

## VIDEO SURVEYS OF CORAL REEFS: UNI- AND MULTIVARIATE APPLICATIONS

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**ABSTRACT**

Many survey and monitoring programs rely on repeated sampling of permanently-marked transects or quadrats. However, the repeated measures approach is impractical for sampling more than a few places on a few reefs. Independent sampling provides a useful alternative. In one such sampling program, 10, 25-m long transects are videotaped and then analyzed by point counts, with 50 stop-action frames per transect and 10 random points per frame assessed. The technique provides sufficient power to test univariate and multivariate hypotheses of community composition. In a univariate example, differences between Caribbean reefs as low as 3.6% coral cover were detected at the  $\alpha=0.05$  level. A multivariate example involved testing the hypothesis that community composition at a ship-grounding site was more similar to a natural hardground site than to a spur-and-groove reference site representing the undisturbed condition. Discriminant analyses classified transects from the ship-grounding site predominantly with the hardground site based on: (1) multivariate percent coral cover, and (2) multivariate percent cover of algal categories. The independent sampling approach has wide applicability, especially where human and financial resources are limited.

**INTRODUCTION**

The question of whether or not reefs are in decline worldwide has aroused considerable debate (e.g., Done 1992; Jackson 1992; Porter and Meier 1992; Woodley 1992; Ginsburg 1994). Long-term data sets are clearly needed to resolve this question (Ogden and Wicklund 1988; Rogers 1988; Ray and Grassle 1991; Smith and Buddemeier 1992; and many others), but such data sets do not exist for most reefs. The paucity of long-term studies is due to two related problems. The first difficulty is the effort and expense required to collect the information. Traditional monitoring studies rely on establishing permanent transects and/or quadrats. The permanently marked areas are sampled multiple times in a repeated measures statistical design. Logistical considerations generally limit the number of reef sites at which a research team can deploy permanent markers, limiting the generality of the results. The second impediment is that the effort and expense are difficult to justify in light of the difficulty of formulating and testing hypotheses (Hughes 1992).

Over the past several years we have developed a video transecting technique that does not require permanent markers for long-term studies (Aronson et al. 1994). The method relies on an independent sampling strategy, in which different transects are videotaped each time the sites are surveyed. In order to develop the sampling strategy within a reasonable period of time, we compared parameters of community structure among reefs instead of sampling the same reef at infrequent (multi-year) intervals. We showed that the approach is statistically powerful in comparisons of univariate parameters such as coral cover and diversity. However, its value in solving multivariate problems has yet to be established. Multivariate tests are therefore the primary focus of the present paper.

We first describe the mechanics of the video technique and briefly review its application to a univariate problem: testing the hypotheses that coral cover and diversity differ among reef sites (Aronson et al. 1994). We then explore the utility of the sampling design for solving a multivariate problem: testing the hypothesis that a ship-grounding disturbance shifted community composition in a predictable fashion. Our results demonstrate the potential of this approach for examining a variety of problems in coral reef ecology.

**THE VIDEO METHOD**

The sampling protocol involves videotaping 25-m long by 0.4-m wide belt transects that are haphazardly placed within the habitat of interest. A diver swims slowly along the transect, videotaping at a height of approximately 40 cm from the substratum,

using a high-resolution (Hi-8) video camera with a wide-angle lens in an underwater housing. A 15-cm gray plastic bar is attached to a rod that projects forward from the video housing. The bar, which is held at the level of the substratum, provides scale in the video frames and ensures that the camera remains a constant distance from the bottom.

By holding the video camera perpendicular to the substratum and swimming slowly along the transect it is possible to produce clear stop-action images for analysis in the laboratory. Corals, zoanths, and some sponges and gorgonians can be identified to species, down to a diameter of approximately 5 cm. Algal turfs, crustose coralline algae, most macroalgae, and many sponges and gorgonians cannot be identified to species using this technique.

Experimentation with video lights has shown that using a pair of commercially available, 50-watt lamps does not significantly enhance color saturation when ambient light levels are reasonably high. Lights are generally unnecessary for videotaping to a depth of 9 m. At 15 m depth, the advantage conferred by video lights is greatest under turbid conditions, in stormy weather, and near sunset. Using 100-watt lamps improves color saturation at the cost of shortened battery life. In many cases the use of lights does not substantially improve the accuracy of species identifications, and lights are often more trouble than they are worth.

Individual video frames are displayed on a high-resolution monitor in the laboratory. A clear plastic sheet containing random dots is laid over the monitor screen, and the identities of the sessile organisms underlying the dots are recorded. The videotape is then advanced to a new, non-overlapping position, and another set of random dots is laid over the screen. Ten different sheets of random dots are used on a rotating basis. Each 25-m transect comfortably fits 50 evenly-spaced video "quadrats", which cover almost the entire length of the tape. Since each transect is treated as a single replicate, there is no need to randomize the positions of the frames that are analyzed.

**UNIVARIATE STATISTICAL HYPOTHESES**

Photographic studies of reef dynamics generally involve taking still images of permanent quadrats. The photographs are either digitized (e.g., Porter et al. 1982; Hughes 1989, 1994; Porter and Meier 1992; Witman 1992) or projected onto a screen containing a Cartesian grid or random dots. When point counts are used, the number of counts per photograph is generally 100 or more (e.g., Bohnsack 1979; Bak and Luckhurst 1980; Edmunds and Witman 1991; Hughes 1994; Rogers et al. 1994). Yet rarely have investigators of coral reefs (or other marine habitats) sought to determine the minimum number of dots necessary to obtain estimates of cover and diversity adequate for the purposes of the particular study (but see Bohnsack 1979).

Aronson et al. (1994) analyzed video transects from two reef sites using different numbers of random dots per frame. The sites were spur-and-groove habitats at 15 m depth at (1) Discovery Bay, Jamaica, which has low coral cover (<3%), and (2) Carrie Bow Cay, Belize, which has relatively high coral cover (>16%, high for 15 m depth in the Caribbean at present). Ten transects were videotaped per site over a distance of 0.5-1 km. This sample size was considered logistically reasonable in most field situations. The substratum occupants were recorded under 25 random dots per frame, in groups of 5 dots.

The means and variances of percent coral cover and Shannon-Wiener diversity ( $H'$ ) remained essentially constant when the number of dots was  $\geq 10$ . Therefore, the appropriate sampling design is 10 random dots per frame and 50 frames per transect, given the constraint of 10 transects per site. Each 500-dot data set generates a single estimate of percent cover and species diversity, requiring as little as 2 hours for trained personnel to extract from the videotaped transect. Because the sample size is the

number of transects, increasing the number of dots per frame yields no advantage in terms of statistical power. Carleton and Done (1995) reached similar conclusions in designing videotape surveys for the Great Barrier Reef.

As detailed in Aronson et al. (1994), the minimum detectable difference,  $\delta$ , was calculated for Analysis of Variance (ANOVA) comparisons of percent coral cover and  $H'$  among 4 sites: Discovery Bay, Carrie Bow Cay, and Conch and Carysfort Reefs (both in the Florida Keys). Ten 500-dot samples (from 10 transects) were collected from each site and used as replicates in one-way ANOVAs comparing coral cover and  $H'$  among sites. For (arcsine-transformed) coral cover, the minimum detectable difference between sites at  $\alpha=0.05$  with a power of  $(1-\beta)=0.90$  was on the order of  $\delta=5-10\%$  cover; in fact, the ANOVA with Tukey HSD a posteriori comparisons detected a significant difference of only 3.6% cover between two sites. At the same significance and power levels,  $\delta=0.81$  for an ANOVA comparing  $H'$  among sites; a posteriori comparisons detected a significant difference between sites that differed in mean  $H'$  by only 0.57. Studies requiring lower minimum detectable differences will require larger numbers of transects per site.

#### MULTIVARIATE STATISTICAL HYPOTHESES

In some studies the hypotheses to be tested do not involve univariate parameters such as coral cover or diversity; rather, the expectation is that species composition varies among sites or among sampling times. For example, managers and policymakers often wish to understand the effects of anthropogenic disturbance on coral reefs. Will a disturbed reef recover to its "original state", i.e., to the state in which it would now be had the disturbance not occurred? Or will it "recover" to a community state that is predictably different from the "original state"? As part of an effort to evaluate the effects of ship-groundings on reefs of the Florida Keys National Marine Sanctuary, USA, we used the video method to test a multivariate hypothesis.

When a ship runs aground in a shallow spur-and-groove habitat, it eliminates the bottom topography and produces a large, flat area of substratum (Smith 1985; Gittings et al. 1994). We predicted that such disturbed areas should not recover to their initial spur-and-groove community configurations, at least on a decadal time scale. According to our hypothesis, the community that develops on the exposed primary substratum should resemble a hardground community typical of shallow-water limestone pavements in the western Atlantic. Thus, instead of developing spurs dominated by the scleractinian *Acropora palmata* (elkhorn coral) and the hydrocoral *Millepora complanta* (fire coral), these communities should come to be dominated by the corals and other sessile organisms that are commonly associated with hardground habitats.

In 1994 we compared a ship-grounding site to two reference sites off Key Largo, in the northern part of the Florida Reef Tract. The disturbed site was the 1500-m<sup>2</sup> area in which the M/V Wellwood ran aground at Molasses Reef (25°01'N, 80°22'W) in 1984, leveling the spur-and-groove topography (Hudson and Diaz 1988; Gittings et al. 1994). One reference site was the spur-and-groove habitat on Molasses Reef adjacent to the impact site. This area approximates the community that would be found at the Wellwood site today, had the ship-grounding not occurred. The other reference site was a natural hardground habitat at Conch Reef (24°57'N, 80°28'W), 10.2 km to the northeast. All three study sites were within the narrow depth range of 4-7 m.

#### METHODS

Ten 25-m fiberglass surveyor tapes were positioned haphazardly at each site. The topographic complexity of the reef surface was measured along each transect to confirm that the substrata at the Wellwood and Conch Reef sites were significantly flatter than the Molasses Reef spur-and-groove site. Topographic complexity was measured by carefully conforming a 5-m length of fine brass chain to the substratum along the central portion of each transect (Aronson et al. 1994). The chain was conformed to the finest topographic features that the 17-mm links permitted; it was carefully inserted into small cavities and into the spaces within thickets of foliose and branching corals. A com-

plexity index,  $C$ , was calculated as  $C=1-d/l$ , where  $d$  is the horizontal distance covered by the conformed chain (measured against the transect tape) and  $l$  is its length when fully extended (e.g., Risk 1972; Rogers et al. 1982). Values of  $C$  were arcsine-transformed and analyzed by a one-way ANOVA to compare the three sites.

Each transect was videotaped as described in The Video Method. The video transects were analyzed by point counts to determine the percent cover of the various species of hard corals (Scleractinia and Milleporina) and three algal categories: fine turfs, crustose corallines and bare space combined; fleshy macroalgae and thick turfs combined; and *Halimeda* spp. These algal categories were employed due to the ambiguities inherent in distinguishing their individual components in the videotapes (e.g., fine turfs, crustose corallines and bare space were difficult to distinguish). In addition, individual colonies of hard corals, gorgonians, zoanths and sponges in the video transects were counted and identified to the lowest taxonomic level possible (species for corals and zoanths; genus or species for gorgonians and sponges).

The point count and colony count data from the videotapes were logarithmically transformed to increase their conformity to the assumptions of parametric statistics (normality and homoscedasticity). The data sets were analyzed by Multivariate Analysis of Variance (MANOVA), followed by discriminant analysis to determine if the three sites could be distinguished. Significance levels for the MANOVAs were assessed using the Pillai Trace statistic, which is robust to violations of the parametric assumptions of normality and homoscedasticity (Johnson and Field 1993). Separate analyses were conducted for four data sets: (1) the point count (percent cover) data on hard corals, (2) the colony count data on hard corals, (3) the colony count data on gorgonians, zoanths and sponges, and (4) the point count (percent cover) data on the algal categories.

For each data set, a second discriminant analysis was run in which the discriminant functions were calculated based only on the Conch and Molasses transects. The Wellwood transects were then treated as unknowns and classified as either Conch or Molasses. For the first three data sets, species (or genera) that were absent from Conch and Molasses, and present only at Wellwood, were irrelevant to classifying the Wellwood transects. Those categories were therefore omitted from the analyses.

#### RESULTS AND DISCUSSION

Mean topographic complexity,  $C$ , was significantly greater at the Molasses site than at Wellwood or Conch, which did not differ significantly from each other (one-way ANOVA on arcsine-transformed  $C$ :  $F_{2,27}=26.075$ ,  $P<0.0005$ ; Tukey HSD multiple comparisons: Molasses>Conch=Wellwood; Fig. 1). In other words, the Wellwood and Conch sites were indeed flatter than Molasses. Wellwood was therefore expected to show greater similarity to Conch than to Molasses in community composition.

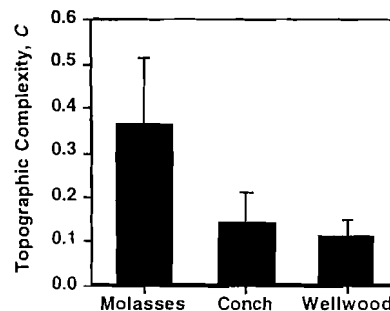


Fig. 1: Mean topographic complexity,  $C$ , measured along transects at the Molasses, Conch and Wellwood sites. Error bars represent standard deviations. Horizontal bar indicates lack of significant difference between Conch and Wellwood.

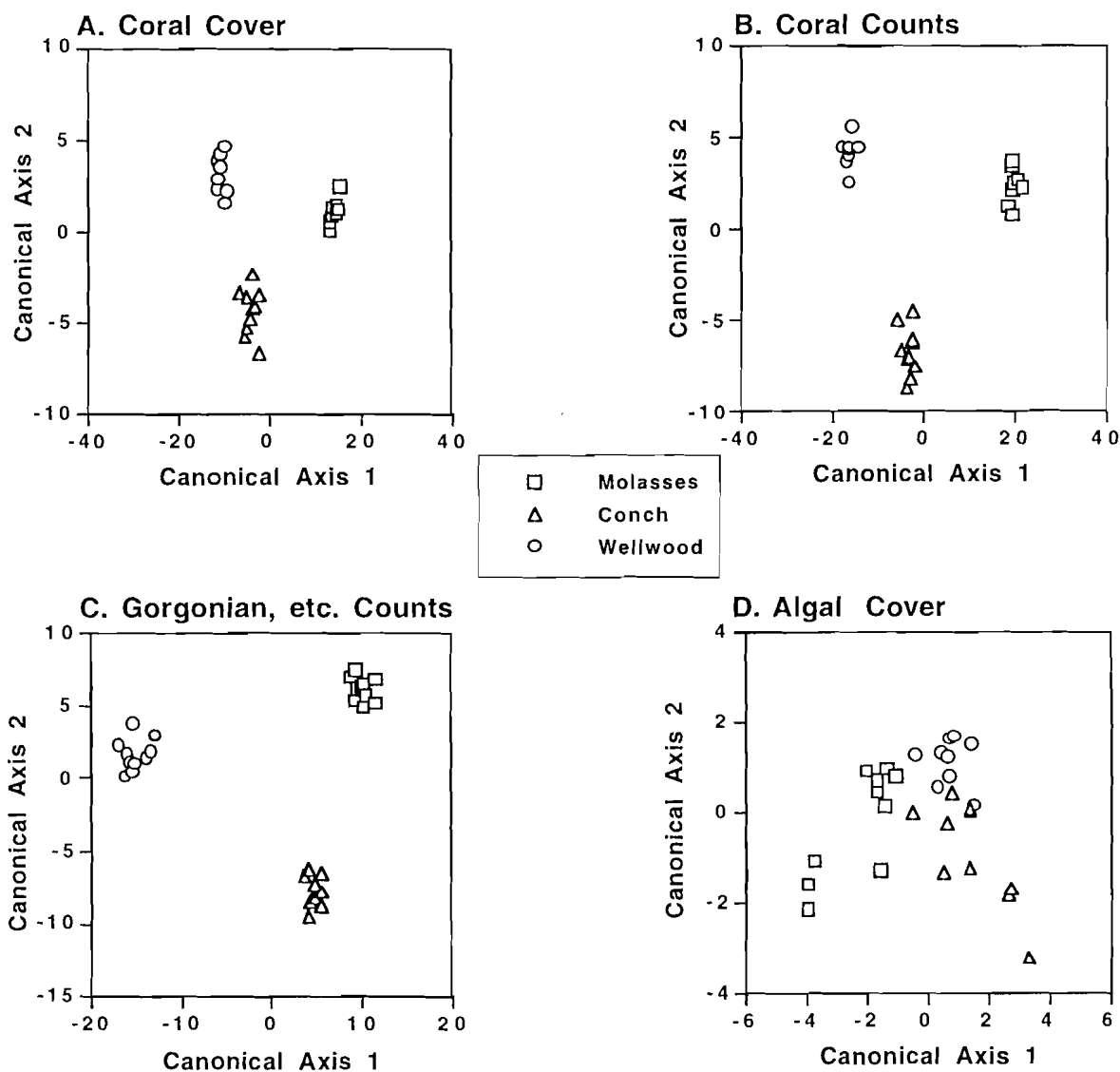


Fig. 2: Results of discriminant analyses of three sites, based on (A) percent cover of hard corals, (B) colony counts of hard corals, (C) colony counts of gorgonians, zoanthids and sponges, and (D) percent cover of algal categories. Each point represents a transect at one of the three sites. Fewer than 10 transects per site appear in some cases due to overlapping coordinates.

For the first three data sets from the video transects--coral cover, coral colony counts, and gorgonian-zoanthid-sponge colony counts--MANOVAs indicated significant among-site differences (Pillai Trace,  $p < 0.005$  in all cases). For all three data sets, discriminant analysis effectively separated the three sites along two canonical axes, with 100% correct classification of the transects (Fig. 2A-C).

The two coral-based analyses, coral cover and coral colony counts, produced similar patterns of separation: Molasses separated strongly from the other two sites along the first canonical axis, and Conch separated from Wellwood and Molasses along the second axis (Figs. 2A and 2B). Examination of the canonical loadings revealed that in both analyses *Acropora palmata*, the primary constructor of the shallow spur-and-groove topography at Molasses, was the most important species in the strong separation observed along the first axis. Judging from anecdotal reports and from the number of dead colonies standing in life position in 1994, this species has experienced considerable mortality in recent decades; the mean cover of *A. palmata* was only 3.9 ( $\pm 3.4$  sd) percent at Molasses in 1994, with a mean of 7.1 ( $\pm 6.2$  sd) colonies per transect. Even so, *A. palmata* displayed the highest percent cover of any coral species at any one site, and it

contributed strongly to discrimination among sites because it was entirely absent from Conch and Wellwood. The most important species separating sites along the second canonical axis in the coral cover analysis were, in decreasing order, *Siderastrea siderea*, *Dichocoenia stokesi*, *Millepora complanata* and *A. palmata*. For coral colony counts, the species most influential along the second canonical axis were, in decreasing order, *Millepora complanata*, *Favia fragum*, *A. palmata*, and *Agaricia agaricites*.

The discriminant analysis of gorgonian-zoanthid-sponge colony counts showed clear separation of Wellwood from the other two sites along the first canonical axis (Fig. 2C). Conch separated strongly from Molasses and Wellwood along the second axis. No single taxon was strongly influential in these separations.

Discriminant analysis using the algal categories separated the three sites less clearly (Fig. 2D). All 10 Molasses transects were classified correctly, 2 Conch transects were incorrectly classified as Wellwood, and 1 Wellwood transect was incorrectly classified as Conch. These ambiguities in classification accord with the hypothesis that Conch and Wellwood were similar in community composition. Separation along the first canonical axis was

strongly influenced by both *Halimeda* spp. and the thick turf-macroalgae category, and separation along the second axis was most strongly influenced by *Halimeda* spp. (Fig. 3).

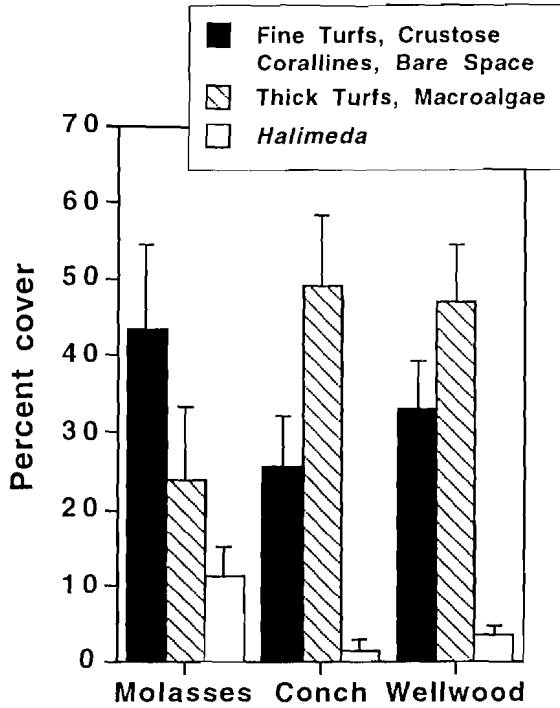


Fig. 3: Abundance of algal categories at the three sites. Error bars represent standard deviations.

When the Wellwood ship-grounding transects were treated as unknowns, the majority of transects classified with Conch in three of the four tests (Table 1). The Wellwood transects were significantly more like the Conch transects based on coral cover and algal category cover (after Bonferroni adjustment of the significance level to  $\alpha=0.05/4=0.013$  to control experimentwise error). However, the Wellwood transects did not classify significantly more frequently with Conch based on coral colony counts or gorgonian-zoanthid-sponge colony counts.

The difference between the coral cover and coral colony count results can be traced to two causes: (1) the strong influence on coral cover of individual, large colonies at Molasses, and (2) the strong influence on colony counts of many small colonies at Wellwood. The cover of hard corals was higher at Molasses than at Conch and Wellwood (Fig. 4A). However, there were more small colonies at Wellwood than at Conch (Fig. 4B).

#### CONCLUSIONS

The video transect method was initially developed to test univariate hypotheses of significant differences in total coral cover and coral diversity among sites. In a multivariate test, the point count estimates of hard coral cover discriminated perfectly among three sites. This result demonstrates the utility of the video point-count method and suggests that it may be applicable to other multivariate problems in coral reef ecology. The multivariate coral and algal percent cover data supported our specific hypothesis of the response of reef communities to disturbance: when treated as unknowns, the Wellwood ship-grounding transects classified overwhelmingly with the Conch hardground transects, as opposed to the Molasses spur-and-groove transects.

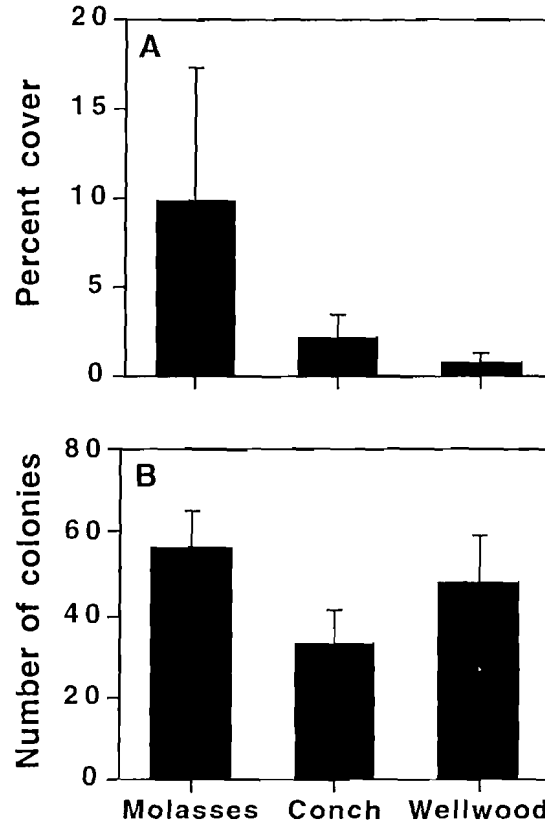


Fig. 4: Abundance of hard corals at the Molasses, Conch and Wellwood study sites. (A) mean percent coral cover per transect, (B) mean number of colonies per transect. Error bars represent standard deviations.

In addition to the percent cover estimates, the transects provided large sample sizes of coral colonies and colonies of other sessile invertebrates. Such large data sets are unlikely to be obtained from still photographs of permanent quadrats. As with coral cover, colony counts enabled the three sites to be discriminated perfectly. The fact that counts of coral colonies and counts of gorgonian, zoanthid and sponge colonies from the Wellwood transects did not classify overwhelmingly with Conch does not mitigate the value of the approach. Our hypothesis simply was not supported for either set of colony counts. For both sets of colony count data, Wellwood was different from both Molasses and Conch, and Wellwood was no more like one than the other.

The video method has obvious value for rapidly surveying large numbers of reefs to test geographic-scale hypotheses. It also provides a logistically feasible, time-efficient, statistically powerful alternative to photographing permanent quadrats in long-term studies at selected sites. The advantage of the traditional, repeated measures design is that it is possible to follow the fates of individual colonies and patches of substratum. On the other hand, the independent sampling design encompasses a greater area and more of the spatial variance within reefs. When temporal or among-reef differences are detected despite this increased variance, investigators are justified in having greater confidence in the biological significance of those patterns.

**Table 1.** Results of discriminant analyses classifying Wellwood transects as Conch or Molasses. *P*-values are one-tailed binomial probabilities. \*: Categories rather than species.

Analysis	Species	Number of Wellwood transects classified with		<i>P</i>
		Conch	Molasses	
Coral cover	17	9	1	0.011
Coral colony counts	22	6	4	0.377
Gorgonian, etc colony counts	21	5	5	0.623
Algal category cover	3*	9	1	0.011

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