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The Benthic Ecological Assessment for Marginal Reefs (BEAMR) Method

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ABSTRACT

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The Benthic Ecological Assessment for Marginal Reefs (BEAMR) method is a universal assessment procedure which helps to quantify the "health" condition of a coral reef habitat over time. Coral reefs, due to their complexity as an ecosystem, have presented problems in the past to marine researchers trying to assess the performance of the habitat through statistical evaluation. Previous methodologies such as the Atlantic and Gulf Rapid Reef Assessment method and the Caribbean Coastal Marine Productivity Program, while being useful, were created specifically for reefs within the Caribbean Sea and are biased toward one or two main indicator organisms (*e.g.,* stony corals). However, given that most reefs worldwide are considered *marginal* habitats, which describes them as having an impoverished community condition with biogeographic limits, the BEAMR method offers a more comprehensive analysis of all benthic functional groups defining the reef. Assessments and analysis using the BEAMR method provide marine researchers with accurate *in situ* documentation of all aspects within benthic coral communities, allowing conservation managers to more effectively protect these marine habitats. Coral reef resources are under a constant threat from both human and natural forces, making habitat assessment protocols, such as the BEAMR method, an important tool in the worldwide conservation of coral reef communities.

ADDITIONAL INDEX WORDS: *Coral reefs, biological assessment, marine survey, coastal management, coral stress.*

INTRODUCTION

Within the marine scientific community, various approaches attempt to characterize coral reef habitats worldwide in terms of statistical evaluation. Coral reefs consist of essential substrate-building components that fulfill the niches of many key marine species. Among those marine species are a wide array of organisms: from reef fish that help clean and maintain the habitat, to invertebrate hard and soft corals that provide a structural framework for the reef, to the benthic macroalgae that supply food to green sea turtles. The overall health of the reef community relies on a synergistic relationship between all these components and is dependent upon adverse influences being avoided or minimized (Costanza, 1992).

In addition to its use in universities and scientific research centers, the procedure of statistically evaluating the *health* of marine ecosystems has rapidly emerged as standard practice among federal and state environmental conservation agencies. However, until recently, a scientifically accurate characterization method for localized and marginal coral reef habitats has not been described in detail for marine researchers (Guinotte, Buddemeier, and Kleypas, 2003). Such a method is imperative not only from a research-based perspective but also from a protection management position (Costanza, 1992; Rapport *et al.,* 1999). By implementing a quantitative standard for reef characterization, marine researchers can utilize statistically valid data to reveal if the reef community health has begun to negatively fluctuate, or remain static, when exposed to potential stresses (Costanza, 1992; Done, 1995).

The purpose of this paper is to introduce the Benthic Ecological Assessment for Marginal Reefs (BEAMR) procedure. While other *in situ* monitoring protocols (*e.g.,* Atlantic and Gulf Rapid Reef Assessment, or AGRRA, and Caribbean Coastal Marine Productivity, or CARICOMP) put an emphasis on the presence of one or two indicator organisms (Kjerfve, 1998; Kramer, 2003), BEAMR focuses on recording the interrelationship between all coral reef habitat functional groups (*e.g.,* size and health of hard corals, macroalgae genera, substrate type, *etc.*) within a fixed area, thereby assessing the reef's health condition, or performance, accurately over time. Given that many reef communities worldwide are best described as having an impoverished community condition with specific biogeographic limits (Guinotte, Buddemeier, and Kleypas, 2003), BEAMR data supplies detailed quantification of physical characteristics, macroalgae cover, and overall coral density, allowing for habitat assessment, change detection,

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and habitat equivalency analyses necessary to determine if the reef has sustained harmful effects from a particular adverse pressure.

METHODS

This section details the standard operating procedure for the BEAMR assessment protocol. The materials and methods described herein are universal in their application, allowing for the assessment of any coral reef habitat.

Materials to Be Used

A BEAMR datasheet template (Figure 1) is photocopied onto both sides of a vellum-type waterproof paper (*e.g.,* DuraCopy™ or Xerox NeverTear™) and secured to a plastic clipboard. These datasheets allow two to four quadrat assessments per side, and they offer a list of standard abbreviation formats at the bottom of each sheet. Plastic metric rulers, graduated specifically in centimeters, are used to take direct measurements, and mechanical plastic lead pencils are used to complete the datasheets.

Transects are delineated by Kenson® fiberglass surveyor's ropes graduated in metric. Typically, a 100 m × 5 cm rope, weighing approximately 1.8 kg, is preferred. QuickReel plastic storage and retrieval reels are used to lay out and collect the fiberglass rope along the BEAMR transect. Soft lead-shot dive weights are placed on the rope to keep the transect delineation fixed while performing BEAMR assessments.

Assessment quadrats used in BEAMR are square in shape and constructed of perforated PVC® pipe (perforation allows the PVC® to fill up with water and remain negatively buoyant) approximately 0.64 cm (one-fourth in.) in diameter. Each quadrat contains a precalculated assessment area (*e.g.,* 0.25 m^2, 0.50 m^2, 1.00 m^2) and displays specific scaling features to improve the accuracy of percent cover estimations during BEAMR assessments (Figure 2). The perimeter of the quadrat is marked with opaque electrical tape to create alternating black and white bands, each 10 cm in width, while the interior is divided with elastic strings, creating two areas equal to 10% cover and one area equal to 1% cover.

Orientation and Frequency of BEAMR Assessments

For proper statistical analyses (*e.g.,* analyses of variance [ANOVAs], PRIMER-E® v.6), a minimum of six BEAMR transects is recommended over the designated study area. The spacing of the BEAMR transects is dependent upon the amount of area to be assessed. For example, for marginal coral reef habitats restricted to less than 0.40 ha (1 acre), BEAMR transects would be established at a maximum distance of 10 m from one another. However, for reef habitats $\geq$ 0.40 ha in area, the minimum distance between BEAMR transects would be 10 m. The exact azimuth of the BEAMR transects will greatly depend on the orientation of the reef resource in relation to the coast; as such, a direct offshore heading is most commonly used. Transects are not to exceed 200 m in length; instead, a separate transect should be established.

To ensure a high enough power for statistical analyses, a recommended sample size (n) of at least 10 BEAMR quadrat assessments per transect is recommended. The spacing of BEAMR quadrats to be performed along each transect will be directly related to the benthic substrate composition and the chosen number of BEAMR quadrat assessments per transect. To guarantee that the amount of marginal reef resource is being accurately assessed, the following line intercept calculation is performed to determine the distance interval between BEAMR quadrats along the transect:

$$d = m/n \tag{1}$$

where d is the quadrat distance interval, m is the total distance (in meters) of marginal reef substrate along the transect, excluding sand patches, and n is the number of BEAMR quadrats per transect.

For example, if there are approximately 140.0 m of marginal reef substrate along a 150.0 m BEAMR transect, and 20 BEAMR quadrat assessments have been assigned for that transect, then the distance between the quadrat assessments would be 7.0 m. The first assessment begins at the 0 m mark of the transect tape, with the BEAMR quadrat being placed on the reef adjacent to the right side of the transect (Figure 3).

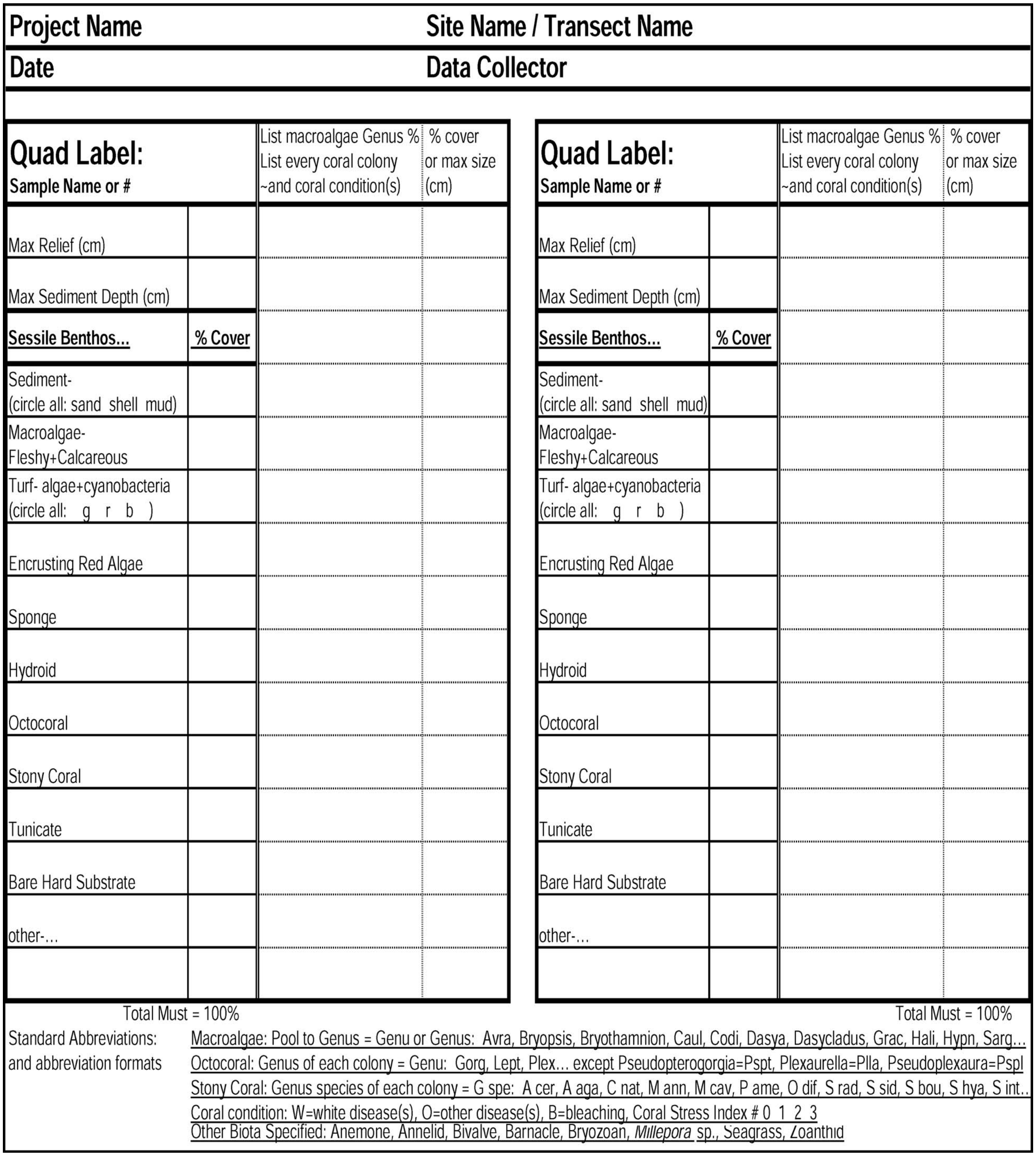
Physical Measurement of Substrate

Maximum vertical relief of the hard reef substrate (nearest cm) is measured parallel to gravity from the lowest to highest point within the BEAMR assessment quadrat. This measurement is inclusive of attached substratum and organisms with stony skeletons. In addition, the maximum sediment depth is recorded by taking two random measurements within the unconsolidated sediment, recording the greater of the two values to the nearest cm. Sediment bound in a turf algae matrix, and/or a dusting of sediment on bare substrate, would have to be at least 1 cm deep to be recorded as an accumulation of sediment. The length of the ruler used will predetermine the maximum detectable sediment depth (*e.g.,* for a ruler with a maximum scale of 30 cm, a value of 30 cm on the BEAMR sheet would denote sediment that is $\geq$30 cm deep).

Estimation of Benthic Functional Groups

An estimate of percent cover for each sessile benthic functional group is recorded to the nearest 1%. Every visible functional group within the BEAMR assessment quadrat is assigned a minimum value of 1% cover, whereas 0% cover would denote that a specific functional group is completely absent. A percent cover estimation for the following benthic functional groups is recorded for each BEAMR assessment quadrat: bare hard substrate, sediment, macroalgae, turf algae/cyanobacteria, crustose coralline algae, seagrass, sponge (bioeroding species vs. nonbioeroding species), hydroid, octocoral, stony coral, anemone, zoanthid, wormrock, sessile annelid, bivalve, bryozoan, barnacle, tunicate, and *Millepora* sp.

The left side of the BEAMR datasheet provides preassigned labels for the 10 most frequently encountered functional groups on marginal coral reef (Figure 4). This includes sediment, macroalgae, turf algae/cyanobacteria, encrusting red



Project Name	Site Name / Transect Name
Date	Data Collector

Quad Label: Sample Name or #		List macroalgae Genus % List every coral colony ~and coral condition(s)	% cover or max size (cm)	Quad Label: Sample Name or #		List macroalgae Genus % List every coral colony ~and coral condition(s)	% cover or max size (cm)
Max Relief (cm)				Max Relief (cm)			
Max Sediment Depth (cm)				Max Sediment Depth (cm)			
Sessile Benthos...	% Cover			Sessile Benthos...	% Cover		
Sediment- (circle all: sand shell mud)				Sediment- (circle all: sand shell mud)			
Macroalgae- Fleshy+Calcareous				Macroalgae- Fleshy+Calcareous			
Turf- algae+cyanobacteria (circle all: g r b)				Turf- algae+cyanobacteria (circle all: g r b)			
Encrusting Red Algae				Encrusting Red Algae			
Sponge				Sponge			
Hydroid				Hydroid			
Octocoral				Octocoral			
Stony Coral				Stony Coral			
Tunicate				Tunicate			
Bare Hard Substrate				Bare Hard Substrate			
other-...				other-...			
Total Must = 100%				Total Must = 100%			

Standard Abbreviations: and abbreviation formats

Macroalgae: Pool to Genus = Genu or Genus: Avra, Bryopsis, Bryothamnion, Caul, Codi, Dasya, Dasycladus, Grac, Hali, Hypn, Sarg...
Octocoral: Genus of each colony = Genu: Gorg, Lept, Plex... except Pseudopterogorgia=Pspt, Plexaurella=Plla, Pseudoplexaura=Pspl
Stony Coral: Genus species of each colony = G spe: A cer, A aga, C nat, M ann, M cav, P ame, O dif, S rad, S sid, S bou, S hya, S int..
Coral condition: W=white disease(s), O=other disease(s), B=bleaching, Coral Stress Index # 0 1 2 3
Other Biota Specified: Anemone, Annelid, Bivalve, Barnacle, Bryozoan, *Millepora* sp., Seagrass, Zoanthid

Figure 1. An example of a BEAMR assessment datasheet providing space for two separate quadrat assessments. Standard BEAMR abbreviation formats are located at the bottom of the datasheet.

algae, sponge, hydroid, octocoral, stony coral, tunicate, and bare hard substrate. Each of the remaining 9 functional groups are specifically identified in the "Other" section of the datasheet. Overall, the sum of all functional group percent cover estimates must equal 100% for each BEAMR assessment quadrat.

When sediment percent cover is positive within the BEAMR quadrat, the appropriate sediment type(s) is then recorded as either sand, shell, or mud. This differentiation is carried out as part of the BEAMR *in situ* assessments and is based solely on visual and consistency differences. Even though no mechanical sieve or geotechnical evaluation takes

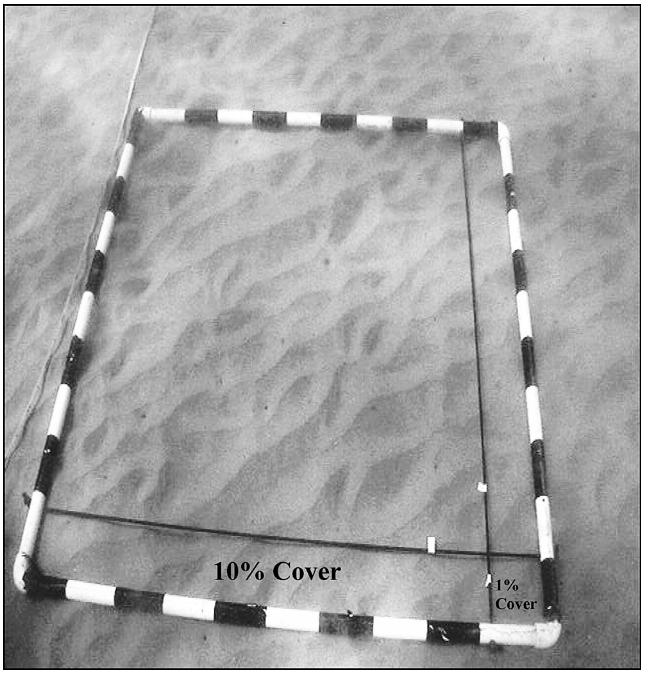


Figure 2. A 1.00 m² BEAMR quadrat with appropriate percent cover scaling features. Alternating black and white 10 cm bands are located along the outside of the quadrat, and internal elastic strings define the 10% and 1% cover areas for *in situ* data sampling.

place during the assessment, physical sampling and textural analysis aides in the differentiation between coarser sand and fine mud.

If turf algae is present within the BEAMR quadrat, the specific type(s) would be identified as either green, red, or brown. Naturally exposed substrate void of any benthic vegetation, and containing a veneer of sediment that is less than 1 cm, is recorded as bare hard substrate. Unattached, floating, and/or motile organisms are not included in data acquisition, with the exception of *Acropora cervicornis;* in this case, the researcher would assess the area(s) under the unattached *A. cervicornis.* The crustose coralline algae functional group includes species from the Corallinaceae, Sporolithaceae, and Peyssonneliaceae families.

Identification of Macroalgae Cover

A genus-level identification of macroalgae cover is recorded along the right side of the BEAMR datasheet. Abbreviated genus names are used by writing the first four letters of the genus name. When the first four letters are inadequate to distinguish between genera, writing the entire genus name is warranted (*e.g., Bryopsis* sp. and *Bryothamnion* sp.). For each macroalgae genus identified within the BEAMR quadrat (*i.e.,* ≥1%), the estimated percent cover is also recorded. In doing so, the total macroalgae percent cover value located on the left side of the BEAMR datasheet ensures that the genus-level breakdown was accurate (*i.e.,* the total macroalgae percent cover value must equal the sum of all genus-level percent cover values).

Identification of Individual Coral Colonies

The right side of the BEAMR datasheet is also reserved for the species-level identification of individual coral colonies. Each colony of octocoral and stony coral is identified, and the maximum length, width, and height are measured to the nearest cm. For crustose stony coral colonies (*e.g., Diploria clivosa*) a measurement of maximum diameter is taken. When individual coral recruits are observed with a diameter ≤1cm, 1 cm is recorded as the maximum colony size. Abbreviated stony coral names are recorded by writing the first letter of the genus name and the first three letters of the species name (*e.g., Solenastrea hyades* = S hya). A record of all abnormal conditions (*e.g.,* bleaching, disease, stress) is written next to each identified coral. Hydrocorals (*Millepora* sp.) are excluded from this component of data collection.

Application of the Coral Stress Index

A coral stress index is applied to individual stony coral colonies to assess tissue damage in response to increased abiotic factors (*e.g.,* sedimentation, turbidity, nutritification). This index was originally developed by Vargas-Angel *et al.* (2006), and it correlated a histopathological condition of the coral tissue based on one or more of the following effects: (1) swelling of mucus secretory cells (MSC) and changes in the appearance and staining properties of the mucus secretions; (2) accumulation of cell debris and tissue granularity; (3) changes in zooxanthellae densities and/or zooxanthellae degeneration; (4) swelling and granularity of the calicoblastic epithelium; (5) degenerative changes in mesenteries and mesenterial filaments; (6) presence of protozoa, algal, and/or fungal infiltrates; and (7) necrosis. Based on these parameters, a four-tiered stress index score is applied as part of the BEAMR assessment to visually record coral health (Table 1). The appropriate stress index number is recorded on the right side of the BEAMR datasheet next to each identified coral colony.

Assessment of Fish Communities

Fish communities are assessed as part of the BEAMR *in situ* survey protocol through a modified rover-diver fish count technique (Schmitt, Feeley, and Sealey, 1998). As the benthic assessment portion of BEAMR is carried out along the reef, all fish species encountered within the diver's field of vision are documented along the empty outside columns of the datasheet. Even though no abundance or size data are recorded, the researcher is free to investigate under reef ledges, in crevices, and overhead in the water column during the fish census. This allows for an overall fish species list along marginal reefs where poor underwater visibility conditions often hinder the efficacy of traditional visual fish surveys (Sale, 1998; Schmitt, Feeley, and Sealey, 1998).

Statistical Analysis of BEAMR Data

For the purposes of accurate statistical evaluation, all BEAMR data is entered into a Microsoft© Access–based data entry tool that is similar in appearance to the underwater BEAMR datasheet (Figure 5). This data entry form contains built-in quality control features such as standardized spell-

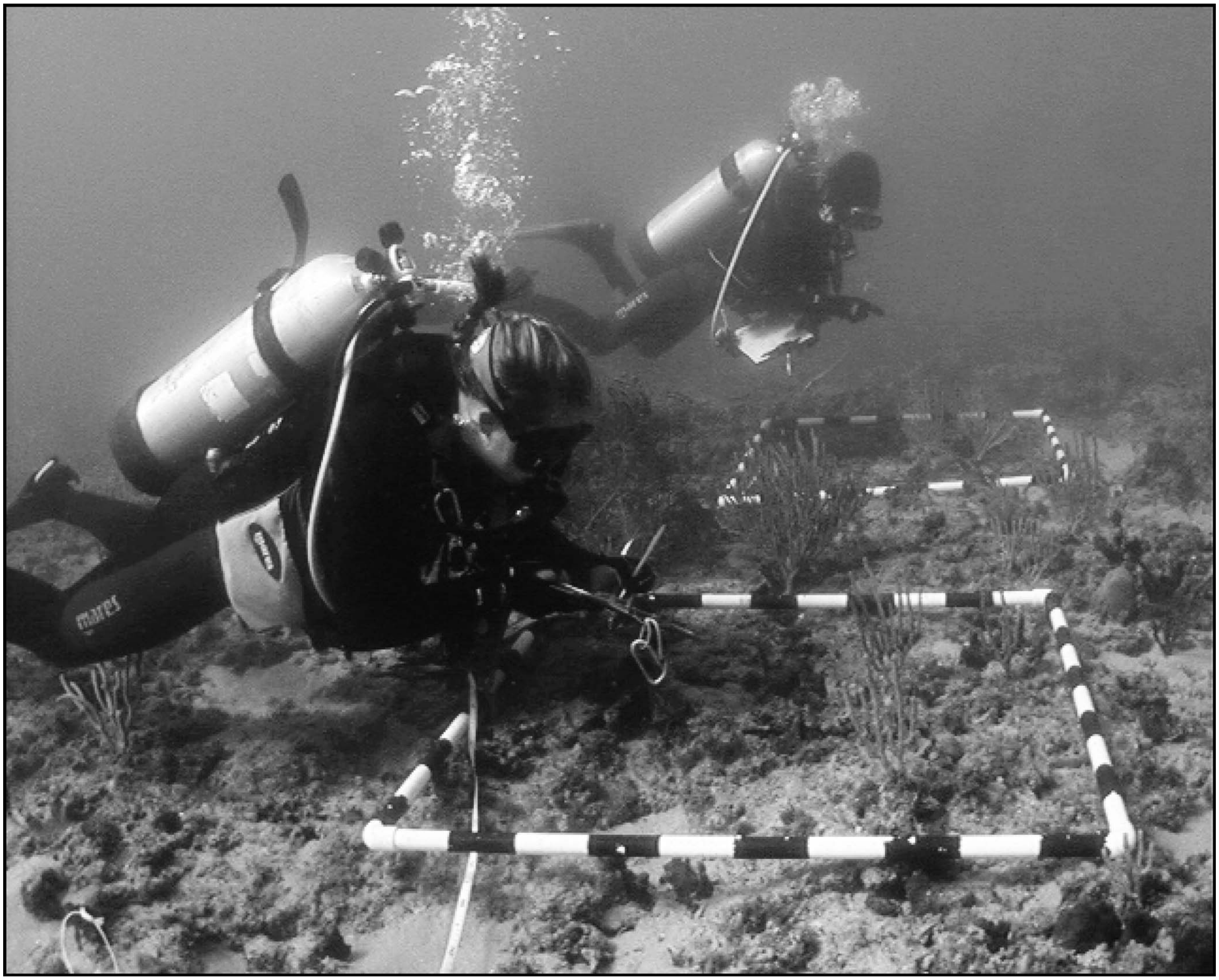


Figure 3. Marine researchers conducting the BEAMR assessment method along a marginal coral reef habitat. The BEAMR quadrats are placed adjacent to the transect at a predetermined interval.

ings, number format validation, and automatic summation of functional group percent cover (which must total 100%). Once all data has been entered into the BEAMR Microsoft© Access database, individual queries can be carried out for specific parametric statistical tests (*e.g.,* t tests, ANOVAs, regression).

In addition to standard parametric statistical tests, the BEAMR data can be directly imported into nonparametric, trend analysis statistic packages (*e.g.,* PRIMER-E® v.6; see Clarke and Gorley, 2006). This allows for a comprehensive nonmetric, multidimensional scaling (MDS) of the BEAMR data, which enables a researcher to view an entire reef community, and all of the benthic functional groups, as one collective statistical factor. By doing so, change detection within the reef community over time is evident. If changes are detected, an analysis of similarity, the approximate analogue to the parametric ANOVA (Clarke and Gorley, 2006), is applied to see if there were any significant differences occurring within the BEAMR benthic functional group data among the different sampling series. When significant differences are calculated between sampling series, a similarity of percentages analysis is performed directly on a particular BEAMR data series to target which specific benthic functional groups contained dissimilarities and by how much they differed (Clarke and Warwick, 2001).

DISCUSSION

The BEAMR method is a scientifically accurate data collection protocol that assesses the community status along marginal coral reef habitats worldwide. While other methodologies take a more general-based approach to characterize

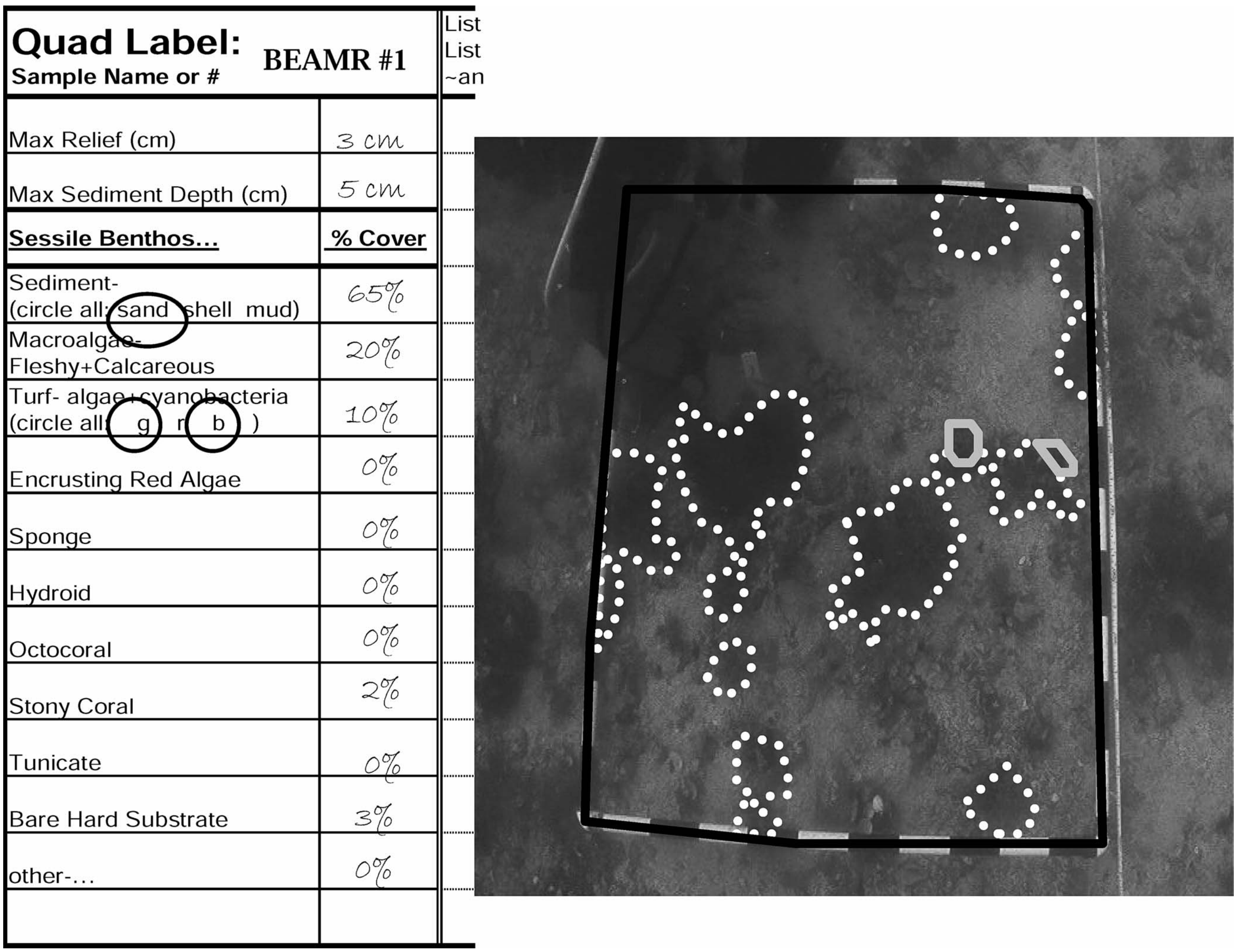


Figure 4. An example of percent cover estimations within a BEAMR assessment quadrat, outlined with the black square. The white dashed lines represent macroalgae cover, estimated to be approximately 20% of the BEAMR quadrat, and the solid gray lines represent stony coral cover, estimated to be approximately 2% of the quadrat. Overall, all functional group estimates on the BEAMR datasheet must add up to 100%.

Table 1. *Four-tiered coral stress index table with registered values and associated coral conditions (Vargas-Angel* et al., *2006).*

Stress Score	Coral Condition
0	Clear structural integrity; no observable lesions, swelling, or mucus sheets over the tissue
1	Slight to moderate polyp swelling and increased mucus production; swelling of MSC, cell debris, and zooxanthellae degeneration
2	Apparent changes in coloration (*e.g.,* intensification, patchy discoloration, bleaching); advanced swelling or tissue thinning; cellular atrophy (*i.e.,* degeneration of the epidermal muco-ciliary system and swelling of the calicoblastic epidermis)
3	Severe tissue swelling or thinning; extensive color changes (*i.e.,* dullness or fully bleached); advanced tissue atrophy; focal to multifocal necrosis

a benthic marine habitat (*e.g.,* Coates, Jones, and Williams, 2002; Gilliam *et al.,* 2001; Kjerfve, 1998; Kramer, 2003), the BEAMR assessment protocol documents the specific interrelationship of functional groups, both abiotic and biotic, which aid in the determination of whether the coral reef is self-sustaining or in decline. By doing so, data collected under the BEAMR method helps to distinguish the true condition of the coral reef over time, with the elimination of false adverse positives.

Previous *in situ* methods used to characterize coral reef communities have typically focused on one or more performance indicator organisms (*e.g.,* coral colonies). The use of these indicators helps to manage the extraordinary complexity that typifies coral reef habitats (Done, 1995, 1998; Kjerfve, 1998). One such protocol is AGRRA, which was specifically designed to provide a "snapshot" characterization of the western Atlantic's coral reefs. The data sampling method

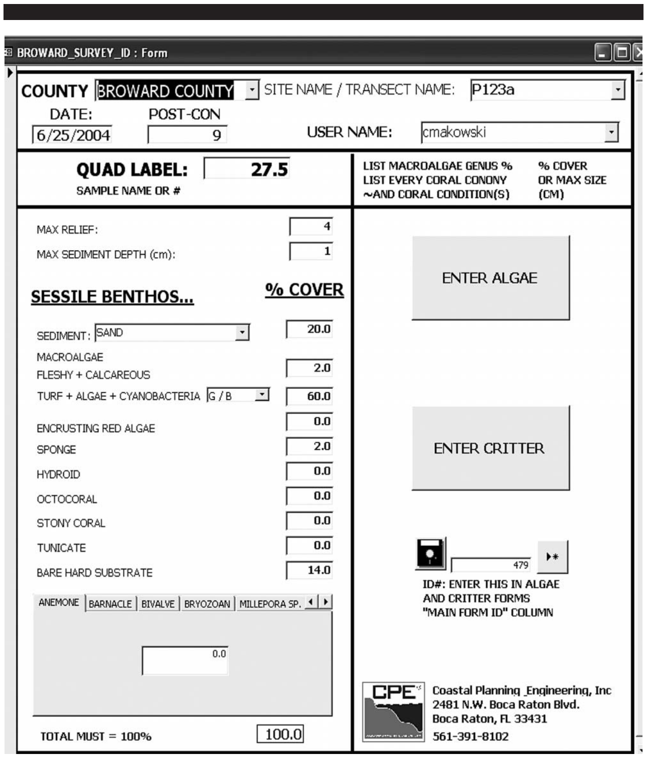


Figure 5. An example of a Microsoft© Access–based BEAMR data entry tool. This interface allows all BEAMR assessment data to be stored for later queries and analyses. Features such as the "Enter Algae" and "Enter Critter" icons allow researchers to record specific macroalgae and coral species identified within the BEAMR quadrats, along with any notes associated with the *in situ* observations.

used in AGRRA evaluates larger-scaled areas with an emphasis on two key stress indicator categories, scleractinian hard coral species and coral reef fishes (Coates, Jones, and Williams, 2002; Kramer, 2003). Other methodologies, such as CARICOMP (Kjerfve, 1998) and the Coral Reef Evaluation and Monitoring Program (Gilliam *et al.,* 2001), have similarly used hard coral indicators to examine the condition of reefs over larger spatial areas (>100 km²).

Even though these other methods are important and useful, many nearshore marine communities are listed as *marginal* habitats, which describes them as having an impoverished community condition with biogeographic limits (Guinotte, Buddemeier, and Kleypas, 2003). Furthermore, many of these habitats lack the presence of an indicator organism that many assessment protocols are skewed toward. When a habitat lacks a key health quality indicator, such as prominent coral colonies, other methodologies (*e.g.,* AGRRA) have the potential of underrepresenting the true health condition of the reef community.

The BEAMR method was created to provide a scientifically valid *in situ* data collection method, while being specifically tailored to characterize these marginal reef habitats. Marginal habitats are typically less complex than fully developed coral communities; for example, there are usually fewer species associated with marginal reefs. However, marginal reefs are subject to a wide array of physical and biological variation, and in this way these habitats are actually more multifaceted. For instance, because most marginal habitats are located in nearshore waters close to the surf zone, these communities are heavily influenced by temperature extremes, sedimentation, and turbidity. In return, BEAMR, while shying away from the reliance on one or two indicator organisms, records measurements on all indicators, biotic and abiotic, equally. By placing the same sampling pressure on all functional groups, the entire marine habitat can be viewed as a single community entity for statistical analyses.

Currently, coral reef habitats are under constant stress, from devastating disease and bleaching events, to the nutrification of the water column, to increasing seawater temperatures (Green and Bruckner, 2000; Woodley *et al.,* 2000). The BEAMR method allows for a universal standard of *in situ* data collection that provides coral reef managers, as well as marine scientists, the necessary information to track community changes within these fragile ecosystems. In doing so, a better understanding and practice of marine habitat conservation can be achieved by identifying which functional groups within the BEAMR data set are more susceptible to the surrounding stresses in a particular study area.

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