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A Comparison of Rapid Visual Assessments and Photo-Quadrat Analyses to Monitor Coral Reef Habitats

Data Report

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This report compares two techniques used by the Coral Reef Ecosystem Division (CRED) of NOAA's Pacific Islands Fisheries Science Center to assess benthic cover when conducting coral reef monitoring as part of the Pacific Reef Assessment and Monitoring Program (Pacific RAMP). Data collected from American Samoa, Hawaii, and the Mariana Islands from 2010 – 2013 are compiled and analyzed.

ABSTRACT

The Coral Reef Ecosystem Division (CRED) uses two techniques to gather data on habitat composition: a photo-quadrat survey technique and a rapid visual assessment technique. The photo-quadrat surveys provide higher taxonomic resolution of benthos and an archived record, but require time-consuming analysis. In contrast, rapid visual assessments by divers provide quicker but coarser estimates of percent benthic cover. Here, we compare benthic composition data collected from the two methods from sites surveyed by divers in American Samoa (n=228 sites) in 2010, the Mariana Islands (n=305) in 2011, and the main Hawaiian Islands (n=410) in 2010 and 2013. For selected benthic functional categories (encrusting algae, fleshy macroalgae, hard coral, and turf algae), we compared percent cover estimates from each method.

Overall, compared to photo-quadrat surveys, rapid visual assessments by divers underestimated hard coral cover (-3.0% in absolute terms), encrusting algal cover (-2.3%), and turf algal cover (–11.1%) and overestimated fleshy macroalgal cover (6.5%).

The use of multiple observers is common practice for large-scale and long-term monitoring programs and is a necessary aspect of CRED's ongoing survey efforts. Intra-observer differences can introduce uncertainty and variability in estimates of the parameters of interest. Therefore, we also investigated among-diver differences in visual estimates of hard coral cover, a coarse but frequently used indicator of coral reef health. Among-diver differences were statistically significant in many cases, but the absolute scale of differences in cover tended to be small (< 6%).

Although the rapid visual assessment technique cannot replace the photo-quadrat method, which should remain the core approach for CRED's long-term monitoring program, rapid visual estimates do provide useful and low-cost estimates of hard coral cover that have utility in circumstances where photo-quadrat data are not available. Targeted training to improve observers' ability to estimate cover of encrusting algal, macroalgal and turf algae is recommended.

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INTRODUCTION

Ecosystem monitoring is an important component of coral reef conservation and resource management science. Habitat composition, typically measured as percent benthic cover, is used in coral reef monitoring programs to assess temporal and spatial trends in reef state in response to natural forces or management actions [1]. A challenge for most ecosystem monitoring efforts is to cost-effectively and reliably characterize habitat composition and produce results that can be communicated rapidly to inform management decisions [2].

Several methods are available to estimate percent benthic cover on coral reefs, with rapid visual assessment, line-point intercept, and photo-quadrat surveys being common. Rapid visual assessments involve an observer classifying benthic composition and estimating percent cover by eye [3,4]. This method is quick and gives results that are available immediately [3]. The subjective nature of visual assessments raises concerns about the potential for observer bias, but there is evidence that visual assessments conducted by trained observers can yield results similar to those from the line-point-intercept (LPI) transect methods [4-7]. LPI is more time consuming in the field than visual assessments (15–30 min vs. 1–2 min) and can be difficult to conduct in high surge conditions; however, when done by experienced observers, the LPI method can generate data at finer taxonomic resolution (e.g., to genus or species). Photo-quadrat surveys involve taking photographs at a fixed distance from the substrate, generally at random or regular intervals along a transect line. As with LPI, the photo-quadrat survey method can be used to classify benthic cover to a finer taxonomic level than is generally feasible for visual assessment surveys. Photo-quadrat surveys require more time in the field than rapid visual assessments, as well as substantial additional time for *post hoc* photo-analysis, meaning there is often a lag before photo-quadrat data become available. The photo-quadrat method, however, yields some benefits: a set of archived images that can be revisited for subsequent analysis or quality checks, and not requiring a specialist to conduct the surveys (e.g., identification and counting) in the field [8].

Here, we compare results from two of these commonly used benthic survey methods, the rapid visual assessment and the photo-quadrat survey. Specifically we compare estimates derived from the two methods of cover of the following reef substrate functional groups: encrusting algae, fleshy macroalgae, hard coral, and turf algae. The survey sites are all those where we had data from the two methods at the time of conducting this analysis – and include sites in American Samoa, the main Hawaiian Islands, and the Mariana Islands. In addition, to better understand the extent of observer bias in visual estimates of benthic cover, we also examined among-observer differences in visual estimates of hard coral cover. These differences can be a source of uncertainty and variability in estimates of parameters of interest, so it is important to monitor and minimize them.

MATERIALS AND METHODS

Surveys were conducted by CRED of NOAA's Pacific Islands Fisheries Science Center (PIFSC) as part of the NOAA Pacific Reef Assessment and Monitoring Program (RAMP). In 2010, 228 sites were surveyed in American Samoa across the islands of Ofu and Olosega, Swains, Ta`u, Tutuila, and Rose Atoll. In 2010, and in 2013, a total of 410 sites were surveyed in the main Hawaiian Islands across the islands of Hawai`i, Maui, Lāna`i, Kaua`i, Ni`ihau, O`ahu, and Moloka`i. In 2011, 305 sites were surveyed in the Mariana Archipelago at the islands of Agrihan, Aguijan, Asuncion, Farallon de Pajaros, Guam, Maug, Pagan, Rota, Saipan, and Tinian. Benthic surveys were conducted by divers using the stationary-point-count (SPC) method, and survey site locations were selected randomly by means of a depth-stratified design in hard bottom habitats in waters less than 30-m deep. At each site, a pair of divers first laid a 30-m transect line along a depth contour, then surveyed fishes within adjacent visually estimated 15-m-diameter cylinders centered on the transect line- i.e., the two divers surveyed separate but adjacent cylinders on the transect line (for more details, see [9]). After completing the fish survey, divers assessed benthic cover using the following two methods:

Rapid Visual Assessment

Divers each scanned benthos within their cylinder, while remaining relatively close to the center of their survey cylinders, and visually estimated benthic cover per functional group: hard coral, macroalgae, turf algae, encrusting coralline algae (crustose coralline algae (CCA) and other encrusting algae such as *Peysonellia* sp.), sand, and soft coral. Total time for benthic visual estimates was around 1–2 min per survey. Visual estimates were averaged between the two divers, to generate a mean site-level estimate of percent cover per benthic category.

Photo-quadrat Survey

Upon completion of the fish survey and rapid visual assessment, one of the divers photographed benthos at 1-m intervals along the transect line (30 photographs per site). A 1-m PVC stick was used to position a digital camera (Canon PowerShot SD1200 IS, 10.0 megapixel) directly above the substrate to frame an ~ 0.7 m^2 area photograph. The program Coral Point Count with Extensions (CPCe, version 4.1[10]) was used to analyze benthic cover in each image by identifying substrate underneath a set of randomly assigned points.

Separate to this study, a pilot analysis was used to establish the optimum density of points identified per photograph, to meet the monitoring program objective of generating island-wide estimates of benthic cover. For the pilot analysis, 27 photo-quadrat surveys were conducted following the same methodology at the islands of Howland (n = 14) and Baker (n = 13) in 2010. Island-wide estimates of mean coral cover, fleshy macroalgae cover, turf algae cover, and encrusting algae cover (± standard error) were calculated with n = 1, 5, 10, 15, 20, and 30 point(s) per frame (30 to 900 points per transect). The coefficient of variation (standard error/mean) of each benthic category was calculated to assess the relative variability in island-level estimates at these different levels of sampling effort. While the coefficient of variation of benthic percent cover estimates initially decreased with the increased density of points identified, there was little difference in the island-scale coefficient of variation calculated from 10, 15, 20 and 30 points per photograph (1% at most for hard coral); therefore, 10 points per photograph was a deemed a sufficient image analysis effort.

Data Analysis

For each site, percent cover per functional group was estimated from the photo-quadrats as the percentage of all identified points in that functional group (i.e. points that were on shadows or unidentifiable substrate were removed from the total number of points). Site estimates for both methods were averaged for each island and depth stratum. Number of sites per island and survey strata are shown in Table 1, and summarized data are in Appendix A. Fish surveys conducted by the CRED are stratified into 3 depth categories: shallow (0-6 m), mid (6-18m) and deep (18-30m).

Table 1. -- Number of survey sites per depth strata per island per region.

Region	**Depth bin Strata**	**Number of island/depth bin strata**	**Number of Sites**
Mariana	Deep	9	107
	Mid	7	99
	Shallow	8	99
Hawaii	Deep	7	116
	Mid	7	178
	Shallow	7	127
Samoa	Deep	5	77
	Mid	5	88
	Shallow	5	63

The selected functional groups analyzed were hard coral, encrusting algae, fleshy macroalgae and turf algae. These made up the majority of the percent cover estimates. We did not include sponges, tunicates, corallimorphs, or other invertebrates, due to their relative scarcity. Combined cover from the analyzed groups ranged from 27%–100% for the photo-quadrat data (mean 92.6%), and 32%–100% (mean 91.3%) for the visual estimates.

Differences between estimates of benthic cover derived from the rapid visual assessment and the photo-quadrat survey methods were investigated by using the limits of agreement approach and visualized with Bland-Altman plots [11]. Data were averaged by island and by depth strata (i.e. the island of Oahu has 3 averages: one for deep sites, one for mid-depth sites, and one for shallow sites). For each benthic category, the difference between the benthic cover estimates (photo-quadrat survey estimate minus rapid visual assessment estimate) per island and depth bin strata was regressed against the mean of the two methods [11]. With the exception of turf algae, the estimates of benthic cover were heteroscedastic, therefore, we fitted generalized least squares regression models, with variance modeled as a function of percent cover value (i.e. as percent cover increased, variance increased). Variance was modeled as a power, exponential, or fixed function of percent cover, and best-fit models were determined by Akaike's Information Criterion (AIC) values (Table 2) [12]. A 95% confidence interval was calculated for the slope of each regression line for each functional group. The benefit of this approach rather than directly correlating one method against the other is that bias can be considered across the full range of values recorded. If the two methods yield identical results across low to high cover estimates, then the difference between the two methods would be zero across the range of cover values; if one method shows consistently higher estimates relative to the other, then the resulting difference will be a flat line offset from the *x*-axis; and lastly, if the relationship between methods differs as percent cover changes, then the trend in difference between methods will have non-zero slope [11]. The rapid visual assessments made by divers were of their entire 15-m-diameter survey cylinders (~ 177 m^2 per diver), whereas the photo-quadrat surveys sampled a subset of the survey area (i.e., a single photo-quadrat transect running through the middle of the two adjacent cylinders). We therefore expected a certain degree of difference in the cover estimates between the two methods due to the different scales at which cover was estimated by the two methods.

To investigate observer variability, we assessed the consistency of a diver's *in situ* coral cover estimates by comparing their rapid visual assessment to that of their dive buddy at the same site. A diver's estimate is compared to those of a 'population' of dive buddies, i.e. for each diver separately the difference between their estimate and that of their dive partner at each site is calculated. Dive partners are regularly rotated throughout a survey cruise; therefore this approach gives a measure of an individual's performance relative to the entire pool of other divers participating on a survey mission. Variation in observer estimates of coral cover (diver versus diver) was compared using paired t-tests (per diver versus their buddies, with Bonferroni correction) and visualized using boxplots. We limited the observer variability analysis to hard coral cover based on the fact that this is the most frequently reported benthic metric collected at the fish survey sites.

Table 2. -- Akaike's Information Criterion (AIC) values for generalized least squares models with modeled variance for each functional group. Four models were tested: normal, fixed, power, and exponent. DF = degrees of freedom, ΔAIC = difference in AIC values from the lowest AIC value in each functional group minus each model's AIC value. The model with the lowest ΔAIC value was used.

Functional Group	Variance Model	DF	AIC	ΔAIC
Hard coral	Normal	3	319.3	18.1
	Fixed	3	306.0	4.8
	Power	4	301.3	0.0
	Exponent	4	312.2	10.9
Encrusting algae	Normal	3	326.8	16.9
	Fixed	3	312.0	2.1
	Power	4	311.3	1.4
	Exponent	4	309.9	0.0
Fleshy macroalgae	Normal	3	413.9	6.6
	Fixed	3	407.3	0.0
	Power	4	409.1	1.9
	Exponent	4	411.3	4.0
Turf algae	Normal	3	413.9	0.0
	Fixed	3	450.0	36.1
	Power	4	450.8	37.0
	Exponent	4	450.1	36.2

RESULTS

Comparison between the rapid visual assessment method and photo-quadrat survey method of estimating benthic cover

On average across all sites, rapid visual assessments of hard coral cover were similar to but less than those derived from photo-quadrat surveys with a mean absolute difference of –3.0% (SD 3.3), and visual assessments underestimated cover significantly more as cover increased (*y*-intercept = –1.2, slope = –0.1, t-value $_{2,58}$ = -3.2, $p < 0.01$), Fig. 1B). For several sites in American Samoa, hard coral cover was slightly overestimated. Similarly, in American Samoa, encrusting algal cover was underestimated by the rapid visual assessment relative to the photo-quadrat survey by –2.3% (SD 5.4). As percent cover of encrusting algae increased, rapid visual assessments yielded lower values than photo-quadrat surveys (*y*-intercept = 2.0, slope = –0.3, t-value $_{2,58}$ = -7.7, $p < 0.01$, Fig. 1D). Visually estimated fleshy macroalgal cover was consistently greater than photo-quadrat survey estimates by 6.5% (SD 7.4), and differences between methods increased significantly at higher cover (*y*-intercept = 0.3, slope = 1.1, t-value $_{2,58}$ = 5.5, $p < 0.01$,

Fig. 1F). Relative to photo-quadrat surveys, turf cover was underestimated by the rapid visual assessment by –11.1% (SD 13.1), and there was a clear trend for the difference between methods to increase as percent cover of turf increased (y-intercept = 10.2, slope = –0.4, t-value $_{2,58}$ = -6.6, $p < 0.01$, Fig. 1H).

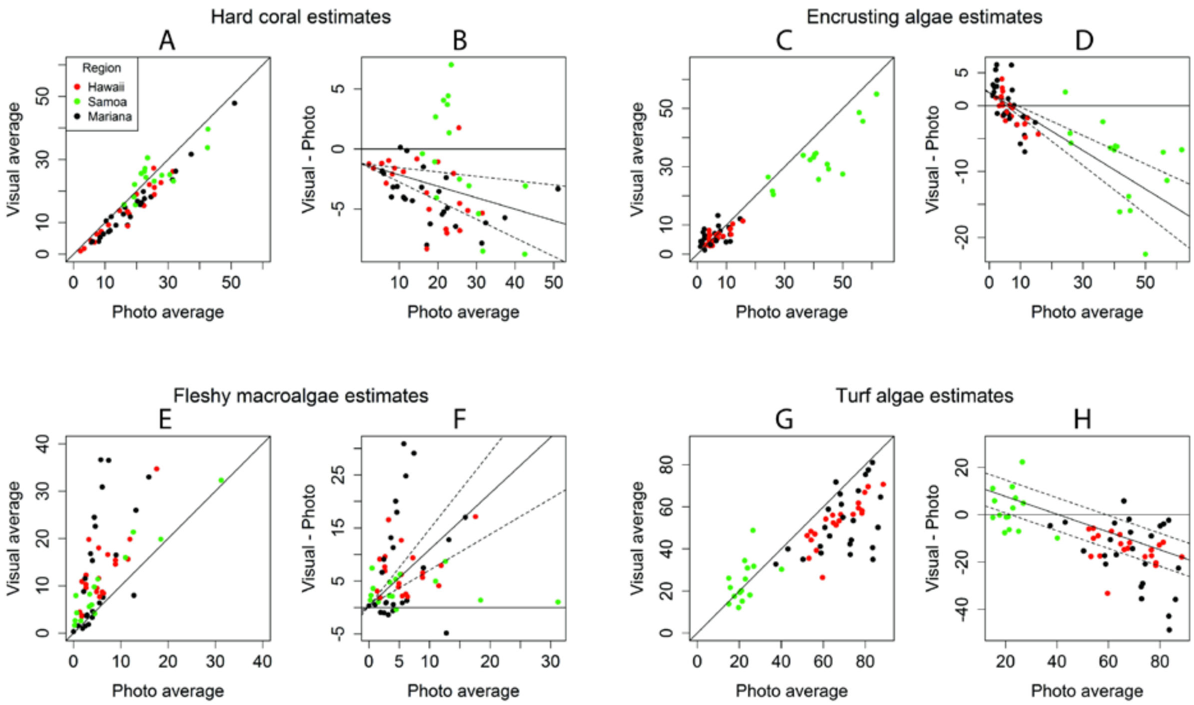

Figure 1. --Rapid visual assessment estimates compared to photo-quadrat survey estimates by benthic category at island/depth bin strata. Scatterplots of photo-quadrat and visual estimates of percent cover of benthic categories, with a 1:1 line (A, C, E, G). Bland-Altman plots of the limits of agreement between estimates of percent cover from visual and photo-quadrat methods (B, D, F, H). The *y*-axis on the Bland-Altman plots is the difference between the two methods and the *x*-axis is the mean percent cover averaged from both methods. The black line is a generalized least squares regression line. The dashed lines indicate the 95% confidence interval of the slope of the regression line.

Differences in visual estimates of hard coral cover between dive buddies

A total of 20 divers participated in the 943 surveys used in this analysis. When compared to their buddies' estimates, 12 of the 20 divers' estimates did not differ significantly from their buddies' (Table 3). Of the 8 divers who differed significantly, 5 overestimated and 3 underestimated relative to their buddies (Fig. 2).

Table 3. -- Mean differences and related statistics between diver's rapid visual assessments at the same sites. Bold entries indicate significant p-values. df= degrees of freedom, n= number of sites surveyed per diver.

Diver	**Mean difference (95% Confidence interval)**	**t-statistic**	**df**	**n**	***p*-value**
1	0.4 (-1.0 – 1.8)	0.6	42	43	0.66
2	**1.7 (0.7 – 2.6)**	**3.5**	**106**	**107**	**0.01**
3	2.6 (0.1 – 5.0)	2.1	33	34	0.84
4	**-2.4 (-3.1 – -1.7)**	**-7.2**	**304**	**305**	**<0.01**
5	**-2.5 (-3.5 – -1.5)**	**-5.0**	**106**	**107**	**<0.01**
6	**4.5 (2.7 – 6.3)**	**5.1**	**69**	**70**	**<0.01**
7	3.0 (0.5 – 5.4)	2.5	23	24	0.38
8	-0.6 (-1.2 – 0.1)	-1.7	292	293	1.00
9	-0.1 (-1.0 – 1.0)	-0.2	152	153	1.00
10	-5.6 (9.6 – -1.6)	-3.0	16	17	0.18
11	2.3 (-1.2 – 5.7)	1.7	5	6	1.00
12	**2.0 (1.0 – 3.0)**	**3.9**	**225**	**226**	**<0.01**
13	-2.1 (-3.5 – -0.7)	-3.4	10	11	0.13
14	**3.0 (2.1 – 4.0)**	**6.2**	**183**	**184**	**<0.01**
15	-1.9 (-3.4 – -0.5)	-2.7	56	57	0.21
16	**1.5 (0.6 – 2.4)**	**3.2**	**209**	210	**0.03**
17	-1.4 (-2.4 – -0.4)	-2.7	41	42	0.18
18	**-1.6 (-2.3 – -1.0)**	**-5.3**	**375**	**376**	**<0.01**
19	-0.8 (-2.6 – 1.0)	-0.9	46	47	1.00
20	3.3	2.6	46	35	0.30

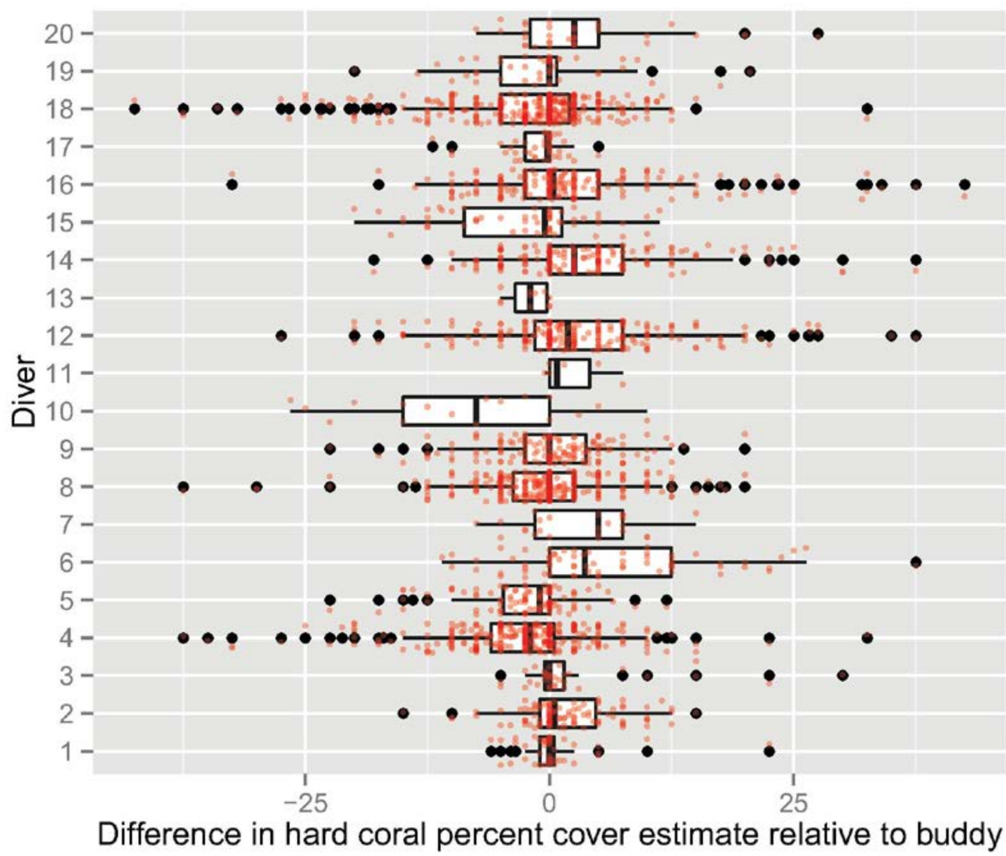

Figure 2.--Boxplots of the differences between each diver's visual estimate and their buddy's estimate. Each number on the y-axis represents a single diver, and the x-axis is the difference in percent cover estimates. The vertical bars in the center of the boxes represent the median difference value for each diver, and the outer limits of the box represent the first and third quartiles (25^{th} and 75^{th} percentiles) of difference values. The range of the box represents the central 50% of the data, and the horizontal lines extending from each end of the box represent values that are outside of the first and third quartile, but are not more than 1.5 times the interquartile range from the first or third quartile. Black dots signify outliers (i.e. those beyond the 1^{st} and 3^{rd} quartiles. Red dots are the actual data point values.

DISCUSSION

Overall, our results indicate that rapid visual estimates of coral cover are broadly comparable to those derived from much more labor-intensive photo-quadrat surveys. Although we found significant differences between the two methods, the absolute scale of differences was generally small and ranged from –8.8% (photo average = 42.5%) to 7.0% (photo average = 23.5%) at the strata level, with an overall site mean difference of 3.0% (photo average = 17.3%). Three earlier studies have shown similar results when comparing visual estimates of reef benthos with line-point-intercept transect estimates [5–7]. The fairly close agreement between rapid visual and photo-quadrat estimates of coral cover reflects the relative ease of identifying hard coral both from photographs and by an observer in the field (hard corals are conspicuous and have distinct boundaries). The absolute scale of difference between hard coral estimates derived from the two contrasting methods was generally small, and the general tendency was for hard coral cover to be underestimated by the visual method compared to the photo quadrat method (at 55 of 63 strata). An exception to this pattern was evident for survey strata at a few islands in American Samoa, where visual estimates of coral cover were higher than photo-quadrat estimates. The reason for this reverse pattern for divers to overestimate coral cover in American Samoa, while at other regions generally the opposite was the case, remains unclear. Notably these sites in American Samoa were all areas with substantial encrusting coral and CCA cover. Several sites also had large cover of encrusting zoanthids and foliose sponges that divers may have mistaken for corals. Scope for similar errors could be minimized if training materials included photographs of benthos that may potentially be mistaken for coral.

Cover of encrusting algae and turf algae cover were consistently underestimated, and fleshy macroalgae cover was generally overestimated by the rapid visual method relative to photo-quadrats. Those differences could reflect the different perspectives from which cover is estimated, i.e., that the view of the diver from the middle of their survey cylinder is different than the planar view from photo-quadrats. Upright and higher-canopy cover will tend to obscure divers' view of the benthos, thus leading to underestimation of benthos that adheres to the substrate such as encrusting algae and turf algae [13].

Rapid visual assessments of encrusting algae for Hawaii and the Mariana islands were relatively similar to the photo-quadrat estimates, possibly due to the fact that cover of encrusting algae was generally low (< 20%) there. In contrast, in American Samoa, where encrusting algae cover can be much higher, it was underestimated by the rapid visual assessments.

When there are consistent biases between two methods measuring the same thing, it offers scope for a methodological calibration, which can increase the reliability of the data types collected. In the case of the visual and photo-quadrat methods compared here, these differences are not consistent among strata and regions; therefore it is likely to remain problematic to mix data from the different approaches when generating spatial or temporal trends.

As noted above, divers estimated cover from the entirety of their survey areas (adjacent 15 m-diameter cylinders), whereas photo-quadrat estimates come from a single 30 m transect line running through the middle of the divers' SPC cylinders. Thus diver estimates are of ~177 m^2 per diver (~353 m^2 per site), whereas the photo-quadrat samples come from a narrow strip (each photo is 0.7 m^2, so 30 photos * 0.7 m^2 = 21 m^2 total per site). There are advantages to a method that encompasses a larger sample unit [14], even if it is performed via a less refined method. For our purposes, specifically in terms of understanding relationships between fish assemblages and the benthic community, an advantage of the rapid visual assessment is that it provides estimates of cover coming from precisely the same portion of reef in which fishes are surveyed. It would be possible to develop a photo-survey method to subsample the entire fish-count survey cylinders, however, such a method would substantially increase the time required to conduct those photo-quadrat surveys, which would in turn reduce the overall time available for the main priority of the reef fish surveys – the fish counts themselves.

In addition to survey method, observer variability is another potential source of error and variability in the data we collect. We found systematic differences in the visual estimates of hard coral cover collected by particular divers when compared to their buddy; however, those differences were relatively small: the average of differences between buddies on adjacent cylinders was < 6%, and the highest mean difference for any one diver from their buddies was 5.6%. However, for 16 of 19 divers, the absolute scale of mean difference with their buddies was < 3%. This indicates that the CRED fish survey divers yield consistent and comparable rapid visual assessments of hard coral cover at the fish survey sites.

A major advantage of the visual assessment method is that it is rapid – both in time spent in the field, and in terms of the immediate availability of the data. It takes a diver roughly 1–2 min to estimate benthic cover, and the data are available immediately. For a program such as Pacific RAMP, the cost to gather such data at the end of a fish count is essentially nil. In contrast it takes a diver a little longer (~ 2–5 min) to take benthic photographs, and more importantly these must subsequently be managed and analyzed. It takes an analyst ~ 30–45 min to analyze one site of 30 photos. Thus, total photo analysis time from one round of surveys at the main Hawaiian Islands (~180 sites), is roughly 90-135 hours. In addition to costs of analysis, there are significant costs associated with maintaining and organizing the photo archive. Overall, there is certainly value in gathering visual estimate data, particularly of hard coral, for use in situations where high data precision is not critical.

SUMMARY

A common problem for monitoring programs is a lag between collecting and disseminating results [2]. Here, we have shown that the visual assessment of hard coral cover can provide a timely, generally reliable estimate, broadly comparable with values derived from photo-transect surveys, with known relative bias. Photo-quadrat analysis is critical in cases where a more detailed appraisal of habitat composition at finer taxonomic level is necessary and when time and resources permit. A benefit of conducting rapid visual assessments in addition to the photo-quadrat surveys is that the visual estimates are instantly available. Visual estimates of encrusting algae, and particularly fleshy macroalgae and turf algae estimates were not in as close agreement with the photo-quadrat estimates, highlighting the importance of improved and more rigorous training of observers. It is highly desirable for observer errors to be reduced as much as possible through improved training and the regular assessment of inter-observer variability.

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APPENDIX A—SUMMARY DATA

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Marianas

REGION	ISLAND	Depth bin	Visual estimates								Photo-quadrat estimates							
			CCA mean	CCA SD	Hard coral mean	Hard coral SD	Macroalgae mean	Macroalgae SD	Turf mean	Turf SD	CCA mean	CCA SD	Hard coral mean	Hard coral SD	Macroalgae mean	Macroalgae SD	Turf mean	Turf SD
Mariana	Agrihan	Deep	7.29%	7.24%	21.07%	12.15%	1.36%	1.57%	60.29%	11.88%	12.79%	4.04%	17.40%	13.82%	1.14%	0.81%	63.55%	15.69%
Mariana	Agrihan	Shallow	3.79%	4.54%	6.29%	6.18%	8.14%	10.90%	77.68%	18.20%	5.21%	5.17%	4.18%	4.24%	6.04%	5.98%	81.91%	10.34%
Mariana	Aguijan	Deep	2.60%	1.85%	11.60%	8.05%	36.50%	5.48%	35.00%	9.20%	1.10%	0.66%	7.42%	1.59%	7.43%	5.16%	83.62%	6.55%
Mariana	Asuncion	Deep	4.42%	2.04%	25.21%	15.54%	9.29%	9.70%	36.92%	12.06%	7.09%	6.28%	18.85%	9.53%	14.77%	12.17%	42.08%	16.91%
Mariana	Asuncion	Mid	4.38%	2.03%	17.16%	11.89%	3.31%	2.19%	66.09%	9.18%	11.38%	7.35%	9.15%	8.82%	3.96%	2.30%	68.02%	9.16%
Mariana	Asuncion	Shallow	9.20%	16.12%	12.00%	10.94%	1.50%	2.24%	71.80%	23.05%	10.88%	10.12%	11.85%	11.73%	2.49%	1.65%	65.97%	20.15%
Mariana	FDP	Shallow	1.40%	1.39%	8.05%	8.98%	0.30%	0.67%	81.10%	15.77%	2.59%	1.53%	4.04%	4.31%	0.00%	0.00%	83.41%	13.63%
Mariana	Guam	Deep	5.91%	6.57%	11.93%	14.31%	32.96%	19.24%	38.06%	15.86%	8.82%	8.62%	9.13%	10.57%	15.94%	10.40%	58.91%	17.85%
Mariana	Guam	Mid	7.98%	7.04%	14.41%	7.93%	25.96%	17.12%	46.12%	14.09%	7.90%	7.13%	12.63%	8.98%	13.21%	15.47%	63.01%	15.84%
Mariana	Guam	Shallow	12.13%	8.31%	21.73%	15.98%	16.48%	14.14%	35.05%	16.39%	14.71%	10.17%	23.54%	13.37%	9.00%	9.30%	50.32%	16.80%
Mariana	Maug	Deep	7.71%	4.54%	7.71%	4.54%	1.64%	2.63%	34.79%	14.58%	4.64%	3.72%	48.14%	25.87%	2.86%	2.08%	38.78%	20.95%
Mariana	Maug	Mid	4.92%	3.50%	4.92%	3.50%	3.82%	5.41%	50.22%	19.26%	6.19%	3.59%	26.26%	15.02%	2.88%	2.40%	60.74%	17.24%
Mariana	Maug	Shallow	4.67%	6.01%	4.67%	6.01%	1.00%	1.01%	75.38%	12.81%	5.58%	4.04%	10.47%	12.78%	1.92%	2.27%	80.09%	14.42%
Mariana	Pagan	Deep	2.94%	2.29%	2.94%	2.29%	6.94%	4.90%	66.31%	16.14%	4.49%	2.59%	8.18%	5.49%	5.06%	2.93%	75.81%	10.41%
Mariana	Pagan	Mid	4.58%	3.01%	4.58%	3.01%	4.15%	4.45%	68.25%	14.04%	6.03%	3.76%	6.19%	3.60%	4.01%	2.64%	77.48%	9.95%
Mariana	Pagan	Shallow	10.55%	14.15%	10.55%	14.15%	5.05%	4.95%	55.65%	20.48%	5.22%	3.86%	16.27%	9.03%	3.28%	3.85%	68.52%	10.17%
Mariana	Rota	Deep	6.38%	8.24%	6.38%	8.24%	36.63%	28.11%	40.63%	18.15%	2.53%	2.87%	3.95%	4.49%	5.76%	4.49%	83.46%	6.94%
Mariana	Rota	Mid	3.56%	3.47%	3.56%	3.47%	22.56%	20.57%	42.31%	19.73%	1.52%	2.58%	17.59%	22.94%	4.61%	4.64%	72.72%	21.37%
Mariana	Rota	Shallow	7.50%	7.29%	7.50%	7.29%	30.88%	28.83%	37.38%	19.74%	2.05%	1.44%	16.32%	18.70%	6.09%	5.06%	72.87%	19.41%
Mariana	Saipan	Deep	4.48%	2.44%	4.48%	2.44%	15.29%	12.51%	64.65%	15.61%	1.67%	1.27%	5.24%	4.14%	4.00%	2.55%	87.22%	5.12%
Mariana	Saipan	Mid	5.28%	2.68%	5.28%	2.68%	11.53%	8.47%	53.47%	13.98%	2.37%	2.68%	11.81%	11.57%	2.45%	2.41%	74.25%	17.45%
Mariana	Saipan	Shallow	9.69%	5.95%	9.69%	5.95%	8.78%	10.12%	41.25%	18.02%	7.33%	5.49%	31.62%	17.51%	2.16%	2.57%	58.53%	16.79%
Mariana	Tinian	Deep	8.57%	10.63%	8.57%	10.63%	16.79%	15.05%	44.21%	9.38%	2.37%	2.40%	16.75%	17.29%	3.64%	2.02%	73.29%	17.44%
Mariana	Tinian	Mid	4.38%	2.83%	4.38%	2.83%	24.47%	20.34%	50.25%	15.66%	1.22%	0.75%	6.37%	4.70%	4.42%	3.48%	86.04%	6.49%

Hawaii

REGION	ISLAND	Depth bin	Visual estimates								Photo-quadrat estimates							
			CCA mean	CCA SD	Hard coral mean	Hard coral SD	Macroalgae mean	Macroalgae SD	Turf mean	Turf SD	CCA mean	CCA SD	Hard coral mean	Hard coral SD	Macroalgae mean	Macroalgae SD	Turf mean	Turf SD
Hawaii	Hawaii	Deep	8.74%	6.57%	8.74%	6.57%	4.48%	6.03%	53.34%	20.69%	11.54%	11.02%	15.74%	17.42%	1.39%	1.32%	67.08%	20.43%
Hawaii	Hawaii	Mid	11.37%	9.32%	11.37%	9.32%	3.66%	6.40%	48.36%	19.93%	15.71%	13.08%	22.62%	14.31%	1.84%	3.68%	54.09%	17.21%
Hawaii	Hawaii	Shallow	10.33%	6.81%	10.33%	6.81%	3.51%	5.33%	54.23%	22.29%	12.20%	10.96%	21.13%	17.12%	1.74%	4.07%	61.17%	19.51%
Hawaii	Kauai	Deep	6.08%	9.50%	6.08%	9.50%	19.78%	19.24%	57.01%	22.45%	8.95%	9.04%	4.30%	3.79%	3.26%	4.15%	78.38%	11.42%
Hawaii	Kauai	Mid	5.44%	7.79%	5.44%	7.79%	17.99%	12.36%	58.13%	17.97%	7.05%	7.62%	6.36%	6.32%	5.34%	8.24%	78.42%	15.82%
Hawaii	Lanai	Deep	2.81%	2.43%	2.81%	2.43%	34.69%	25.75%	26.44%	14.40%	4.34%	2.85%	8.87%	7.07%	17.59%	18.28%	59.63%	21.70%
Hawaii	Lanai	Mid	5.13%	3.43%	5.13%	3.43%	14.52%	14.49%	35.57%	19.41%	3.95%	2.99%	26.21%	22.33%	8.87%	13.20%	53.15%	25.73%
Hawaii	Lanai	Shallow	6.59%	6.11%	6.59%	6.11%	10.64%	10.03%	60.25%	16.93%	3.97%	3.65%	11.27%	13.49%	2.71%	3.21%	78.23%	14.19%
Hawaii	Maui	Deep	6.73%	7.53%	6.73%	7.53%	8.64%	13.22%	46.32%	26.26%	11.55%	10.90%	18.88%	22.83%	6.09%	7.50%	52.33%	24.54%
Hawaii	Maui	Mid	2.95%	2.66%	2.95%	2.66%	11.57%	12.38%	52.44%	20.68%	5.24%	6.61%	15.36%	17.50%	5.35%	7.97%	64.74%	19.96%
Hawaii	Maui	Shallow	7.08%	5.88%	7.08%	5.88%	9.46%	15.82%	56.08%	20.92%	7.44%	8.76%	18.97%	20.07%	4.95%	7.62%	64.44%	16.45%
Hawaii	Molokai	Deep	4.58%	4.44%	4.58%	4.44%	8.72%	10.05%	47.09%	19.88%	5.58%	5.39%	27.23%	26.40%	4.88%	6.90%	55.97%	24.61%
Hawaii	Molokai	Mid	3.13%	2.34%	3.13%	2.34%	15.41%	13.55%	44.23%	20.31%	3.17%	4.40%	22.04%	27.21%	8.88%	13.65%	54.18%	23.74%
Hawaii	Molokai	Shallow	6.85%	6.87%	6.85%	6.87%	9.56%	7.78%	56.42%	16.16%	4.17%	6.89%	13.78%	18.14%	2.67%	4.37%	68.24%	20.34%
Hawaii	Niihau	Deep	3.35%	3.37%	3.35%	3.37%	7.69%	7.54%	69.65%	18.41%	2.17%	1.76%	0.95%	0.69%	5.52%	8.75%	81.28%	17.85%
Hawaii	Niihau	Mid	4.38%	5.74%	4.38%	5.74%	12.25%	11.80%	70.68%	13.42%	4.10%	5.37%	1.75%	2.08%	2.66%	3.17%	88.50%	8.83%
Hawaii	Niihau	Shallow	6.60%	5.64%	6.60%	5.64%	8.40%	8.05%	66.90%	13.82%	6.54%	7.60%	3.81%	4.00%	6.37%	14.69%	79.71%	18.09%
Hawaii	Oahu	Deep	4.95%	4.34%	4.95%	4.34%	19.52%	13.66%	38.97%	13.31%	4.11%	3.75%	13.96%	15.09%	9.45%	11.94%	58.67%	15.96%
Hawaii	Oahu	Mid	4.43%	3.81%	4.43%	3.81%	16.59%	14.65%	56.46%	16.01%	4.38%	6.05%	9.21%	9.59%	7.23%	10.28%	74.20%	15.74%
Hawaii	Oahu	Shallow	8.10%	7.20%	8.10%	7.20%	15.63%	15.18%	51.38%	17.16%	4.06%	5.52%	7.22%	7.78%	11.54%	12.53%	66.07%	17.49%

American Samoa

REGION	ISLAND	Depth bin	Visual estimates								Photo-quadrat estimates							
			CCA mean	CCA SD	Hard coral mean	Hard coral SD	Macroalgae mean	Macroalgae SD	Turf mean	Turf SD	CCA mean	CCA SD	Hard coral mean	Hard coral SD	Macroalgae mean	Macroalgae SD	Turf mean	Turf SD
Samoa	Ofu & Olosega	Deep	33.25%	6.47%	33.25%	6.47%	10.50%	10.22%	20.10%	8.95%	42.57%	10.41%	21.42%	12.64%	5.34%	4.72%	20.31%	7.07%
Samoa	Ofu & Olosega	Mid	30.97%	8.45%	30.97%	8.45%	6.72%	9.50%	27.03%	14.87%	45.99%	17.20%	25.05%	8.01%	0.34%	0.63%	24.55%	18.36%
Samoa	Ofu & Olosega	Shallow	44.75%	15.76%	44.75%	15.76%	1.96%	3.05%	27.39%	11.71%	55.26%	22.18%	25.49%	10.26%	0.32%	0.56%	17.65%	15.91%
Samoa	Rose	Deep	32.34%	9.74%	32.34%	9.74%	19.84%	13.50%	20.16%	17.40%	38.77%	7.63%	18.12%	13.17%	18.45%	11.64%	21.01%	12.78%
Samoa	Rose	Mid	48.58%	15.59%	48.58%	15.59%	15.97%	11.07%	13.89%	7.97%	55.66%	13.47%	15.60%	12.64%	11.00%	9.39%	15.03%	5.57%
Samoa	Rose	Shallow	54.93%	13.27%	54.93%	13.27%	8.21%	3.98%	17.50%	9.62%	61.64%	6.21%	15.64%	9.66%	3.44%	1.45%	17.65%	12.25%
Samoa	Swains	Deep	21.67%	5.30%	21.67%	5.30%	32.28%	16.84%	12.11%	7.99%	25.86%	5.78%	23.16%	10.70%	31.24%	11.85%	19.67%	6.99%
Samoa	Swains	Mid	20.47%	5.04%	20.47%	5.04%	21.34%	14.36%	15.16%	18.55%	26.15%	6.47%	39.57%	12.53%	12.65%	9.50%	21.41%	12.42%
Samoa	Swains	Shallow	33.93%	10.17%	33.93%	10.17%	4.11%	5.53%	18.11%	12.91%	36.38%	11.11%	33.74%	15.59%	4.49%	6.91%	25.09%	11.49%
Samoa	Tau	Deep	29.17%	9.19%	29.17%	9.19%	11.39%	8.83%	21.61%	11.12%	45.12%	16.19%	25.16%	7.60%	5.15%	4.10%	15.71%	10.95%
Samoa	Tau	Mid	25.64%	14.17%	25.64%	14.17%	4.28%	3.76%	34.44%	19.00%	41.75%	14.73%	25.56%	10.80%	0.68%	0.76%	22.59%	18.84%
Samoa	Tau	Shallow	26.75%	14.91%	26.75%	14.91%	1.75%	1.62%	47.85%	22.82%	49.85%	7.93%	23.41%	16.35%	0.22%	0.33%	25.72%	10.70%
Samoa	Tutuila	Deep	25.76%	15.52%	25.76%	15.52%	6.30%	8.10%	30.34%	18.64%	23.23%	16.79%	23.47%	17.33%	4.05%	4.63%	41.77%	25.23%
Samoa	Tutuila	Mid	33.29%	17.69%	33.29%	17.69%	5.68%	8.33%	32.03%	19.97%	40.05%	17.58%	26.53%	15.23%	3.47%	5.93%	27.25%	19.71%
Samoa	Tutuila	Shallow	34.24%	12.77%	34.24%	12.77%	2.59%	3.11%	31.63%	18.41%	40.76%	18.31%	29.42%	17.05%	1.55%	2.45%	24.54%	19.95%