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REEF CHECK BENTHIC SURVEY ERROR. A CASE STUDY ON THE GREAT BARRIER REEF.

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THESIS FORMAT

This paper is written in the format requested by the *Bulletin of Marine Science* journal. It is intended that this work be submitted, with minor modifications, to this journal in 2003.

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ABSTRACT

Minimization of observer-related error is important for coral reef monitoring programs because highly variable data will decrease the resolution by which environmental change can be detected. Thirty-eight Reef Check volunteers were tested on their benthic identification skills on the Great Barrier Reef and their performance improved after practice and feedback sessions. Participants who had prior experience with environmental volunteer programs initially scored consistently higher than those without this experience. A similar but less consistent trend was found for more experienced divers. This information can be used to assess how much training volunteers require to remove the effects of different experience attributes. All participants' scores moderated towards the end of the study. The misidentifications still made involved similar benthos for all participants. This may reflect a lack of previous familiarity with these benthos types. The Reef Check categories that participants found most difficult to identify included hard coral, soft coral, recently killed coral, sponge and other benthic organisms. The effectiveness of future training sessions could be increased if focus is placed on these problem areas of identification within these categories.

INTRODUCTION

The use of non-professional volunteers as a cost-effective means of collecting environmental data is well established (Mumby et al, 1995; Wells, 1995; Campbell, 1997; Basinger, 1998; Keller, 2002; Lang, 2002; Seagrant, 2002) and an increasing number of non-government initiatives worldwide are using recreational divers to monitor coral reefs (Drake, 1996; Wilkinson, 1996). The Reef Check (RC) volunteer monitoring program forms the community-based arm of the Global Coral Reef Monitoring Network (GCRMN) and all GCRMN training begins with RC (Hodgson, 1999). Worldwide use of this standard protocol enables a pan-tropical comparison of a set of indicators that represent human impacts on coral reef health (Drake, 1996; Wilkinson, 1996; Hodgson, 2000). Another important goal of RC is to increase the general public's knowledge of the coral reef crisis (Hodgson, 1999; 2000), however the focus of this paper is data quality.

LIMITATIONS OF ENVIRONMENTAL MONITORING DATA

Minimization of observer-related error is important for coral reef monitoring because highly variable data caused by inter-observer error will decrease the resolution by which environmental change can be detected (Mundy, 1991). Indeed, coral reefs are complex ecosystems and research has indicated that if we are to come any closer to understanding how these ecosystems function, long-term studies on large spatial scales are essential (Done, 1997; Aronson, 2001). Few monitoring programs can secure the same observers throughout the course of study (Thompson and Mapstone, 1997; Musso and Inglis, 1998). In addition, international volunteer-dependent programs, such as RC, must also use many observers at many different sites. This situation where data from multiple observers must be compared has led to a number of studies concerned with measuring the validity of environmental data in terms of its accuracy and precision (Wells, 1995). While it is desirable that the data collected is unbiased and accurate, for the purpose of comparing data sets for monitoring, it is sufficient to aim for precision (Thompson and Mapstone, 1997; Brown, 1999).

One way to validate the measurements of reef condition collected by non-professional observers is to compare their data with the measurements made in the same context by trained professionals (Wells, 1995). Bias and imprecision in sampling data can be considerable among scientists (Andrew and Mapstone, 1987; Mundy, 1991; Mundy and Babcock, 1993; Carleton and Done, 1994; Thompson and Mapstone, 1997). However inter-observer error is often higher among non-professionals due to large variations in prior knowledge and experience (Musso and Inglis, 1998). As a result, many scientists and managers remain skeptical about the value of volunteer data (Beeh, 1996; Basinger, 1998; Brown, 1999).

SOURCES OF ERROR FOR TRANSECT-BASED MONITORING PROGRAMS

The sources of error that originate from inconsistencies among observations for shallow (<12m), transect-based methods, such as RC, can be categorized into (1) technical, (2) perceptual and (3) individual. Musso and Inglis (1998) estimated that 26% of the inter-observer error they recorded from volunteers performing successive surveys along the same transect was due to the transect problems described in (1) and (2) below.

(1) TECHNICAL. —For re-surveys or comparisons between observers, technical errors occur when the transect line is not re-laid in exactly the same position or sways in the current or swell so that successive observers are not surveying the same point (Mundy, 1991; Musso and Inglis, 1998; Hallacher and Tissot, 1999). Technical errors, are difficult to ameliorate, therefore, minimization of human error is essential to reduce the over all error in the data set.

(2) PERCEPTUAL. —Parallax error occurs when different observers look at the reef beneath the transect line from a different angle and becomes important when comparing data sets between observers. Minimization of parallax error can be achieved by following tight procedural guidelines on the angle of which observations are taken. For example, RC require that observers use a plumb line to determine the reef point that is directly below the transect line.

(3) INDIVIDUAL CHARACTERISTICS. —Individual characteristics can influence the skill level of a volunteer. These can include diver proficiency (Halusky, 1994; Musso and Inglis, 1998) and past experience with underwater work or environmental monitoring (Wells, 1995). The RC protocol is designed for experienced divers who are led by a marine biologist and RC defines suitable participants as those with more than 50 dives on a coral reef (Hodgson, G. pers. comm.). Dive experience is necessary because confident divers are more likely than anxious divers to be able to perform the tasks required for monitoring (Musso and Inglis, 1998); whereas inexperienced divers often need to concentrate more on their buoyancy than experienced divers and task overload can occur when also concentrating on survey methods (Halusky *et al.*, 1994). Experienced divers are also likely to be familiar with some components of coral reef communities, which they are required to identify. Musso and Inglis (1998) found that data collected by non-professionals with more than 30 logged dives was consistently more precise than data from less experienced

participants. The main issue with using a non-professional workforce is getting everyone up to speed from his or her different backgrounds. Knowledge of how individual characteristics affect observer ability can be useful to ascertain training needs of participants.

‘ADEQUATE’ TRAINING TO MINIMIZE OBSERVER ERROR

At present guidelines exist to ensure standard quality control for the training methodology and the recording of RC data. However, standard identification training or validation guidelines for trainers are not provided; therefore, the final precision level of volunteers is left up to the discretion, training ability and financial resources available to the RC scientist. There is a growing body of literature on the utility of non-professional data for detecting temporal ecological change and the general consensus is that inter-observer error can be reduced to that comparable of scientists if adequate practice and training is provided (Darwall and Dulvy, 1994; Halusky, 1994; Mumby et al, 1995; Wells, 1995; Miller and De'ath, 1996; Schmitt and Sullivan, 1996; Basinger, 1998; Levy, 1998; Musso and Inglis, 1998; Brown, 1999; Rubens, 1999; Harding, 2000; Roxburgh, 2000; Brown et al, 2001; Mackney, 2001; Lang, 2002). Indeed, Darwall and Dulvy (1994) reported that after 11 dives, the imprecision between volunteers and scientists dropped from 13% to 0.6% for fish identification. Similarly, Musso and Inglis (1998) found that mean volunteer estimates of hard coral were similar to that of scientists after 8-10 transects, although inter-observer error was still high. They concluded that 8-10 practice sessions are required but that training should continue until obvious inconsistencies have been overcome. It is important to highlight that ‘adequate’ training has been reported by its extent by many studies in this field.

The amount of training necessary for RC participants will depend upon their prior experience and knowledge level. RC suggest that training will typically take less than one day (Hodgson, 2000) with a half-day land-based training followed by at least one in-water practice if possible (RC, 2002). Following this recommended half-day training, Roxburgh (2000) observed that RC volunteers only correctly identified the benthos categories on 62% of their survey. These scores improved to 73% and 84% respectively after a further 3 weeks of training then 4 weeks of practice. It is important to note that these results were likely to have been affected by both line movement and parallax error, however, Roxburgh (2000) suggested that these observations emphasize the importance of adequate training and testing of volunteers before they begin to survey. However, this is a slow rate of improvement.

Although many researchers have reported that training should continue until problems have been ameliorated, extension of training and practice sessions is not always an option to ensure volunteers attain a sufficient level of proficiency. This is because the concept of using non-professionals stems from a lack of funding for environmental monitoring. Instead of measuring training proficiency by its duration, 'adequate' training should also be considered in terms of training quality. Indeed, Musso and Inglis (1998) did suggest that the remaining inter-observer error could be affected by the training content participants receive where insufficient decision rules were provided for discriminating between particular benthos. To address this issue we must focus training sessions to maximize their efficiency to increase the capacity of volunteers, whilst keeping costs low. To know where to place this focus we need to determine where identification difficulties remain and improve training to provide for these needs.

EFFECTIVE TRAINING SESSIONS

Effective training is more than the delivery of instructions (Kepler and Scott, 1981; Wells, 1995; Tovey, 1997) and sessions can be designed to maximize learning benefits by addressing theories of cognition and learning (Kerr, 1997; Brylske, 2000; Erickson, 2001) and placing focus on training needs (Mumby et al, 1995; Levy, 1998). Learning of new information can be facilitated if learners can link new knowledge with previously familiar concepts on their memory template. This theory is known as constructivism (Bodner, 1986; Mayer, 1992) and dominates research on learning of the sciences (Adey and Shayer, 1994; Matthews, 1998; Johnston and Southerland, 2001). The use of analogy-based instruction as a constructivist technique has been proven to increase learning potential (Bodner, 1986; Glynn, 1994; Jonassen, 1994; Dagher, 1995; Newby, 1995). Adults also need to test their learning as they progress and will remember an estimated 90% of what they say and do (Kerr, 1997; Tovey, 1997) as opposed to only 10% or 20% of what they read or hear respectively. A test and feedback loop is important to help volunteers focus their own efforts (Mumby et al, 1995; Musso and Inglis, 1998) as well as to provide an active learning environment (Boud and Griffin, 1987; Billington, 1988; Darwall and Dulvy, 1994; Mumby et al, 1995; Tovey, 1997; Harding, 2000). Levy (1998) and Brown (1999) noted that volunteer data correlated with that from scientists improved when more focus was placed on key problems and the use of constructivist and active learning techniques may speed up this learning process further.

The identification of the potential sources and magnitudes of error in volunteer data is necessary to ensure an appropriate training focus (Mumby et al, 1995; Levy, 1998; Musso and Inglis, 1998) and error sources have been identified in a number of studies. Roxburgh (2000) found that mistakes made by RC volunteers were significant for the 'fleshy seaweed', 'rock', 'sponge', 'recently killed coral', 'soft coral' and 'other' categories. For manta tow and non-RC transect methods, Miller (1996) and Musso and Inglis (1998) found that observer precision did not increase evenly across categories with increased practice and training and problem areas were similar to those of Roxburgh's (2000) volunteers with the addition of digitate and encrusting hard coral lifeforms, sand and rubble. This information should alert trainers to concentrate on these areas.

OBJECTIVES OF THIS INVESTIGATION

The purpose of this investigation was to determine which benthos types participants find difficult to identify in order to clarify where an effective RC training session should focus. These observations were made over a series of 5 tests, which were punctuated with feedback opportunities. In addition, the relationship between participant identification abilities and their background experience is explored in order that recommendations can be made for training and selection of non-professional researchers.

METHODS

For the RC benthos survey, observers are required to assign coral reef benthos under specific transect points to one of 10 benthos categories as described on the RC website (RC, 2002) and listed in Table 1. The precision with which participants identified the benthos in this study was measured by their performance in a series of 5 tests. The researcher participated in each test and the participants' answers were corrected against those of the researcher. In order to determine the precision of the researcher's classifications, three scientists participated in the SCUBA field tests in order to use their data to calibrate that obtained by the researcher should significant differences between the identifications be found. No replication of test was used to avoid practice effects (Fraenkel and Wallen, 1996). The procedure details that follow are summarized in Figure 1.

PARTICIPANTS AND LOCATIONS. —Thirty-eight participants were used and consisted of members of local community groups, university students and tourists on board a livaboard dive boat. These participants made up 7 separate groups, which each received the same treatment at 7 different locations in Queensland (Appendix B). The use of separate groups and locations was necessary because it was not logistically feasible to use a single group at one site. The study locations included 7 different reefs that were local to each of the participant groups. Participants with a range of dive experience from beginner to advanced were advertised for, and those used were self-selected through their interest in participating in this study.

PHOTOGRAPH PRE-TEST. —The first section of the treatment was carried out during an evening on land and involved a 10-minute briefing, on the background to RC and a summary of the identification requirements involved in the RC benthos survey. After this briefing, questionnaires were completed to obtain background information about each of the participants, which included their previous experience with diving and volunteer programs (Table 3). Participants were then asked to complete a photograph pre-test. For this test, the researcher pointed to a particular place on 50 different photographs of coral reef benthos and participants were required to identify the RC benthic category to which the specified reef item should be classified.

RC TRAINING. —Following this test, participants were given the full RC identification training, which lasted 1.5 hours. A standard length for the benthic identification component of a RC training session would be between 1 and 1.5 hours.

This training involved a brief overview on the biology of the living benthic categories and in addition to the standard RC descriptions (see RC, 2002), participants were given extra information on which descriptive characteristics to look for to differentiate between the different benthos (Table 1). Participants were advised to use these characteristics in conjunction with the decision rules outlined in Table 2, as this approach is thought to help volunteers assign reef organisms to the correct category (Carlton and Done, 1994; Musso and Inglis, 1998). Analogies for the appearance of the different coral reef benthos were provided and participants were encouraged to ask questions throughout the training. Following training, participants were allowed 1 hour to look through coral reef guides to review what they had learned.

PHOTOGRAPH POST-TEST. —The following day, the participants completed a second photograph identification test that was identical to the first.

FIELD TESTS ONE TO THREE. —Following the photo post-test, participants were taken to the reef to complete three SCUBA post-tests where participants were asked to identify 50 benthic items that were labeled using numbered tags attached to fishing sinkers. No questions for any test were randomly selected. Labeled benthos tests were used to ensure all the substrate categories of interest were represented and that technical and perceptual errors associated with transect tests were minimized. The sinker trail was placed at a depth of 5m and took between 25 and 35 minutes to complete, which ensured that the dive profile for participants was safe and the problems associated with deeper surveys were avoided (see Mumby *et al.*, 1995). The trail was marked out with a tape measure and participants were required to swim along the tape in their buddy pairs to locate the sinkers and identify the benthos. No feedback was given between the photograph post-test and the first field-test so that performance under these two conditions could be compared. However, between field tests 1 and 3, the test answers were provided as identified by the researcher who discussed with participants why they might have made their misidentification errors and reminded them of which characteristics to look for to correctly identify these benthos in the future. Coral reef guides were available for consultation during this 1-hour feedback period.

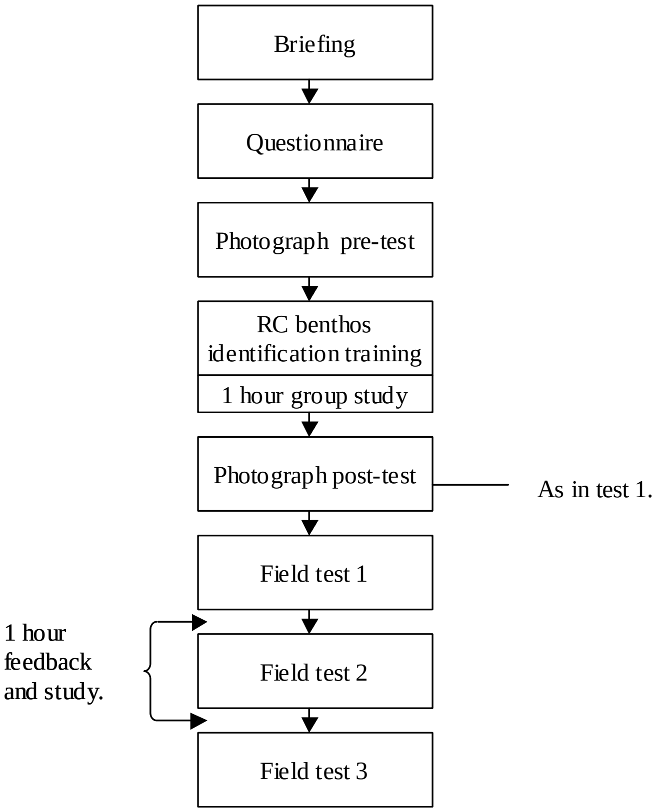

Figure 1: The quasi-experimental time-series design using a combination of written response and performance instruments.

PRECISION MEASUREMENTS. —The 'hard coral', 'soft coral' and the 'other' categories were separated into sub-categories when recorded by the researcher although participants were only using the basic RC categories (Table 1). The separation of these categories provided more specific information on which benthos participants misidentified and how these benthos were consequently classified. The sub-categories included those found to cause problems in their identification for RC participants from similar studies (Musso and Inglis, 1998; Roxburgh, 2000) and from past RC training sessions. Therefore these categories are not necessarily ecologically important divisions but rather phenotypically important for identification training of non-biologists.

Equal numbers of questions could not be asked for all benthos categories because some benthos were not sufficiently abundant on the reef to include in the trail. The underwater labels had to be in close proximity in order for participants to locate them easily as well as to provide sufficient time for participants to complete the test within a safe dive profile. A higher number of questions were asked for the more abundant benthos on the reef and the actual question allocation used was determined in a pilot study (Table 1).

Table 1. Division of questions across the RC categories and subcategories and a summary of the identification checklist provided to participants in the training session.

RC CATEGORIES	SUB-CATEGORIES	FREQUENCY IN TEST	IDENTIFICATION CHECKLIST
Hard coral	▪ Goniopora sp. (assumed to similarly represent Alveopora sp.	9	24 tentacles (6x4); hard skeleton (*waft to see skeleton underneath).
	▪ Encrusting lifeforms	2	Presence of coral cups.
	▪ All other hard coral lifeforms	5	6 or multiples of 6 tentacles; hard skeleton (waft and see no movement); presence of coral cups.
Soft coral	▪ Soft Coral: zoanthids	3	Look like cogs with teeth around the edge; waft and they will close.
	▪ Soft Coral (all soft corals)	3	8 and no more tentacles; soft skeleton.
Fleshy Seaweed		4	Fleshy body, not low growing and wiry.
Sponge		3	Irregular; covered in irregularly spaced holes and may collect silt on their surface.
Rock		10	
Other	▪ Other: ascidians	3	Waft and holes will close; shiny and do not collect silt like sponges.
	▪ Others (all other living and dead substrata)	2	
Rubble		1	Dead coral pieces between 0.5 and 15cm in diameter.
Silt		1	Pat on the surface and a cloud of silt will suspend in the water.
Sand		1	As above, sand will fall directly to the bottom.
Recently Killed Coral		3	Some white skeleton visible; coral cups not eroded.
Total		50	

*Waft means to wave a hand near to the reef organism to cause movement in the local water column

Table 2. Identification decision rules.

	YES	NO
Protruding structures: Waft the structure with your hand. Does it move?	Look for coral cups or irregular holes to differentiate between soft coral and sponge.	Look at the texture to differentiate between hard coral, recently killed coral or rock.
Encrusting structures: Look at the texture. Are there polyps or coral cups?	Count the tentacles and check if they look like cogs that close when wafted to differentiate between soft coral, Goniopora sp. and zoanthids. Gently touch to determine if hard or soft bodied.	If there are holes, waft to see if there is a reaction and look for regularity to differentiate between sponge and ascidians. Gently touch to check if it is hard or soft bodied.

ANALYSIS

Test results were transformed to percentages for analysis and the percentage test score was used as a surrogate for the percentage precision achieved. In order that the data from the 7 groups could be pooled for analysis the treatment was tightly controlled for each group to retain consistency across group and location and all treatments were carried out over a weekend period where participants were prevented from doing extra practice or study in-between tests. Variables in the training environment that could not be controlled, such as weather, were described for each location in order that differences across location could be considered as covariates in the analysis.

Several of the statistical analyses that were undertaken were based on differences across individuals. The total sample size only permitted comparisons between two groups and Table 3 shows the specific individual characteristics used to define these groups. For instance, in the comparison of coral reef dive experience related differences two groups were formed with one group of 17 individuals having under 50 dives and a second group of 21 individuals having over 50 dives.

Table 3. Participant characteristic groups used for data analysis.

PARTICIPANT CHARACTERISTIC	GROUP 1	NUMBER OF PARTICIPANTS	GROUP 2	NUMBER OF PARTICIPANTS
Age (years)	21 – 29	18	30-63	20
Sex	Male	18	Female	20
Academic/occupational background	Scientific	16	Non-scientific	22
Number of coral reef dives	<= 50	17	>= 50	21
Previous volunteer experience	Yes	18	No	20
Wanted more study time	Yes	21	No	17

RESULTS

STANDARDIZATION OF DATA. —Training and field conditions were similar at all locations with calm seas and negligible currents so these variables were assumed equal for all participants and discarded from the analysis. The scientists who participated in the SCUBA test scored a mean of 98% when corrected by the researcher. The difference between the researcher and scientists' data was assumed to be negligible and the calibration of the researcher's data unnecessary.

DOES VOLUNTEER PRECISION IMPROVE WITH TRAINING AND FEEDBACK?

A repeated measures MANOVA model IV was used with the mean % correct test scores of each of the five tests used as the dependent variables. Assumptions of homogeneity of variance were met. Mean test scores increased from the photograph pre-test and the photograph post-test to field test 3; and between field tests 1 and 3. Although sphericity is significant, this effect is catered for using the Greenhouse-Geiseer correction (F = (2.304, 68.83) = 37.22, $p < 0.05$) (Figure 2). A linear increase in test scores with test was found from the photograph tests to the last field test (F (1,29) = 186.81, $p < 0.05$).

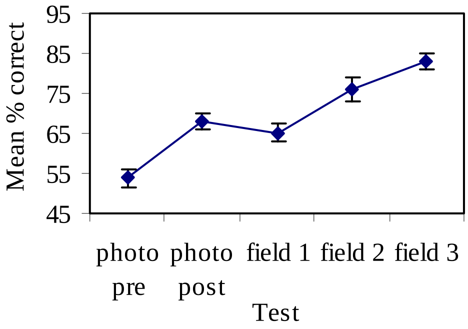

Figure 2: Mean % test scores (+- SE) across all participants.

DO PARTICIPANTS FIND SOME RC CATEGORIES MORE DIFFICULT TO IDENTIFY THAN OTHERS?

BETWEEN BENTHOS EFFECTS. —A 3-way repeated measures MANOVA mixed model IV with tests and benthos scores as dependent variables and participant characteristics as independent variables illustrated that between benthos scores were consistently different between hard coral and *Goniopora sp.*, ascidians and zoanthids and between soft coral and *Goniopora sp.*, zoanthids and sponge (F (4,9) = 9.74, p = 0.04). A trend for encrusting hard coral, rock and recently killed coral to cause problems for participants was also apparent. There was insufficient data to include the sand, silt and rubble categories in this analysis, nor the final field-test scores because 8 participants were unable to complete this test.

BENTHOS SCORES ACROSS TESTS. —Differences between benthos scores across the 5 tests were found consistent with the Greenhouse-Geisser adjustment for sphericity (F (7.18, 78.97) = 2.13, p = 0.49). Differences between scores across each benthos were investigated using a paired-t-test. The Bonferroni procedure (Winer et al, 1991) was used to control the Type 1 error rate at $\alpha = 0.01$. Between the photograph post-test and the first field test there was a trend for mean % scores to decrease (figure 3) but a significant decrease in mean scores was only found for Sponge (t (1,37) = 4.63, $p < 0.05$). Between field test 1 and 2 the trend is for test scores to increase, but this was only found to be significant for recently killed coral (t (1,30) -4.91, $p < 0.05$). The precision by field test 2 reached between 82.18 (+- 8.82 SE) and 95.85% (+- 4.03 SE) for all categories except ascidians, zoanthids and sponge, with means between 59.08 (+- 14.21 SE) and 69.42% (+- 7.74 SE).

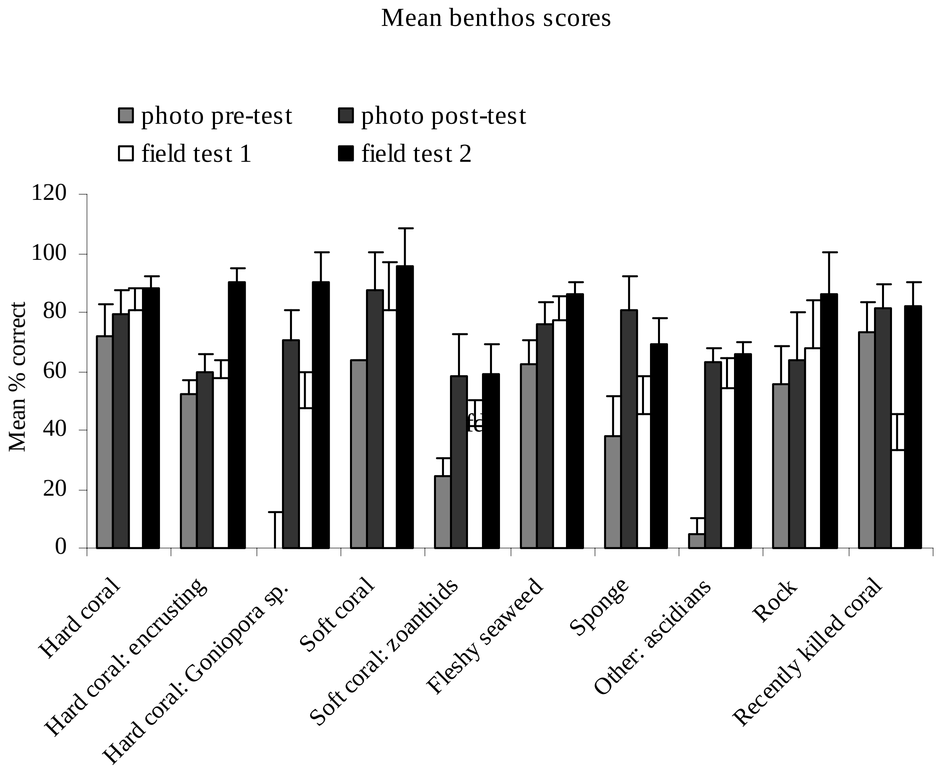

Figure 3: Mean % test scores (+ SE) for each benthos for all 5 tests.

WHAT ARE ERRONEOUSLY IDENTIFIED BENTHOS AND REEF BENTHOS CONFUSED WITH?

The confusability of a benthic item with another benthic category is illustrated in figure 4. There is a trend for particular benthos to be confused with particular benthic categories or sets of categories. This trend is particularly apparent for zoanthids confused with hard coral, *Goniopora sp.* with soft coral, recently killed coral with hard coral; and ascidians with sponge and hard coral. The training does not appear to alter the pattern of where the confusion lies for the majority of cases but to decrease this effect (Figure 4).

Field post-test 1

Benthos categories with which misidentified benthos were confused	Benthos that were confused												
SCUBA post-test 1	*Fleshy seaweed*	*Hard coral*	*Encrusting hard coral*	*Goniopora sp.*	*Ascidians*	*Rocl*	*Recently killed coral*	*Soft coral*	*Zoanthids*	*Sponge*	*Silt*	*Sand*	*Rubble*
Hard coral	3				15	13	29	6	26	10	3		
Soft coral	2	8	4	29	3	2	4			8			
Fleshy seaweed		1	1		7	6	5	1	2	3	1		
Sponge	3	2	5		14	2	2	4	5				
Other	8	5	8	13		3	2	11	18	14			
Rock	7	2	11	3	8		15	4	7	13	18		14
Recently killed coral	1	3	4	7		10		1		3			
Silt	1		1			1						3	
Sand											9		
Rubble	1								1				

☐ 0 – 9 %

🟧 10 – 19 %

■ 20 – 29 %

Field post-test 3

Benthos categories with which misidentified benthos were confused	Benthos that were confused												
	Fleshy seaweed	*Hard coral*	*Encrusting hard coral*	*Goniopora sp.*	*Ascidians*	*Rock*	*Recently killed coral*	*Soft coral*	*Zoanthids*	*Sponge*	*Silt*	*Sand*	*Rubble*
Hard coral	1				6	10	21		11	3			2
Soft coral		2	1	20	3					5	1		
Fleshy seaweed		1				2	3	1		1			
Sponge	2		1		20	2		5	2				
Other	6	4	1					2	6	3			
Rock	1	2	11				4	1	1	8	2		8
Recently killed coral	1	2	1			8							
Silt	2					1				2			5
Sand											2		
Rubble													

Figure 4: Mean % of instances where benthic items were confused with other categories in field post-test 1 and 3.

IS PARTICIPANT BACKGROUND LINKED TO THEIR PERFORMANCE?

The repeated measures MANOVA model IV illustrated that participants with previous volunteer experience consistently scored higher than those without (F (1,29) = 4.99, p = 0.03) (figure 5a). A linear interaction effect between test and previous volunteer experience was also found as both these groups increase their scores at the same rate through the series of tests (F (1,29) = 6.16, p = 0.02). A between subjects t-test indicated that this consistent difference between test and previous volunteer experience was significant for the photograph pre-test 1 (F (34.04) = .91, p = 0.07), and the photograph post-test (F (34.69) = .011, p = 0.04) and test 3 (F (29.2) = 1.86, p = 0.03).

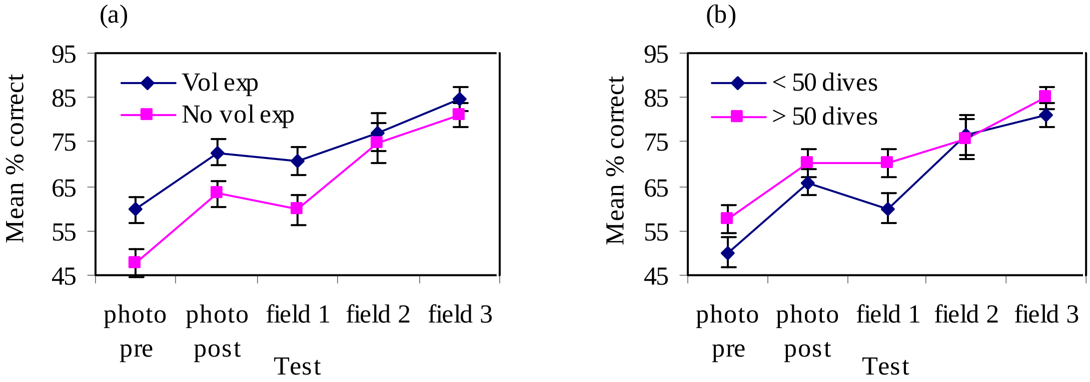

Figure 5: (a) Mean % test scores (+-SE) of participants with previous volunteer experience and participants without previous volunteer experience; (b) Mean % test scores (+-SE) of experienced and less experienced divers.

No other participant characteristics were found to consistently affect test performance, however, there was a slight trend for those with scientific backgrounds to score higher following a similar trend to those with previous volunteer experience and a trend for participants with > 50 previous dives to score higher than those with < 50 for tests 1 to 3 (Figure 5b) and this trend is most apparent in field test 1 where experienced divers score similar marks to their photo post-test whereas scores of less experienced divers drop. In this study, the number of coral reef dives held by participants closely matched their overall number of dives; therefore, no differentiation between these figures is made here.

DISCUSSION

The training and feedback sessions did help to correct the imprecision of participants but not eliminate it for any benthos category examined here. Most categories were identified with a mean precision between 82.18 (+- 8.82 SE) and 95.85% (+- 4.03 SE) in field test 2 after the first feedback session, however, some benthos appeared to be more difficult to identify by participants than others, such as *Goniopora sp.,* zoanthids, ascidians, recently killed coral and sponge. This difficulty was apparent by the number of participants who persisted to misidentify these benthos throughout the study. Encrusting hard coral also caused difficulties in similar studies (Musso and Inglis, 1998; Harding, 2000; Roxburgh, 2000); however participants made fewer mistakes with this benthos after one feedback session. The feedback appeared to help participants to focus their subsequent efforts and to remind them of the identification checklist and decision rules to use to correct their mistakes.

WHY DID ERRORS PERSIST?

A number of limitations and sources of error associated with the methods used in this study include (1) limited time (2) familiarity effects, (3) technical errors, (4) training bias; and (5) learning bias.

(1) LIMITED TIME. —Feedback sessions were restricted to 1 hour and many participants felt they had been asked to absorb a lot of information and were increasingly fatigued towards the end of the weekend. Indeed, Thompson and Mapstone (1997) suggested their success in eliminating most observer bias by their third session was due to increasing discussion opportunities during training. In the future, increased rest and discussion opportunities should be provided.

(2) FAMILIARITY EFFECTS. —Difficulties with the identification of zoanthids and *Goniopora sp*. may have occurred because participants were initially unfamiliar with these benthos; and the analogies or photographs provided in the training were not sufficient or suitable to ameliorate these mistakes in the time available. Difficulties with recently killed coral and fleshy seaweed may have occurred for similar reasons if recreational divers normally focus their interest on the attractive components of a reef. The branching and plate hard corals and brightly colored soft corals were identified with most precision and the general public, including recreational divers, tend to be

most familiar with these coral forms because they are often used to advertise coral reefs (Fenton et al, 1998).

(3) TECHNICAL ERRORS. —Some benthic items were difficult to label using sinkers because of their shape or position on the reef and included zoanthids, ascidians, sponge and branching hard coral. Question selection was, therefore, subject to a high level of bias against those that could not be labeled. Consequently, the relative abundances of each benthos type and form appearing in the test could not be assumed to represent a random selection from the study area. Learning rates of participants may have been restricted for non-abundant benthos that have a wide diversity of form, such as ascidians and sponges, because participants had less opportunity to practice their identification as low numbers of questions were asked.

(4) TRAINING BIAS. —The training focused on reef organisms that can be confused with other benthos. For example, participants were told that zoanthids can be confused with some hard corals, usually with the family Faviidae. However, it was apparent from the high instances of hard coral confused with soft coral, the category in which zoanthids belong, that Faviids were frequently confused with zoanthids. Misidentification in this case was ameliorated after feedback sessions when participants were reminded to waft potential zoanthids to double check that their polyps close. Likewise, participants were informed that coralline algae can be confused with encrusting hard coral (see Musso and Inglis, 1998), and rock was confused persistently with hard coral. Although a range of photographic examples were used to familiarize participants to a range of lifeforms that exist for some benthos, as suggested by Musso and Inglis (1998), these photographs were selected from a field guide, which typically contain aesthetically pleasing examples of coral reef invertebrates and few if any examples of recently killed coral, silty environments or those that demonstrate clearly the identification characteristics described in the training. Therefore, participants were not equally prepared to identify all benthic categories.

Training photographs that include examples of the identification characteristics suggested might increase the land-based learning capacity of participants instead of necessitating a costly increase in field training as suggested by Musso and Inglis (1998), and Roxburgh (2000). As an example for the training methods used here, a suitable photograph set for zoanthids should include an example of both closed and open zoanthids to provide a visual reference for the characteristic for them to close when wafted. Videos are also useful for the same reasons and some volunteer groups now have video cameras for training purposes.

Scientists have suggested that the use of broader reef benthic classifications for non-professional monitoring programs, like RC, enables non-professionals to collect more precise data than if they are required to identify benthos to a higher resolution (Musso and Inglis, 1998). However, errors can occur if classifications of reef organisms are not clearly defined or easily understood (Musso and Inglis, 1998; Mumby and Harborne, 1999) and some discrepancies persist among scientists (Mundy, 1991). Although an attempt was made in the training to clearly define groups for this reason, it is clear that more concise definitions are required because participants were not confident to determine the cut off point for dead coral for when it should be classified as recently killed or rock. Likewise, similar problems occurred between fleshy seaweed and turf algae that are also classified as rock and similar problems were encountered in other studies (Miller and De'ath, 1996). Photographic examples of the cut-off points between these categories might help participants to develop a mental image of how to classify these benthos when used with concise category definitions.

It has been suggested that trainees find it easier to learn a specific genus or species compared to teaching general rules for hard coral, for example (Harbourne, A. pers. comm.). However, rather than splitting up hard coral by genus, it might be easier to split them up by appearance as done in this study and results indicate that *Goniopora sp.*, for example, might need an extra explanation because of its tendency to be confused with soft coral, and encrusting hard coral because of its tendency to be confused with rock. It can be argued that *Goniopora sp.* is not of sufficient ecological importance to warrant this extra attention and this decision is best left to the trainer to determine according to its abundance on their local reef. This concept can also be applied to ascidians from the 'other' category and zoanthids from the 'soft coral' category.

(5) LEARNING BIAS. —Learning bias occurred because participants did not remember all of the identification decision rules or items on the checklist although they were designed for use collectively. Wafting appeared to be the favorite decision rule but counting the tentacles to differentiate between *Goniopora sp.* and soft coral was frequently forgotten and for this example, wafting persisted to convince participants that this hard coral was indeed a soft coral. Although wafting the benthos is useful to help with the identification of a number of benthos, its use is limited to

soft-bodied organisms that have enough vertical growth to sway in the water. Indeed low-growing soft corals, such as, *Sinularia sp.* were frequently confused with sponges or put in the ‘other’ category. It would help future teams to list the identification characteristics and decision rules on their underwater slate to remind themselves what they are and to ‘double check’ their initial category choice.

Touching soft corals, sponges and ascidians early on in training may help participants to learn to visually discriminate between these textures and reduce the confusion with hard benthos that persisted here. Many participants were unenthusiastic about contact with the reef as this seemed against their interest in conservation. Haken (pers. comm.) found that divers were more comfortable about carefully touching the reef to steady themselves after they had been shown how and where by an instructor. Likewise, RC trainers could show participants where and how it is acceptable to touch the reef when doing a RC survey.

INTERPRETATION OF RC DATA

The implications of benthos confusion include under-representation of misidentified benthos and over-representation of those ‘surrogate benthos’ with which they are confused. In this study, the ‘other’ and ‘rock’ categories were the most frequent ‘surrogates’ as they acted as ‘don’t know’ categories in a number of instances. Estimation of potential sources and magnitudes of error in trained surveyors is useful to calibrate time-series data (Marsh and Sinclair, 1989) so that interpreters can separate environmental change from observer error (Thompson and Mapstone, 1997). Estimations of inter-observer error have been attempted to some degree by a limited number of researchers for a variety of volunteer monitoring programs (Darwall and Dulvy, 1994; Inglis and Lincoln-Smith, 1995; Mumby et al, 1995; Schmitt and Sullivan, 1996; Roxburgh, 2000), however, the calibration of RC data or integration of measurements of observer error have not been attempted. A quantitative description of data variability may be estimated from the sources and magnitudes of error provided from a test taken by each volunteer prior to surveying. This quantitative description of error made by an observer on a pre-test for each of the 10 separate RC categories can be presented graphically as an error bar on the survey data they collect so that managers are provided with a known level of trust in the data.

Indeed, (Parker et al, 1995) pointed out that results from scientific models should be accompanied with some indication of the level of confidence that can be placed on the outcome as this avoids the results being either under or over-valued or discounted entirely. This advice would seem to be sensible to extend to data collected by multiple observers in the field. Thompson and Mapstone (1997) suggested that participation in repetitive validation exercises also reminds observers of the importance in standardized data collection and this might function to increase their diligence.

PARTICIPANT BACKGROUND

In order to train all observers to the same level, it is important to understand how their different backgrounds might affect the amount and type of training they require.

DIVE EXPERIENCE. —Experienced divers appeared to be more familiar with some benthos than less experienced divers as is apparent by their higher photograph pre-test scores. However, this advantage ceased after the first in-water test and feedback session where scores between the dive experience groups moderated. Some benthic categories appeared to persist in causing problems that required extended or improved training to ameliorate. It was apparent that both experienced and less experienced divers shared a similar information absorption capacity during the training because both groups achieved similar initial score increases. If this is the case, provision of training materials prior to the formal training session may increase its effectiveness by familiarizing participants with the material.

The exclusion of feedback between the photograph post-test and field test 1 was assumed to minimize improvement due to practice so that the effects between both test environments could be observed. The trend for experienced divers to achieve similar scores in both these tests indicated their familiarity with certain benthos in the coral reef environment as well as from photographs, their comfort with diving, or a combination of both these factors. For the less experienced divers, reduced scores for their first field test may indicate lower comfort levels underwater or that photographic examples, from which they were to become familiar with the benthic classifications, were not sufficiently similar to the real environment. Therefore, these participants were not adequately prepared for field identifications from the land-based training.

Dive experience parameters do not; however, appear to be consistent predictors of RC benthos identification ability. There was a high level of variance in the performance of experienced divers where some had buoyancy problems, which is known to increase task overload, whilst others found the identification learning difficult. In contrast, a number of less experienced divers performed very well. Therefore, it is important for RC trainers to make an additional assessment of their volunteers' comfort underwater and not assign less able divers with data collection roles until their comfort increases or provide extra training in scientific diving techniques.

VOLUNTEER ENVIRONMENTAL MONITORING EXPERIENCE. —It appeared that practical experience with environmental monitoring was a better predictor of performance at the start of the training session regardless of experience with coral reefs. Many of these participants were less experienced divers, which might have influenced the similar results between dive experience groups. Experience with other volunteer environmental projects may have encouraged participants to develop an interest in coral reef communities when diving recreationally. Indeed, experienced volunteers, like experienced divers, appeared to get ahead with certain benthos, with which they may have already been familiar whilst problems with other benthos remained as scores between the 2 groups moderated after the first field test.

ACADEMIC/OCCUPATIONAL BACKGROUND. —A general scientific background, however, did not help participants gain the skills required for marine-life identification more than those without. Schmitt and Sullivan (1996), however, found that participants with a biological background did find identification easier and this was again attributed to familiarity with identification skills obtained through their education.

It would be interesting to determine if the cause of the patterns in participant ability and background recorded here are related to levels of interest and subsequent familiarity in coral reef environments.

OTHER DIFFERENCES. —Variations of participant diligence (Mumby *et al.,* 1995) or cognitive differences among observers can also influence their learning needs and gains (Adey and Shayer, 1994). The differences between volunteer training needs can affect the skill level that they can attain from a particular training session. It is, therefore, important for a trainer to provide for these needs to maximize the learning potential for each volunteer. To identify individual training requirements and those volunteers who are ready to be given a data collection role, a test is necessary and the sinker test method trailed here was successful and favored by participants. The requirement for participants to pass an identification test is standard procedure for other programs, such as Coral Cay Conservation (Mumby *et al,* 1995) and REEF (2002). To reduce the cost of repetitive in-water practice sessions it would be useful to develop a photograph test that could provide a valid prediction of participants' likely ability underwater. This test would require suitable examples of all benthos types that are judged important for participants to identify according to their relative abundance on a reef and subsequent chance of appearing under a RC transect. To relieve disappointment for those who may not pass first time, trainers could buddy these volunteers with experienced participants in order that their training can continue during a survey. It would also be interesting to determine to what extent a standardized set of training and validation materials could be used to reduce inter-observer error across RC teams both regionally in Queensland and on a pan tropical scale.

RECOMMENDATIONS

- Use pre-survey validation tests to provide observers and trainers with feedback as well as to remind observers of the importance of standardized data collection;
- Produce a photograph test that is representative of local reef benthos that participants will be required to identify for surveys in order to maximize the capacity of land-based training sessions;
- Provide observers with training information prior to the formal training in order that they can familiarize themselves with the material;
- Provide adequate rest periods during training workshops to avoid fatigue;
- Encourage participants to touch certain benthos during their training to enhance their ability to discriminate between them;
- If selection of participants is feasible, use criteria that addresses previous scientific monitoring or volunteer experience as well as dive experience.

CONCLUSIONS

Results from this study suggest that efficiency is necessary to reduce fatigue or information overload as well as to minimize costs and volunteers that are likely to perform well are those with prior interest and familiarity with coral reefs as well as with comfort underwater. An acceptable level of data precision must reflect the program's objectives and in Queensland, managers prefer that volunteer data be of a high precision level if it is to be incorporated into the government data sets that are used for decision-making (Wachenfeld, D., pers. comm.). For this situation where precision comparable to that of scientists is desired for all participants and for all benthic categories, then the training used in this study will need improvement. This can be achieved by providing more focus in difficult areas, improved training materials, longer feedback sessions and possible extension of the training to allow more study time and time for participants to take in all of the information presented to them. Knowledge of the areas of confusion provided by this research will be useful to focus future training programs on problem areas and decrease training effort on relatively unproblematic areas by minimizing information overload whilst maximizing the effectiveness of the session. This study highlights where future research is required to maximize RC training potential and efficiency in order to enhance the potential of the RC program and expand the market of RC data users to managers and scientists who require precise data for incorporation into their decision-making processes.

APPENDIX A

Table 4. Repeated measures MANOVA of the dependent variable, mean % scores, and the various independent variables as listed. The alpha level was set at 0.05.

SOURCE OF VARIATION	DF	RESIDUAL DF	MEAN SQUARE	F	P
♦Test	2.3	66.83	3795.35	37.22	0.00
♦Test*Age	2.31	67.16	116.12	1.49	0.21
Age	1	29	1872.80	4.06	0.05
♦Test*Sex	2.31	66.86	40.87	0.22	0.83
Sex	1	29	91.76	0.18	0.68
♦Test*Academic background	2.33	67.42	258.56	1.47	0.24
Academic background	1	29	101.52	0.19	0.66
♦Test*Number of coral reef dives	2.236	68.43	245.41	1.42	0.25
Number of coral reef dives	1	28	841.23	1.72	0.20
♦Test*Volunteer experience	2.30	66.83	152.13	1.49	0.21
Volunteer experience	1	29	2241.29	4.99	0.03
♦Test*Previous research experience	2.38	68.94	420.86	2.54	0.08
Previous research experience	1	29	1373.59	2.87	0.10
♦Test*Wanted more study time	2.31	66.87	162.02	0.91	0.42
Wanted more study time	1	29	126.15	0.24	0.63

♦Sphericity was significant, therefore, Greenhouse-Geisser statistic reported

APPENDIX B

REEF LOCATIONS. —Low Isles, Clam Beds, Cod Hole, Arlington Reef, Geoffrey Bay reef at Magnetic Island, Blue Pearl Bay reef at Hamilton Island, Kingswell Point at Keswick Island.

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Quicksilver Connections	In-kind reef access
Magnetic Island Dive Centre	In-kind tanks
Hayman Island Resort	In-kind access to Blue Pearl Bay and tanks
Order of Underwater Coral Heroes	Volunteers
Cumberland Region Eco-Watch	Volunteers and in-kind reef access
Cairns And Far North Environment Centre	Volunteers

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