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A CRITICAL ASSESSMENT OF DATA DERIVED FROM CORAL CAY CONSERVATION VOLUNTEERS

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ABSTRACT

Since 1986, Coral Cay Conservation (CCC) has utilized a workforce of over 900 specially-trained volunteer divers to collect detailed topographic, bathymetric and biological data for the establishment of management plans for selected areas of the Belize barrier reef. The biological data recorded are ordinal and reflect the abundance of reef organisms including fish, macroalgae and hermatypic corals on a scale of 0–5. Substrate composition and the coverage of principal biotic classes are also visually assessed using an ordinal scale of 0–5. An exercise was carried out to assess the accuracy and consistency of data recorded by volunteers. Transects were laid in each of the major reef zones and in lagoon habitats. Each transect was surveyed independently by six teams of trained volunteers and compared to a reference obtained by experienced CCC staff. Analyses were carried out to test the accuracy and consistency of the coral, macroalgal and habitat data. Further analyses sought to quantify the proportion of species correctly identified, the frequency of erroneous species recordings and the variation of abundance ratings. The overall accuracy of coral surveys varied from 52–70% with the poorer values obtained in deeper outer and inner drop-off reef zones. The trend of reduced surveyor performance in deeper water is discussed in terms of physical, physiological and psychological phenomena. Inter-group consistency exhibited a similar bathymetric trend to that found for coral accuracy. Macroalgae were generally accurately and consistently recorded. No clear trend of improved accuracy and consistency following greater survey experience was apparent. Substrate composition and biological cover were recorded with an accuracy exceeding 90% in seagrass habitats and 70–90% in reef sites. A number of recommendations are made to improve survey methodology and volunteer training.

Volunteer research programs are applied to a wide variety of scientific disciplines. The British Trust for Ornithology uses volunteers to census bird species, Earthwatch organize discrete projects to assist professional researchers and volunteers participating in a Florida Sea Grant Program are trained to monitor artificial reefs. The Marine Conservation Society's SEASEARCH program utilizes volunteers to gather data in preparation for the synthesis of a temperate marine habitat inventory. Volunteer divers and snorkelers also contribute to the REEF-WATCH program that was established by the Tropical Marine Research Unit (York University) to gather broad scale information on the health of coral reefs. Similarly, the Coral Watch Environment Monitoring Program encourages volunteers to assist in efforts to gather information on the health of coral reefs throughout the Florida Keys (National Oceanic and Atmospheric Administration and The Nature Conservancy).

Self-funding volunteer labor can be a valuable resource to a host country operating under financial, manpower and training constraints. Coral Cay Conservation (CCC), a UK-based non-governmental organization, has adopted this concept to assist the Coastal Zone Management Unit of Belize, Central America. CCC trains volunteer divers to conduct detailed surveys of marine resources in preparation for sound management initiatives. Since its inception in 1986, CCC volunteers have undertaken over 2,000 marine surveys, culminating in the submission of the management plan (McCorry et al., 1993) for one of the largest proposed marine protected areas in Belize.

The survey methodology developed by CCC (Raines et al., 1992) is based on ordinal techniques adopted by the Marine Nature Conservation Review (MNCR) who are charged with describing the temperate marine communities of the British Isles (Hiscock, 1990). The ordinal data collected by CCC are used to classify reefal habitats, describe species distributions and provide semi-quantitative analyses of biological communities. These data have also provided ground information for remotely sensed satellite imagery (Mumby et al., 1994).

Quantitative reef sampling techniques have undergone rigorous testing (for example, Weinburg, 1981). However, there is a dearth of literature devoted to the quality of data obtained using volunteers to conduct marine biological surveys and the precision of ordinal marine survey techniques. Although the general assumption that the field scientist consistently assigns ordinal ranks to species is widely accepted, supporting evidence is largely restricted to anecdotal confirmations of confidence and unpublished field tests.

Attempts have been made to assess the data generated by volunteers undertaking coral reef fish censuses. Thus, the voluntary organization "Frontier Tanzania" has studied the relationship between the fish count and length estimates made by volunteers and the data collected by their staff (Darwall, pers. comm.). Similarly, The Nature Conservancy and the Florida based "Reef Environment Education Foundation" studied the consistency of fish census data obtained from volunteers and the changes in accuracy following greater survey experience (Akins, pers. comm.). Both organizations have found encouraging preliminary results to support the use of volunteer reef survey programs.

This study was designed to validate the marine survey techniques employed by CCC and investigate the quality of semi-quantitative ordinal data on sessile coral reef communities. To achieve these aims, the accuracy and inter-group consistency of coral, macroalgal and habitat classification data were critically assessed. The individual sources of data inaccuracy were to be investigated with a view to identifying bathymetric, habitat, experience and species related trends. The general conclusions of this study should apply to any organization that uses volunteers to conduct surveys of the marine environment. The more specific species-level results will enable CCC to refine the volunteer training program and provide a measure of confidence to be incorporated into data analyses.

METHODS

Volunteer Training Program.—Volunteer divers undergo an intensive 8-day training program in marine life identification and survey techniques. The program has been developed and refined since 1986 and incorporates lectures, practical exercises, one-to-one tuition, video, slides and frequent testing. The course syllabus includes the identification of all species of macroalgae, seagrass, coral and other marine invertebrates; training in marine survey techniques (assessment of biological cover, abundance and topographical features); aspects of relevant biological issues (species interactions, taxonomy, physiology) and consideration of current coastal zone management issues and practices.

Synopsis of Baseline Survey Technique.—To describe patterns of habitat zonation, transects are oriented perpendicular to the reef crest. In Belize, the reef crest runs predominantly from north to south and, therefore, transects usually run from east to west, incorporating all major reef zones. The principal geomorphological zones of each transect are then surveyed separately by individual teams comprised of four divers.

Three of the members of each team carry out a biological survey which assesses the abundance of fish, Scleractinia and macroalgae to species level and octocorals and Porifera by lifeform. Abundance estimates are based on an ordinal scale which ranges from 0 (absent) to 5 (abundant). During a biological survey, each diver is responsible for either fish, corals and sponges or macroalgae and other invertebrates. The ordinal scale is also applied to categorize each of five substrate classes (live coral, dead coral, rubble, sand and silt) and each of six principal biotic classes (Scleractinia, gorgonians, Porifera, other invertebrates, macroalgae and seagrass), which are used to broadly classify habitats. In

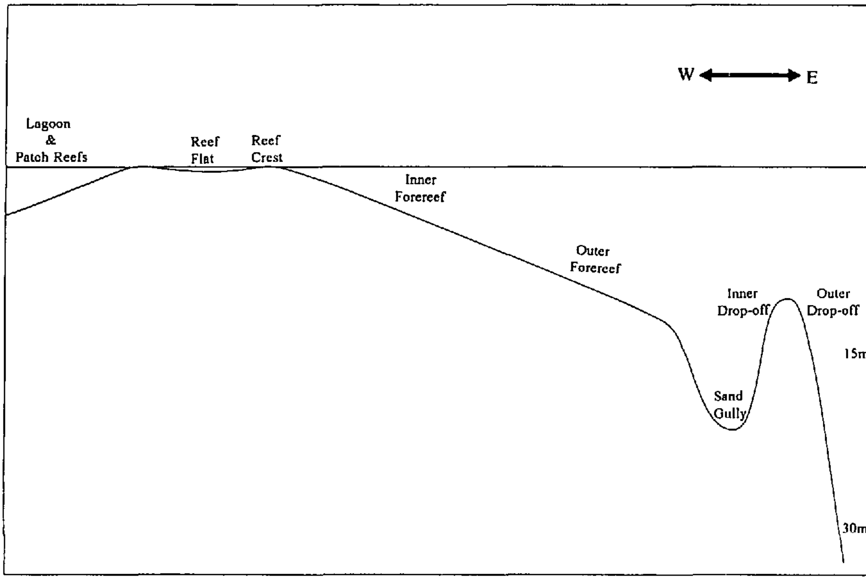

Figure 1. Stylized profile of the study site, east of South Water Cay in the central province of the Belize barrier reef. Two transects were laid in the lagoon (seagrass habitat) and in each of the reef zones: Inner fore reef (IF), outer fore reef (OF), inner drop-off (ID) and outer drop-off (OD).

addition to the biological survey, a fourth diver qualitatively describes topography and records depths to define a bathymetric profile. This diver also notes any gross anthropogenic impacts, such as litter or lobster potting. All the information collected by the divers is transferred to specially designed recording forms after each dive.

Validation Procedure.—To ensure that the results of the validation program were comparable with CCC survey protocols, a stratified sampling regime was adopted to include the outer drop-off (OD), inner drop-off (ID), outer fore reef (OF), inner fore reef (IF) and three lagoonal seagrass habitats in the vicinity of South Water Cay, Belize (Fig. 1). Validation sites were selected by choosing values of latitude prior to any attempt to set transect lines. Latitude was measured using a global positioning system and echo-location used to locate the desired depth. Non-participant divers set a single line transect in each of the reef zones and three transects in shallow lagoonal habitats. All transects were set with an east-west orientation to describe patterns of vertical zonation. The safe diving practices adhered to by CCC restrict 30 m dives to a survey time of 15 min and, therefore, the deeper outer drop-off and inner drop-off zones (15–28 m) were surveyed at an average rate of 1 m per min. All other line transects were 60 m long and surveyed at 2.4 m$\cdot$min^{-1} (concomitant with CCC survey practices). The lagoon seagrass habitats were located between 3–6 m.

CCC staff, with over 100 h of marine surveying experience in Belize, carried out a thorough study of the transects using extended, computer-monitored dive profiles which permitted greater time underwater. A complete species inventory (with abundance ratings) was generated for each site. Six full survey teams of volunteers (24 divers in total) were deployed onto each transect at 15-min intervals and in random order. Full survey teams were used to ensure that the validation procedure was truly representative of CCC data. Each transect was surveyed only once by each team of volunteers. To standardize the area surveyed, volunteers were asked to confine their surveys of the benthic component to that estimated to lie within 1 m either side of the transect line. Teams did not confer until the recording forms were completed. The role assigned to each surveyor within the team was maintained throughout the program.

To attempt to identify changes of data accuracy and consistency with increased experience, the exercise was repeated immediately after the completion of the first set of surveys. New sites were located at similar depths to those used earlier.

Analytical Techniques.—The analyses presented in this study only consider data collected for corals, macroalgae and habitat description, which, it is assumed, do not significantly vary throughout the period of this study. Ordinal abundance data could not be analyzed using parametric techniques.

Table 1. Definition and derivation of terms used to describe components of the accuracy and consistency of volunteer data

Parameter	Definition and derivation of parameter
Accuracy	Similarity of volunteer-generated data to reference values measured as a rank correlation coefficient and expressed as a percentage in the text. This measure of accuracy is assumed to encompass all component sources of error.
Consistency	Similarity of data collected by separate teams of volunteers on the same transect. This was measured as a rank correlation coefficient and expressed as a percentage in the text. This measure of consistency is assumed to encompass all component sources of error.
% Identified	The percentage of the total number of species present that were recorded by the volunteer. The total number of species was derived from the reference data (see Appendix 1).
Correct identification	The percentage of volunteer surveys that correctly identified individual coral and macroalgal species when the species was present.
% Erroneously recorded	The number of species erroneously recorded as being present (when actually absent), expressed as a percentage of the total number of species recorded by each group.
Erroneous recordings	The percentage of volunteer surveys that erroneously recorded individual coral and macroalgal species as being present when the reference data showed them to be absent.
Range of abundance ratings	This analysis quantified the variation in abundance ratings made by volunteers. It only considered variation between volunteers that correctly identified each species, lifeform, substrate or biotic class. If a group failed to identify a species, that specific record, which had a rating of 0, was excluded from the analysis. If all abundance ratings for a species were equal, the range of abundance was 1.

Therefore, Spearman rank correlation coefficients were calculated and the results displayed in terms of the median value and inter-quartile range (IQR) (Samuels, 1989) either per group or per site.

Several terms were used to describe sources of inaccuracy, error and variation in survey data (Table 1).

Results

The overall trends of accuracy and consistency are described for coral abundance, macroalgal abundance and habitat classification. This includes an inspection of the individual components of accuracy (defined above) and species level analysis. To reduce the number of figures presented, the results and analyses are described in full for the coral component but are summarized in tables for the macroalgal and habitat components. Although some inter-zone comparisons are statistically significant, we do not consider the differences, which in this study are based on two sample sites per zone, to be truly representative. Thus, data are intended to evaluate the methods rather than describe zonation.

Coral.—There was considerable variation in the accuracy of coral surveys. The median accuracy of each team ranged from 52% to greater than 70% (Fig. 2A) and group 5 was statistically less accurate than other survey teams (Kruskal-Wallis (KS), $P = 0.005$). Intra-group variation was also high at approximately 20% (IQR) per team. A general trend of greater accuracy in shallower reef zones is apparent in Figure 2B; the median accuracy of outer forereef and inner forereef sites being greater than that of outer and inner drop-offs ($P < 0.05$ for IF1).

Inter-group consistency (Fig. 3) followed a similar trend to that of accuracy since it was greater in the shallower reef zones; the consistency found between volunteers surveying OD and ID transects was worse than that recorded in OF

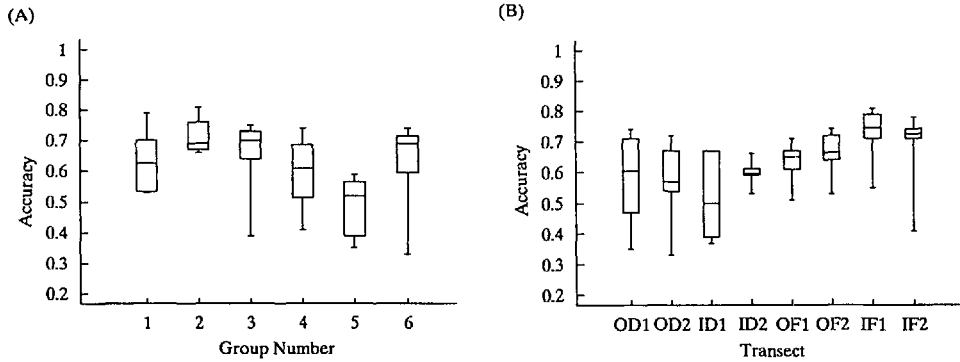

Figure 2. Accuracy of coral data obtained by volunteer surveyors. Results expressed as the median, inter-quartile range and range of Spearman-Rank correlation coefficients. (A) inter-group variation ($N = 8$). (B) inter-site variation ($N = 6$). OD = outer drop-off, ID = inner drop-off, OF = outer fore reef, IF = inner fore reef. 1 = first study site, 2 = second study site.

and IF sites (KS $P < 0.0001$). To simplify, the median consistency of OD and ID sites was below 60% while that of OF and IF sites was above this value.

Almost all survey teams managed to correctly identify approximately 70% of the coral species present per transect and despite some inter-group variation, there was no significant difference between groups. The ability of teams to identify coral species correctly shows a bathymetric trend of better identification in shallower sites (Fig. 4).

One objective of the validation exercise was to assess whether volunteer survey ability improves with increased survey experience. A trend of this kind would appear as a change of accuracy between analogous reef zones (for example OD1/OD2, OF1/OF2), or as an increase in accuracy from seagrass transect 1 to transect 6. Changes from the first to the second survey of each reef zone constituted a significant source of variation in terms of accuracy, inter-group consistency and percentage of coral species correctly identified (Figs. 2B, 3, 4). However, it was

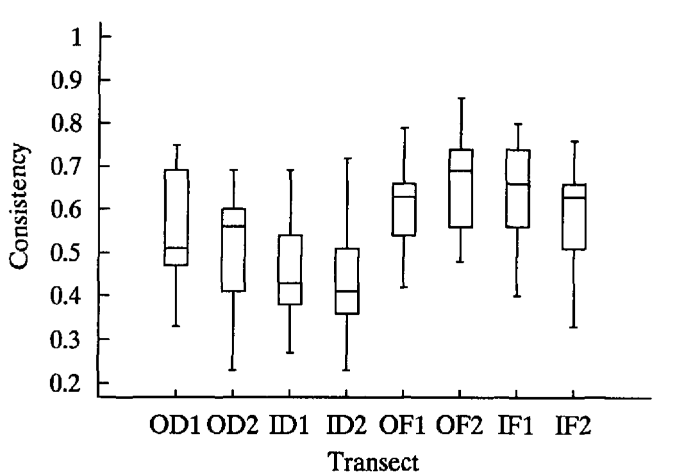

Figure 3. Consistency of coral data obtained by volunteer surveyors. Results expressed as the median, inter-quartile range and range of Spearman-Rank correlation coefficients ($N = 6$). OD = outer drop-off, ID = inner drop-off, OF = outer fore reef, IF = inner fore reef. 1 = first study site, 2 = second study site.

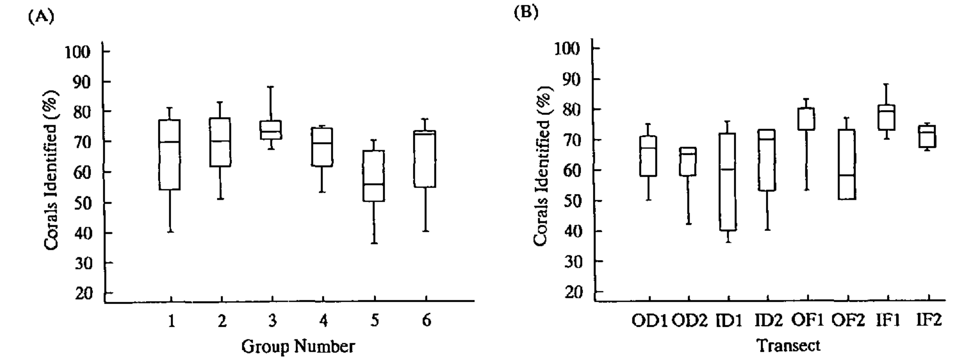

Figure 4. Variation of the percentage of the corals present correctly identified by volunteer surveyors. Results expressed as the median, inter-quartile range and range. (A) inter-group variation (N = 8). (B) inter-site variation (N = 6). OD = outer drop-off, ID = inner drop-off, OF = outer fore reef, IF = inner fore reef. 1 = first study site, 2 = second study site.

not possible to attribute this variation to a consistent trend pertaining to increased experience.

To assess the volunteers' ability to identify individual coral species, the number of groups that correctly identified each species (when present) was calculated and expressed as a percentage of the total number of groups (Table 2). Those species that were, on average, identified by less than 50% of survey teams, may be broadly categorised as the "saucer" corals of the outer drop-off (*Leptoseris cucullata* and *Agaricia fragilis*), the shallow water *Isophyllastrea* and *Isophyllia* species and the finger-like *Madracis mirabilis* and *P. porites* var *divaricata.*

Between 6% and 13% of the coral species recorded by each group were erroneous (Fig. 5). Species that caused the greatest difficulty included *Mycetophyllia aliciae, Siderastrea radians* and *Madracis mirabilis* (Table 2). Spatially, erroneous recordings were more frequent in inner drop-off sites than outer forereef sites ($P < 0.05$) (Fig. 5B).

There was no discernible trend in the range of abundance ratings between reef zones. Table 2 shows that the median range of abundance ratings for each coral

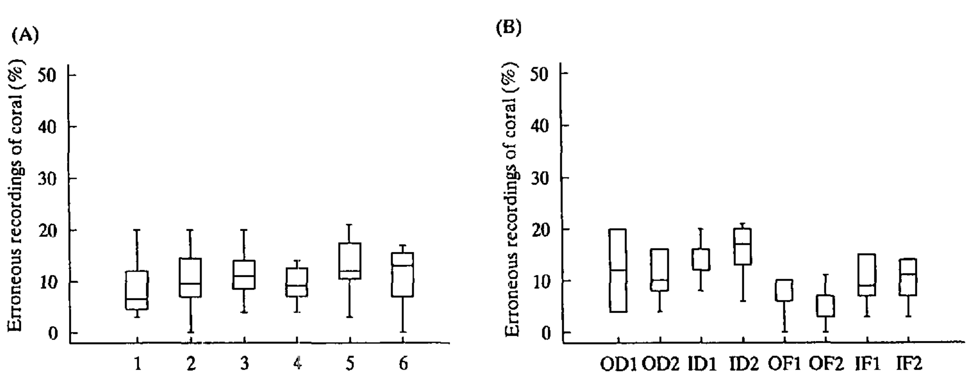

Figure 5. Variation of the percentage of corals erroneously recorded as being present by volunteer surveyors. Results expressed as the median, inter-quartile range and range. (A) inter-group variation (N = 8). (B) inter-site variation (N = 6). OD = outer drop-off, ID = inner drop-off, OF = outer fore reef, IF = inner fore reef. 1 = first study site, 2 = second study site.

Table 2. Species level analyses for coral records generated from volunteers. Refer to Table 1 for definition of terms. Data generated from a maximum sample size of 48 (8 reef sites and 6 survey groups per site) at South Water Cay, Belize, February 1993. Actual sample size for each species shown in parentheses.

Species	Correct identification (%)	Erroneous recordings (%)	Median range of abundance rating
Acropora palmata	100 (6)	0 (42)	1 (6)
Agaricia grahame	100 (24)	0 (24)	1 (24)
Pseudoplexura spp.	100 (48)	—	1 (48)
Montastrea annularis	98 (48)	—	2 (47)
Montastrea cavernosa	98 (48)	—	2 (47)
Agaricia agaricites	98 (48)	—	2 (47)
Pseudopterogorgia spp.	98 (48)	—	1 (47)
Gorgonia ventalina	94 (48)	—	1 (45)
Mycetophyllia lamarckiana	92 (48)	—	2.5 (44)
Diploria labyrinthiformis	90 (42)	0 (6)	1.5 (38)
Diploria strigosa	89 (36)	5 (12)	2 (32)
Agaricia tenuifolia	88 (24)	8 (24)	2 (21)
Porites astreoides	88 (48)	—	2 (42)
Acropora cervicornis	86 (36)	0 (12)	2 (31)
Siderastrea radians	83 (12)	30 (36)	1.5 (10)
Dendrogyra cylindrus	83 (6)	4 (42)	1 (5)
Porites porites	83 (36)	0 (6)	1.5 (30)
Meandrina meandrites	81 (48)	—	2 (39)
Scolymia lacera	71 (48)	—	2 (34)
Mycetophyllia danaana	71 (42)	0 (6)	1.5 (30)
Dichocoenia stokesii	67 (42)	0 (6)	2 (28)
Siderastrea siderea	65 (48)	—	1 (31)
Favia fragum	63 (24)	15 (24)	1 (15)
Mycetophyllia aliciae	61 (18)	45 (30)	1 (11)
Colpophyllia natans	60 (48)	—	1.5 (29)
Eusmilia fastigiata	55 (42)	0 (6)	1 (23)
P. porites var. *divaricata*	50 (42)	0 (6)	2 (21)
Madracis mirabilis	50 (24)	20 (24)	1.5 (12)
Mussa angulosa	50 (6)	11 (42)	1 (3)
Agaricia fragilis	36 (36)	8 (12)	1 (13)
Isophyllastrea rigida	33 (18)	6 (30)	1 (6)
Madracis decactis	27 (48)	—	1 (13)
Isophyllia sinuosa	25 (12)	2 (36)	1 (3)
Leptoseris cucullata	24 (42)	0 (6)	1 (10)

species lies between 1 and 2 (except *M. lamarckiana* at 2.5). Those species with a median range of 1 were recorded with maximum consistency in that the same abundance rating was usually assigned by each team whenever that species was present. A median range of 2 shows that the abundance ratings afforded to that species usually varied between two immediately consecutive rank values. It should be noted that this analysis was only carried out for data sets in which volunteers had actually identified the species correctly. In essence, this examines the range of abundance ratings between volunteers that could correctly identify each species.

Macroalgae.—Volunteers achieved a high level of accuracy surveying the macroalgae found in seagrass beds and reef zones although the level of correct species identification was more precise in seagrass sites (Table 3). The overall range of inter-group consistency was similar between seagrass and reef habitats.

Volunteer groups introduce a significant source of variation in macroalgal accuracy in reef surveys (Table 3). Therefore, although levels of macroalgal accuracy are generally high for reef habitats, reasonable variation exists between the

Table 3. Summary of results of volunteer-generated data on macroalgae present in reef and seagrass habitats (February 1993). Refer to Table 1 for definition of terms. Results expressed as the range of the median values from either each group or each site. Kruskal Wallis (KS) test results are given in parentheses (ns denotes not significant result). Trend refers to either experience-based or bathymetric trends.

		Accuracy	Consistency	Correct identification (%)	Erroneous recordings (%)
Reef	Group results	67–85%	—	51–86%	5–12%
	Inter-group variation	one group anomalous (0.001)	—	considerable variation (0.001)	considerable variation (0.02)
	Site results	63–78%	60–70%	50–87%	4–13%
	Inter-site variation	ns	no clear trend (0.001)	no clear trend (0.03)	ns
Seagrass	Group results	70–80%	—	75–80%	4–14%
	Inter-group variation	ns	—	ns	ns
	Site results	68–81%	58–77%	58–87%	0–9%
	Inter-site variation	ns	improvement from 1st to 3rd transect (0.0000)	ns	no clear trend (0.015)

accuracy of one group relative to another. However, the group variable appears to have a negligible influence on accuracy parameters when surveying seagrass habitats.

The site effect on macroalgal consistency in seagrass areas (Table 3) resulted from the significant improvement in consistency from the first to the second survey and from the second to the third survey. Whether this was an artifact of the seagrass sites surveyed or represents an experience related improvement in consistency is not clear. The variations in inter-group consistency and percentage of macroalgal species correctly identified in reef areas (Table 3) were not attributable to either increased survey experience or a bathymetric trend.

The more abundant reef species in this study (*Lobophora variegata, Dictyota* spp., *Halimeda goreaui, H. copiosa* and *Sargassum hystrix*) were correctly identified by more than 80% of groups (Table 4). It would appear that the more cryptic species such as *Ventricaria* spp. and *Halicystis* spp. were frequently overlooked rather than confused with other species which would have lead to a high percentage of erroneous recordings.

Species of macroalgae surveyed on seagrass transects in this study were accurately identified with approximately half of the species correctly identified by more than 90% of groups (Table 4). The relatively high frequencies of erroneous species identification for *Penicillus dumetosus* and *Avrainvillea* spp. suggested that volunteers had greater difficulty identifying these species correctly.

Habitat.—The accuracy and consistency of habitat descriptions was extremely high, particularly for seagrass habitats (Table 5). Group or site effects showed no trend that may be explicable in terms of volunteer survey experience or bathymetry.

The range of ratings given to substrate and biological coverage classes showed greater precision in seagrass habitats than in reef zones (Fig. 6). The rubble component used in describing reef substrate coverage exhibited greater variation than living coral, dead coral and sand components. Figure 6 also shows that in the

Table 4. Species level analyses for macroalgal records generated from volunteers. Refer to Table 1 for definition of terms. Data generated from a maximum sample size of 48 for the reef (8 sites and 6 surveys per site) and 36 for the lagoon (6 sites and 6 surveys per site) at South Water Cay, Belize, Feburary 1993. Actual sample size for each species shown in parentheses.

	Correct identification (%)		Erroneous recordings (%)		Median range of abundance rating	
Species	Reef	Lagoon	Reef	Lagoon	Reef	Lagoon
Amphiroa spp.	57 (42)	—	0 (6)	—	2 (24)	—
Anadyomene spp.	17 (6)	—	0 (42)	—	1 (1)	—
Avrainvillea spp.	—	28 (18)	—	15 (18)	—	1 (5)
Caulerpa cuppressoides	—	50 (18)	—	0 (18)	—	2 (9)
Caulerpa paspaloides	—	97 (36)	—	—	—	2 (35)
Caulerpa prolifera	—	50 (6)	—	7 (30)	—	2 (3)
Dictyota spp.	96 (48)	58 (12)	—	0 (24)	2 (46)	2 (7)
Encrusting red spp.	69 (42)	—	0 (6)	—	2 (29)	—
Filamentous spp.	19 (42)	33 (6)	0 (6)	0 (30)	1 (8)	1 (2)
Halicystis spp.	17 (6)	—	2 (42)	—	1 (1)	—
Halimeda copiosa	88 (48)	—	—	—	2 (42)	—
Halimeda discoidea	81 (48)	—	—	—	2 (39)	—
Halimeda goreaui	96 (48)	—	—	—	2 (46)	—
Halimeda incrassata	—	97 (36)	—	—	—	2 (35)
Halimeda monile	—	86 (36)	—	—	—	2 (31)
Halimeda opuntia	75 (48)	—	—	—	2 (36)	—
Halimeda tuna	88 (48)	—	—	—	2.5 (42)	—
Kallymenia spp.	22 (18)	—	6 (30)	—	1 (4)	—
Lobophora variegata	100 (48)	—	—	—	2 (48)	—
Padina spp.	67 (18)	—	10 (30)	—	1.5 (12)	—
Penicillus capitatus	—	97 (36)	—	—	—	2 (35)
Penicillus dumetosus	—	66 (12)	—	15 (24)	—	2 (8)
Penicillus pyriformis	33 (6)	77 (30)	7 (42)	0 (6)	1 (2)	2 (23)
Rhipocephalus phoenix	69 (48)	94 (36)	—	—	1.5 (33)	2 (34)
Sargassum hystrix	83 (48)	—	—	—	1 (40)	—
Udotea cyathiformis	63 (24)	97 (36)	0 (24)	0 (0)	1 (15)	2 (35)
Udotea flabellum	—	92 (36)	—	—	—	2 (33)
Udotea occidentalis	67 (6)	33 (30)	2 (42)	0 (6)	1 (4)	1 (10)
Udotea wilsonii	—	100 (18)	—	—	—	1.5 (18)
Ventricaria spp.	33 (24)	—	4 (24)	—	1 (8)	—
Wrangelia argus	77 (30)	—	13 (18)	—	2 (23)	—

Table 5. Summary of the accuracy and consistency of volunteer-generated habitat classification data for reef and seagrass habitats (February 1993). These data are derived from 5 major substrate classes and 6 major biotic classes. Accuracy and consistency are derived from rank correlations between volunteer data and the reference values and within the volunteer data respectively. Results expressed as the range of the medians from either each group or each site. Kruskal Wallis (KS) test results are given in parentheses (ns denotes non significant result). Trend refers to either experience-based or bathymetric trends.

	Accuracy		Consistency	
	Reef	Lagoon	Reef	Lagoon
Group results	73–86%	90–100%	—	—
Inter-group variation	ns	one group anomalous (0.005)	—	—
Site results	71–90%	92–98%	78–87%	91–97%
Inter-site variation	ns	ns	ns	no clear trend (0.0000)

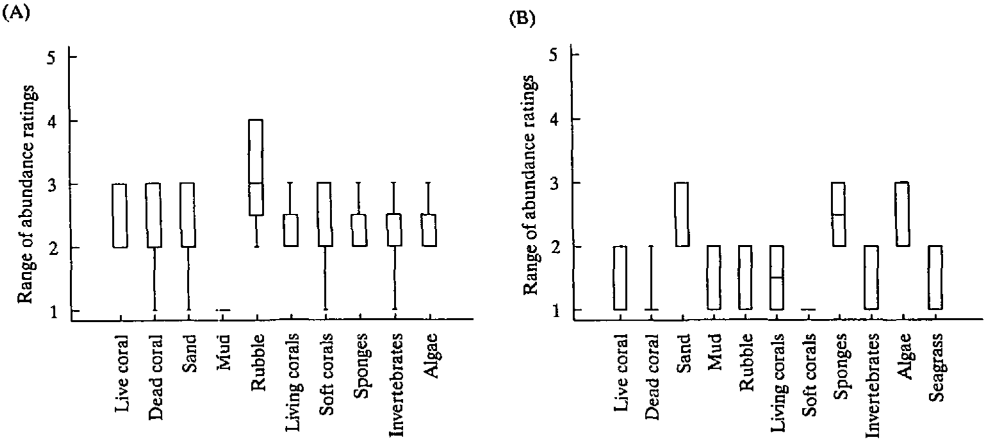

Figure 6. Range of habitat abundance ratings obtained by volunteer surveyors. Results expressed as the median, inter-quartile range and range. (A) ratings on reef. 8 transects (6 surveys per site). (B) ratings in seagrass areas. 6 transects (6 surveys per site).

seagrass transects surveyed, the ordinal categorization of sponge lifeforms presented the greatest difference of opinion amongst volunteers.

Discussion

The levels of accuracy found in this study were encouraging given the number of species surveyed (Appendix 1) and the subjective nature of abundance estimates. At greater than 90%, the accuracy to which volunteers describe substrate and biological coverage was particularly impressive. This result is of great importance since CCC use these habitat data to define the basis of marine resource classifications.

Temporal and spatial comparisons of sites are based upon the survey data obtained by volunteers, not by CCC staff. Attaining high inter-group consistency is, therefore, essential for comparative data analyses. If two sets of data are compared using rank correlation analysis, any differences are attributable to actual community differences and an intrinsic element of volunteer inconsistency. The results of this study allow the degree of inconsistency to be quantified and incorporated into the analysis. For example, the median consistency of coral data in inner forereef zones lay between 60 and 70%. If inner forereef data were compared and gave a low level of similarity, for example less than 40%, there would be reasonable grounds for concluding that the coral communities of the two sites were actually different. In practical terms, however, a community difference that leads to a very low level of similarity is likely to be fairly marked, which highlights the limitation of using ordinal data for detecting subtle community changes. This point was also made by Lumb (1984) who concluded that single visits, unmarked transects and ordinal abundance estimates preclude the use of data for detecting anything other than gross changes in shore communities.

Two major trends relating to data accuracy and consistency emerged. Firstly, the coral data obtained from the deeper drop-off study sites were found to be less accurate and consistent than those of the forereef sites. This trend existed despite the slower survey rate, the shorter transect lengths and the lower species richness (Appendix 1) in the deeper sites and the greater topographic complexity exhibited by the inner forereef zone (Bohnsack and Bannerot, 1986). There are a number of depth-dependent physical, physiological and psychological factors that may plausibly explain this decline of survey or performance at increased depths. The ability to detect and recognise an object depends on both the amount of light available and on the contrast between the image of the object and its background (Ross, 1989). Underwater, light attenuation and scattering from particulate matter restrict the amount of incident light reaching the benthos, thus severely impeding image brightness, color definition and contrast at depth (Muntz et al., 1974). Contrast is reduced further because of absorption and scattering of light reflected from the object. Such declining levels of contrast are known to reduce visual acuity despite the image-enhancing effect of light refraction that causes 4/3 magnification of objects viewed through a face mask (Baddeley, 1971). The reduced levels of lighting, contrast and impairment of visual acuity at depth may be partially responsible for the bathymetric trend of coral data. Supporting ecological data includes Baker (1984), who suggested that color may have been a source of variation in estimates of lichen coverage in intertidal areas. Under wet weather conditions, lichen color was a brighter green and estimates of lichen coverage were found to increase.

It is notable that reduced light reflectance causes divers to tend to over-estimate the distance to a far away object, whereas, at close quarters, divers will under-estimate distance because of the magnification effect of light refraction (Ross, 1989). Distance estimation is therefore a potential source of error in that divers were expected to judge an area 1 m either side of a transect line. This ability may be impaired under different conditions of illumination.

The physiological condition nitrogen narcosis, that arises when divers breathe compressed air at depth, is widely regarded as constituting the overriding constraint to cognition (Ross, pers. comm.). However, the mechanism by which nitrogen narcosis interferes with cognition is not thoroughly understood, although inhibitive effects on arousal and slowed thought processing have been implicated (refer to Ross, 1989 for full discussion). Baddeley (1966) found that manual dexterity dropped to 49% at depths comparable to those attained in this study (33 m). Nitrogen narcosis is known to affect divers at depths of 30 m and a mild degree of narcosis is suspected to occur at slightly shallower depths (Baddeley, 1966). Surveyors almost certainly experienced narcosis on deeper surveys and the evidence cited here suggests that this may slightly retard cognitive and manual processes, thus potentially affecting the quality of survey data.

Using pressure chamber experiments, Baddeley (1966) also concluded that the inhibitive effects of nitrogen narcosis are proportionately greater in open water. He attributed this to psychological anxiety experienced underwater. Anxiety effects were also thought to explain the poorer manual dexterity of divers in open water relative to those in shallow, calm environments (Baddeley, 1966–67). Training bias is an additional psychological consideration. The majority of CCC marine life identification training is accomplished by snorkeling in shallow water. Since the ability of corals to morphologically adapt to differing levels of light intensity is well documented (for example, Foster, 1979, 1980), by training in shallow water, divers become familiar with the identification of coral species in their shallow morphological state and under conditions of high illumination. Furthermore, much of the training for deeper sites is based on studying identification guides which generally use flash photography to illustrate species found in deep water. The possibility that these photographs are not truly representative of the appearance of organisms when actually seen in deep water should be considered.

The second major trend highlighted in this study was the greater consistency and accuracy of habitat classification data generated from lagoonal seagrass communities compared to that from reef zones. This may be partially explained by the general difference in spatial complexity between the two regions since seagrass beds possess a simpler, two dimensional topography which potentially offers fewer cryptic microhabitats. In light of the physical, physiological and psychological evidence, it would appear that in this study, conditions in lagoonal areas are better suited to marine surveying because the water is shallow, clear and generally calm.

The bathymetric trend of greater accuracy and consistency of coral data in shallower reef areas was not seen in the macroalgal data. To explain this apparent anomaly, attention must be drawn to the flexibility afforded to surveyors of macroalgae. If species cannot be identified during the survey, a small sample was removed for detailed examination on land. Coral identification was limited to field recordings, field notes and memory recall.

There were several potential sources of group variation, including the individuals' response to training, diving constraints and diligence. Significant inter-group variation occurred in coral, reef macroalgae and habitat data. The need for consistent data has been expressed and inter-group variation is considered to be highly undesirable. More intensive testing of the volunteers' marine life identification skills would theoretically help to standardize volunteer performance and reduce group variation.

The absence of a clear improvement in data, caused by greater survey experience, was not surprising. The key consideration is the absence of positive feedback during the survey program. If a volunteer mis-identified a species, there was no mechanism for feedback, correction and learning. CCC staff did not discuss each volunteer's data to highlight areas of weakness and sources of inaccuracy because this is not carried out under normal survey conditions. The use of a detailed video transect could potentially improve the training program by addressing some of the issues described. Video footage of outer and inner drop-off communities would improve diver familiarization with differing coral morphology and the identification of species encountered in deeper areas. Greater use of video could also be adapted to test individuals' survey technique, thus providing direct feedback to areas of weakness and problems of species identification. In addition, there is a case to support the use of artificial light sources and extend the training program so that a greater component of identification training is carried out in deep water.

Data accuracy was determined by the proportion of species observed, the proportion erroneously recorded and the variation of abundance ratings. The proportion of species correctly identified was clearly a major component of data accuracy. On a species level, the most abundant coral species in this region such as *Acropora palmata, A. cervicornis, Agaricia* spp. and *Porites porites* (Smith and Ogden, 1993) were all accurately recorded. It seems that the accuracy of survey data is reduced by inconsistent recordings of species such as *Madracis decactis* and *Isophyllia sinuosa* and there is a clear need to address the problem of species identification through feedback into the training program. However, it is worth noting that the difficulties experienced by volunteers in accurately identifying species of the genera *Mycetophyllia, Siderastrea, Madracis, Isophyllastrea* and *Isophyllia* are also reflected in the arguments among coral taxonomists regarding the validity of species within these genera (Fenner, 1993). It can also be noted that the morphologically similar saucer corals, *Leptoseris cucullata* and *Agaricia fragilis* were actually overlooked rather than the expected problem of simple confusion between species.

It was unexpected that up to 15% of the species recorded by a group may be erroneous. It is useful to be able to isolate the key species responsible, but the data do not reveal the entire source of error. For example, although *Mycetophyllia aliciae* was frequently recorded as being present, when in fact it was absent, it is not known which species the volunteer actually observed and mis-identified as *Mycetophyllia*. Increased awareness of these problems must be incorporated into the training program. In this case, the Mussidae should receive more attention in future. The erroneous recordings of *Siderastrea radians* are better understood. Confusion between the identification of *Siderastrea radians* and *S. siderea* is commonly experienced by volunteers (Mumby, pers. obs.). The results suggest that *S. radians* was erroneously recorded as being present while *S. siderea,* which has a much broader distribution and greater abundance, was only recorded by 65% of groups, pointing to confusion between the two coral species. With the exception of *Penicillus dumetosus, Avrainvillea* spp. and *Wrangelia argus,* which all exhibited relatively high frequencies of erroneous identification, the main cause of poor macroalgal identification seemed to be failure to observe the species rather than confusion between species.

To attribute a significant difference to ordinal abundance data, a minimal difference of two or more abundance values is generally stipulated (Little, 1984). The Marine Nature Conservation Review team (MNCR) obtain temperate marine ecosystem data similar to that collected by CCC in Belize. The multivariate software, TWINSPAN is used by the MNCR to undertake community biotope assessment. The software accommodates for recorder variation by amalgamating pairs of abundance ratings and, therefore, assumes that the range of abundance ratings is no greater than two per species on any given survey. The data presented in this study demonstrate firstly that, volunteers are capable of assigning ordinal abundance ratings with the required amount of precision for statistical analysis, and secondly, that despite the subjective nature of abundance estimates, the range of ratings does not constitute a large source of inconsistency. This would validate any use of multivariate data analyses on species that are known to be accurately identified.

A fundamental assumption of this study was the acceptance that reference data collected by CCC staff is correct. Although the responses of staff to the physical, physiological and psychological factors discussed above were not assessed, it seems reasonable to assume that the combination of greater and more diverse survey experience, knowledge of taxonomic literature and the much longer time spent recording the species abundance on each transect, would produce a satisfactory reference data set. The "great survey experience" part of this justification may seem to contradict an earlier conclusion of this study that there is no clear improvement of the volunteer data with increased survey experience. To clarify, the conclusions of this study are based on 1 month of surveying and do not suggest that volunteers would be unable to survey more accurately given the same diverse surveying experience, access to relevant literature and greater survey time that CCC staff possess.

The validity of the other assumptions made in this study also need consideration. Firstly, it was assumed that the results of the study are representative of all the volunteers that undergo the survey program. In an attempt to satisfy this assumption, a large sample size was used, comprising 24 individuals. In addition, despite the refinements made to the training program since 1986, the basic course content has been standard for some time. It was also assumed that no detectable change took place in the sessile community during the interval between the reference survey and the volunteer assessment. This was felt to be justified since the time interval was kept to within 24 h and the reference team carried out a repeat survey while the volunteers made their only survey of each site.

This study was restricted to the Caribbean region and the conclusions presented here need verification worldwide. The data validation studies must also be extended to all other reef taxa. Furthermore, the results of this study are specific to the survey methodology designed by CCC. Other programs and organizations should carry out similar validation exercises. CCC considers that the collection of quantitative quadrat data on coral reefs is a valuable extension to volunteer programs since this information is routinely used for biological monitoring (Brown and Howard, 1985). Quantitative sampling demands accurate species identification skills, and concern that such abilities are beyond the capability of volunteers is not entirely unfounded. However, the results of data derived from volunteers in this study suggest that the identification problems may not be insurmountable.

Recommendations have been made to improve survey practices and training, but perhaps the most important application of this information is to place it at the disposal of the volunteer. Self-awareness of the problems experienced at depth and the species that are proven to cause identification difficulties will no doubt be instrumental in obtaining data of an even higher quality.

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Appendix 1. Species richness of corals and macroalgae at each reef (OD1–IF2) and lagoon (1–6) site surveyed. Values derived from the reference data collected by an experienced marine scientist. South Water Cay, Belize, February 1993.

Site number	Number of species present	
	Corals	Macroalgae
OD1	24	12
OD2	24	17
ID1	25	14
ID2	15	15
OF1	30	22
OF2	26	14
IF1	26	20
IF2	27	15
1	3	14
2	2	14
3	3	11
4	2	12
5	3	13
6	4	15