species and species

Table 3. Comparison of number of species, number of individuals and species diversity with regard to the time of day using survey data combined from both Transect and Point methods. ANOVA indicated no significant difference among the variables with respect to time of day.

Time of Day	N	Mean No. Species	Mean No. Individuals	Mean H'
09:45-11:00	20	15.1	61.0	2.27
11:00-12:59	25	14.0	65.2	2.25
13:00-14:29	19	14.1	61.8	2.19
14:30-19:00	20	14.6	62.0	2.20

diversity; and differences between methods occurred when recording the variables: number of species and number of individuals. It should be noted, however, that no significant diver-method interaction was observed indicating biases were not due to diver-method preference or facilitation (Table 5). Spearman rank and Pearson product correlation coefficients between divers were high and significant indicating good agreement between divers irrespective of the particular method employed (Table 6).

Method Comparison

With regard to the number of species

Table 4. Comparisons between divers using three visual census techniques for the dependent variables: number of species, number of individuals (log transformed), and species diversity (H'). Surveys using each method were conducted on the same section of the reef. (* and ** indicate significant differences beyond the 0.05 and 0.01 levels, respectively)

	Diver	Transect	Point	Random
Mean No. Species	JJK	12.4	19.9	37.4
			**	**
	SAB	12.1	15.6	29.6
Mean No. Individuals	JJK	48.3	77.6	(148.3)
				**
	SAB	46.3	66.0	(115.9)
Mean Species Diversity H'	JJK	2.12	2.44	—
			*	
	SAB	2.07	2.29	—

observed (Table 7), divers employing the Random technique recorded, statistically, the highest number of species per survey (mean = 41.2, $p<0.05$), while divers using the Transect and Point techniques recorded fewer but statistically similar

Table 5. Results of analysis of variance of the independent variables: diver, method of assessment (transect and point), and the interaction effect of diver and method; as contributors to variation in the dependent variables: number of species, number of individuals, and species diversity. F values are marked with *, **, or *** indicating significance beyond the 0.05, 0.01 and 0.001 levels, respectively.

Independent Variables	Dependent Variables No. Species	No. Individuals	H'
Diver	8.75**	0.31	14.83***
Method	4.06*	5.42**	0.94
Diver X Method	0.05	0.05	0.87

numbers of species per survey (13.9 and 15.1, respectively). Since the Random technique generates species abundance data as a score rather than a relative number, it is not possible to compare the derived abundance or species diversity data with data from the Transect and Point methods. In general, divers using

Table 6. Spearman rank and Pearson product correlation coefficients between divers JJK and SAB for species abundance data obtained by three methods. All coefficients are significant beyond the 0.0001 level.

Method	Spearman	Pearson
Transect	.76	.88
Point	.84	.98
Random	.76	.86

the Transect method recorded only 58.4 individuals per survey while they recorded a significantly higher ($p<0.05$) mean number of individuals per survey (68.3) using the Point method. The mean species diversity calculated per survey was nearly equal; 2.21 and 2.25 for the Transect and Point methods, respectively. Overall, there was a tendency for divers using the Point technique to record more species,

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Table 7. Visual census parameter comparison among the three methods. Significant differences ($p<0.01$) occurred between the average number species recorded with the Random technique and both other techniques. Also a significant difference was noted in the average number of individuals recorded by the Transect and Point Methods. Value in parentheses indicates scored abundance.

Survey Parameters	Transect	Point	Random
Number of surveys	48	36	8
Area/Survey (m^2)	67	98.5	10000
Time/Survey (min)	8.3	12.5	50
Mean Species/Survey	13.9	15.1	41.2
Mean Individuals/Survey	58.4	68.3	(166.5)
Mean H'/Survey	2.21	2.25	—
Total Number of Species	54	54	71
Total Number of Individuals	2803	2459	(1332)

more individuals and a higher species diversity per survey than when employing the Transect method. Divers using the Random method certainly recorded more species but the technique's method of accounting for individuals using a scored abundance precludes its use in a direct comparison with the other methods employed here.

We compared diver recorded reef fish assemblage parameters using a random design to determine how the Transect and Point methods differed and if there were other attributes of these methods that would facilitate decisions about which method to employ.

Attributes of visual assessment methods can be compared by examination of how rapidly the parameters recorded by their implimentation stabilize after being repeated, and by direct comparison of the variation that may be an inherent artifact of a given method. A method that provides data that stabilizes in fewer samples (*i.e.*, less effort) could be considered superior to a method which does not. Determination of the tendency for data recorded by divers using Transect and Point methods to stabilize was done in two ways. The means of seven randomly chosen sets of cumulative surveys are presented in Figure 2 indicating the cumulative species recorded by divers using each method. Diver recorded data for both Transect and Point methods tended to accumulate species at nearly the same rate and both seemed to stabilize after about the same number of surveys (32-36). It should be noted, however, that although divers using both methods recorded the same cumulative number of species (54) neither method permitted divers to record the total number of species recorded by divers using the Random method (71). Also, note that divers using the Random method produced a species list which closely approaches the maximum number of species recorded on the reef during the entire study period (76).

The attribute of stability can also be compared among methods by examination of a magnitude independent parameter such as species diversity (H'). Divers using the Transect method recorded a lower (although not statistically significant, $p>0.05$) mean species diversity than when using the Point method. In addition to mean species diversity, the variance in species diversity was significantly greater ($p<0.05$) when using the Transect method (Fig. 3).

Previously, we made comparisons between methods based on parameters either gathered from a total effort or from an average per survey. While the study design did not allow us to use identical survey time or area, it is possible to adjust the data using randomly chosen surveys in an analysis of covariance

(ANCOVA). The results of these analyses indicated that when amount of survey time was used as a covariate (*i.e.*, the numbers of individuals per method were adjusted for time) there was a significantly higher number of individuals recorded by the Transect rather than the Point method (266.12 and 204.98, $p<0.01$). Also, a comparison of number of individuals recorded between methods having been adjusted for area indicated that Transect also recorded a significantly higher number of individuals per survey than did the Point method (212.05 and 181.96 respectively, $p<0.05$).

DISCUSSION

Time-of-Day

Several researchers have indicated that time-of-day can have a significant effect on results of reef fish censuses (*e.g.*, Thompson and Schmidt 1977, Talbot *et al.* 1978, Colton and Alevizon 1981). Our results indicate that no diurnal difference existed in the number of individuals or species in visual surveys conducted at various times of the day. This, however, should not imply that fish populations or assemblages do not undergo daily changes in abundance or species composition. Visual surveys comprising this data base were conducted outside periods of peak crepuscular activity (which occurs before or after the start and termination times of our assessments) when changes in population and community structure often occur (Colton and Alevizon 1981).

Diver Comparison

Our analysis indicates that, although there were some differences between divers in censusing fishes, the results do not disallow further comparisons of the methods. Assuming (for the sake of argument) that divers have equal abilities in identifying and counting fishes, observer differences in the numbers of species and individuals are probably due to subtle differences in each observer's personal protocol for using a particular method as well as the inherent variation in the local assemblage. For example, when using the Point method, variables which could possibly lead to differences between divers could be: 1) their estimation of the limits of the survey area (small errors in linear estimates of the survey radius could significantly alter the area censused); 2) the timing and rate at which divers rotated might cause variation in the field of view; and 3) the total amount of time spent actually observing and not recording might cause variation in a diver's ability to see rapidly moving pelagic or small, cryptic species.

When using the "random" swim techniques such as the Rapid Visual Census of Jones and Thompson (1978) or its quantitative modification by Kimmel (1985), similar problems arise due to subtle differences in personal protocol. Additional variables are present when using these techniques which include inter-diver variation in: swimming speed, local knowledge of micro-habitats (*i.e.*, sponge lumens, worm tubes, crevices etc.), and mental condition (the Rapid Visual Census method is physically tiring as each sample requires 50 min. of observation time).

Method Comparison

In the present study the type of data generated by using the Transect and Point methods appears to be most useful when evaluating a reef biotope as both methods permit divers to record numbers of species and individuals as values relative to area. Random, while clearly allowing divers to record more information in terms of numbers of species, merely presents a score of relative abundance without regard to area. A study conducted by

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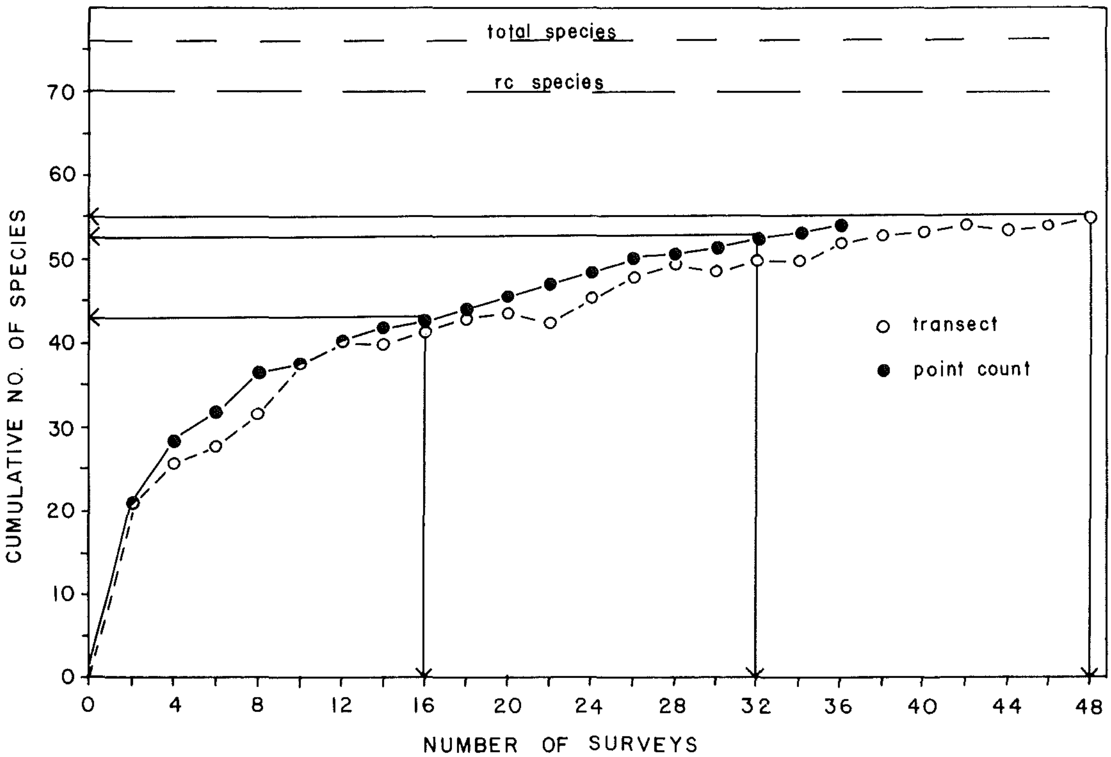

Figure 2. Cumulative species comparison between Transect and Point methods using seven randomly chosen sets of surveys. Line labeled "rc" indicates the total number of species using the Random method. The line labeled "total species" indicates the total number of species observed during the study period.

Kimmel (1985) has developed a modified Random Visual Census method which permits a non-scored abundance value. Even this modified technique, however, does not provide numbers of species or individuals per area data essential for quantitatively comparing and evaluating widely separated or disparate reef biotopes. Divers using the Point method recorded survey data with a higher average and less variable species diversity index than they did when using the Transect method. In contrast, the Transect method permitted divers to record more information (numbers of species and individuals) per unit of time and area than when they employed the Point method.

In view of the statistical comparison of visual census methods from this study and others (Bortone *et al.* 1986, Brock 1982, DeMartini and Roberts 1982, Kimmel 1985, Sanderson and Solonsky 1986) the transect method as proposed by Brock (1954) remains a preferred method for quantitatively censusing fish assemblages. The advantage of the Transect technique is in the simplicity of its design. Most divers can, with minimal practice, obtain comparable results, indicating the precision of the method. In the present study no significant differences were noted between surveys conducted by divers using the Transect method. This is most probably because the method protocol is simple, well defined, and the variations in the ability of a diver to estimate the 2 m transect width and its length are facilitated by the presence of a transect line; the area censused in the present study was clearly defined by reference lines. With the Transect method, observers are able to visually concentrate on the area immediately ahead of them so that

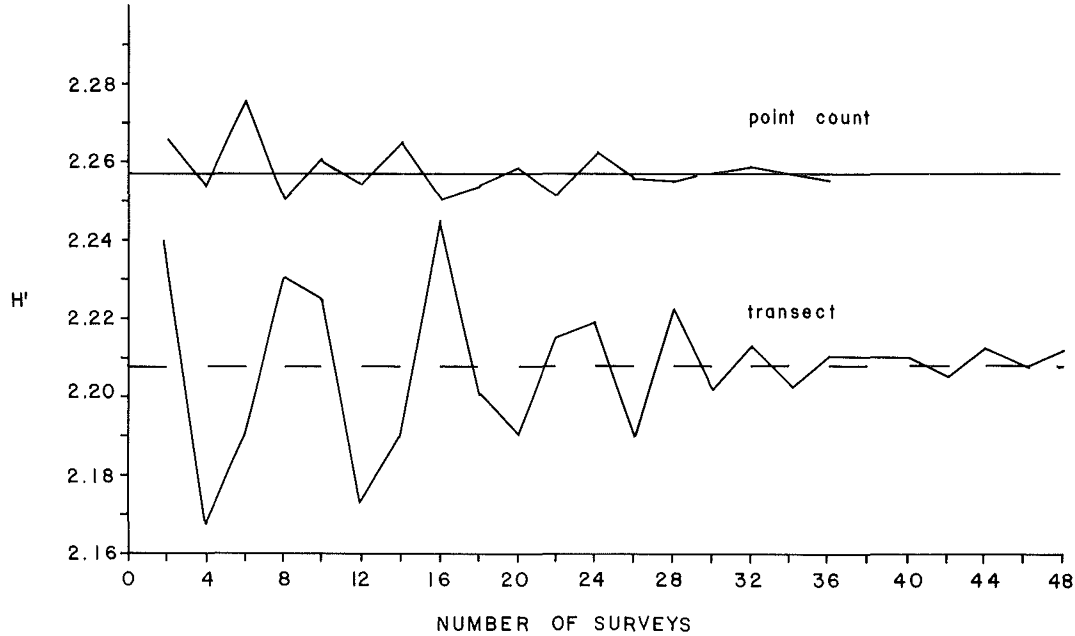

Figure 3. Variation in species diversity (H') for randomly generated sets of surveys. The line through each fluctuating line indicates the mean species diversity for all surveys using that method.

fewer complications arise from trying to "see" fishes at the limit of their visual acuity as would be the case when using the Point technique. It is probably the aspect of having a "standardized" protocol for the Transect method that renders it a more favored technique at present.

The Point method used here was recently adapted from terrestrial animal assessment studies (Bohnsack and Bannerot 1986). It, like the Transect technique, allows divers to collect information in terms of the number of species- or individuals-per-unit-area. The Point method has the advantage of not requiring preplacement of transect reference lines (which can be time consuming and disruptive to the faunal assemblage) and it can also be conducted in a more limited area as is often found on patch or artificial reefs. The Point method also allows divers to account for factors in biotopes with high micro-habitat diversity which can contribute to assemblage variation.

As indicated by Bortone *et al.* (1986), the amount of time per survey is apparently an important attribute of a method. Their study indicated that in order to more accurately compare methods it would be necessary to maintain the survey time (and area) constant. We have demonstrated that, when adjusted for area or amount of survey time, the number of individuals data gathered by divers using the Transect technique for the *in situ* visual assessment of reef fish assemblages is more efficient. Since Bortone *et al.* (1986) demonstrated a direct, positive relationship between the number of individuals and number of species recorded by visual assessment methods, one should expect similar results in a comparison of Transect versus Point for the number of species as well. This feature alone may imply that the Transect technique is to be preferred. Sale and Sharp (1983) demonstrated that transect-type visual surveys results are dependent on the width of the transect.

This and other studies indicate that research is needed to further evaluate the accuracy and precision of visual census techniques. Additionally, further investigations are needed which will specifically document the impact that the independent variables of observation time and area have on the dependent variables generated by visual census techniques. This would permit the development of accurate techniques involving remote and video recording devices which are certain to be the standard data gathering media of the future.

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