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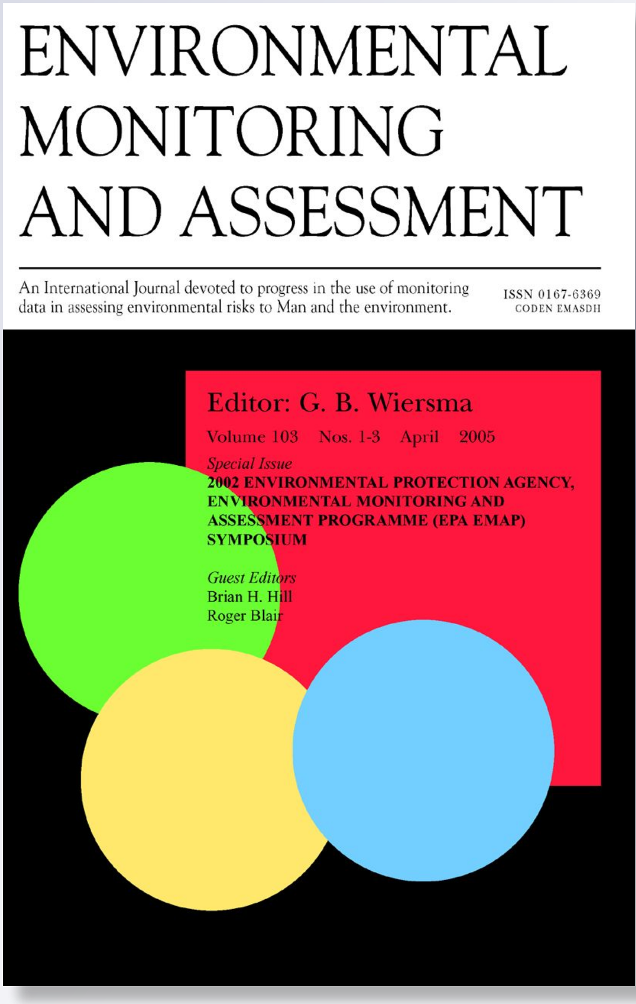

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Abstract Volunteer-based citizen monitoring has increasingly become part of the natural resources monitoring framework, but it is often unclear whether the data quality from these programs is sufficient for integration with traditional efforts conducted by professional scientists. At present, the biological and physical characteristics of California's rocky reef kelp forests are concurrently monitored by two such groups, using similar methodologies—underwater visual census (UVC) of fish, benthic invertebrates, and reef habitat, though the volunteer group limits their sampling to transects close to the reef surface and they use a more constrained list of species for enumeration and measurement. Here, we compared the data collected from 13 reefs that were sampled by both programs in 2008. These groups described relatively similar fish communities, total fish abundance and abundance of the dominant fish species but there were some differences in the measured size distributions of the dominant fish species. Descriptions of the benthic invertebrate community were also similar, though there were some differences in relative abundance that may have resulted from the less detailed subsampling protocols used by the volunteers. The biggest difference was in characterization of the physical habitat of the reefs, which appeared to result from selection bias of transect path by the volunteer program towards more complex structured sections of a reef. Changes to address these differences are relatively simple to implement and if so, offer the promise of better integration of the trained volunteer monitoring with that of professional monitoring groups.

Keywords Rocky reef · Citizen-based monitoring · Reef Check California · Underwater visual census

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Introduction

Citizen-based groups are increasingly contributing to ecosystem monitoring (Foster-Smith and Evans 2003; Pattengill-Semmens and Semmens 2003; Schmeller et

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al. 2009; Leopold et al. 2009; USEPA 2010; http://yosemite.epa.gov/water/volmon.nsf/Home?openform). These data may be collected at a reduced cost, as citizens volunteer the work and often supply their own equipment (e.g., Levrel et al. 2010) and can fill spatial and temporal gaps in traditional monitoring programs conducted by academic or governmental professional scientists (Sharpe and Conrad 2006; Delaney et al. 2008; Schmeller et al. 2009). Other benefits of volunteer monitoring programs include increased interactions between the public and the scientific community, education about ecosystems and resource management, fostering of local stewardship, and increased scientific literacy of the general public (Conrad and Hilchey 2011).

The biggest impediment to incorporation of these volunteer monitoring programs with professionally collected data is concern about data quality. A number of studies have demonstrated that trained volunteers can produce data of comparable quality to professionals for a variety of parameters and habitats, including beach microbiology (Noble et al. 2003), subtropical reef fauna (Halusky et al. 1994), birds (Lepczyk 2005), or freshwater macroinvertebrates (Fore et al. 2001). However, there are also many volunteer programs for which data quality has not been assessed. In absence of comparative examinations, anecdotal concerns about data quality or methodological modifications to simplify data collection have led volunteer efforts to be underutilized in management decision-making (Conrad and Hilchey 2011).

One type of sampling for which volunteer and professional have not yet been compared, is for subtidal rocky reef/kelp forest ecosystems. In southern California, professional scientists at a number of universities, government agencies, non-governmental organizations, and private companies routinely monitor the biological and physical components of rocky reefs, sometimes for permit compliance interests or for regional assessments, such as the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO; http://www.piscoweb.org/research/science-by-discipline/ecosystem-monitoring/kelp-forest-monitoring/subtidal-sampling-protoco) and the California Department of Fish and Game's Cooperative Research and Assessment of Nearshore Ecosystems (CRANE; e.g., Tenera Environmental 2006; Pondella 2009). In 2008, these groups of scientists came together to conduct a probabilistic survey of rocky reef ecosystems in the Southern California Bight using a unified methodology and sampling protocol (Southern California Bight Regional Monitoring Program); referred to hereafter as the Bight program (Bight'08 Rocky Reef Committee 2008). In this same region, the non-profit Reef Check Foundation created a state-wide volunteer monitoring program beginning in 2005; referred to as Reef Check California (RCCA). The RCCA program was designed to draw upon the large number of recreational SCUBA divers in California, many of whom have interest in protecting natural resources. RCCA provides the volunteers with extensive training and certification in survey techniques and species identification (Dawson and Shuman 2009).

RCCA based their general sampling protocols on the professional monitoring programs, which involve SCUBA-based underwater visual census (UVC) of fish, benthic invertebrates, algae, and physical habitat structure in rocky reef ecosystems (Bight'08 Rocky Reef Committee 2008; Dawson and Shuman 2009). Reef Check California protocols, however, include several modifications to the spatial sampling schemes and the extent of taxa recorded to simplify the process and increase the precision of the data collected by volunteers. Thus far, there has been no comparison of the data obtained by these two groups, but the 2008 regional sampling events provided an opportunity to do so. As on outgrowth of this opportunity, the goal of the present study was to determine the comparability of the data collected by trained volunteer (RCCA) and professional scientists (Bight Program) and provide some insight into potential integration of these data in the future. Specifically, we compare measures of habitat characterization, species composition and abundance of fish and benthic invertebrates between data collected at the same reefs.

Methods

Bight sampling protocol

The Bight sampling program was developed to provide a comprehensive assessment of the fish, benthic invertebrate fauna, benthic algae, and physical habitat characteristics of a rocky reef (summarized in Table 1). This protocol was based on protocols previously developed by PISCO and used by the CRANE program (Bight'08 Rocky Reef Committee

2008). A particular reef, or sub-sections of large contiguous reefs, is divided into four-depth strata: inner (~5 m deep), middle (~10 m deep), outer (~15 m deep), and deep (~25 m deep). Within each stratum, SCUBA divers conduct transect-based, visual surveys of the biota and physical habitat. Within each stratum there are two 30-m benthic transects, along which physical habitat characteristics (vertical relief, substrate, and benthic cover), benthic invertebrate fauna, and benthic algae are measured. Physical habitat characteristics are measured using the uniform point contact (UPC) method. Vertical relief, substrate type, and benthic cover at 1-m points along the length of the transect, while benthic invertebrates and algae are counted in a 2-m swath along the length of the transect. Fish abundance and length are recorded along four 30×2×2-m bottom transects, four 30×2×2-m midwater transects, and four 30×2×2-m transects counting fish just below the kelp canopy (when present). This yields a maximum of eight physical habitat, eight benthic invertebrate, and 48 fish transects at each sample site (Table 1).

Transects are laid out in the following process: an initial benthic transect is based upon a random compass heading from a starting point (typically the dive boat anchor/mooring point) and then all subsequent transects are made in relation to the initial benthic transect. All transects within a given stratum are conducted as straight lines along isobaths parallel to shore, where depth is kept constant (±2.5 m) using the divers' depth gauge. If, in the process of swimming a transect, a feature is encountered that would take the diver beyond the 2.5 m of the transect depth, the transect will be altered from the original track. When the benthic invertebrates are surveyed, data are recorded in 10-m intervals along the transect. If the abundance of an individual species is greater than 30 within an interval, the distance at which 30 individuals is reached is recorded. No other individuals of that species are counted within that interval, and the abundance was scaled for the entire 10-m interval. The size of all fish <15-cm total length (TL) are visually estimated to the nearest 1-cm interval, while those fish >15-cm TL are estimated to the nearest 5-cm interval. Bight divers record all species of fish that occur, but only identify a set list of algae (21 taxa) and benthic invertebrates (87 taxa), comprised of common taxa that can be identified underwater without magnification (Online Resource 1).

RCCA sampling protocol

The RCCA sampling program was designed to mimic the PISCO/CRANE protocols as closely as possible, with some minor spatial modification intended to make the program accessible to trained volunteers

Table 1 Comparison of procedural and taxonomic schemes between the RCCA and Bight sampling programs

	RCCA		Bight	
Unit of measure	Numbers	Sample type	Numbers	Sample type
Procedural scheme				
Sampling strata	2		4	
Canopy fish transects stratum^{-1}	0	Fish	4	Fish
Midwater fish transects stratum^{-1}	0	Fish	4	Fish
Benthic fish transects stratum^{-1}	9	Fish	4	Fish
Benthic transects stratum^{-1}	3	Algae, invertebrates, and uniform point contact	2	Algae, invertebrates, and uniform point contact[a]
Taxonomic options				
Benthic Taxa—# possible (unique to the program)	28 (2)		87 (64)	
Algal Taxa—# possible (unique to the program)	8 (2)		27 (10)	
Fish Taxa—# possible (unique to the program)	33 (2)[b]		138 (107)[c]	

[a] Bight uses a more detailed report of benthic flora/fauna in the cover measurements

[b] Fish sized into "small", "medium", and "large" classes

[c] Fish sized into 1-cm classes if <15 cm TL and 5-cm classes >15 cm TL

(Dawson and Shuman 2009; Table 1). An area of reef approximately 250 m in shore length and 250 m wide (perpendicular to shore) with a maximum depth of approximately 18 m is divided into inshore and offshore strata. Within each stratum, three 30×2-m transects are swam parallel to shore by SCUBA divers measuring the physical characteristics (UPC method similar to the Bight'08 program), benthic invertebrates and algae. Fish abundance and length are measured along nine 30×2×2-m bottom transects; three over the same transects for benthic invertebrates/physical habitat and then an additional set of three on either side. This yields a maximum of 6 physical habitat, 6 benthic invertebrate, and 18 fish transects at each sample site. The starting point of the transects are selected haphazardly within depth strata as the divers are swimming out from shore or away from the boat. All transects are swam in a predetermined direction parallel to shore over a constant depth contour of the reef (±2.5 m) using the divers' depth gauges. Like the Bight'08 program, transects are swam in straight lines, except where topography necessitated a change in course to maintain a constant depth. When measuring the benthic invertebrates, if the abundance of an individual species is >50 on a transect, the distance along the transect where the 50th individual occurs is recorded and no more are counted. The measured abundance can then be extrapolated to the 30-m length of the transect. RCCA divers are only trained to record the presence of a constrained list of fish (33 potential species), benthic invertebrates (28), and macroalgae (8) in an effort to simplify the amount of required taxonomic skill and to focus on taxa that are most commonly observed, protected, actively fished, or of ecological importance (Dawson and Shuman 2009; Online Resource 2). The size of most fish are visually estimated into small (<15 cm), medium (15–30 cm), and large (>30 cm) size classes, with the exception of larger species (e.g., *Ophiodon elongatus* or *Sebastes paucispinis*), which have bigger medium (15–50 cm) and large (>50 cm) size classes.

Data selection

Though both programs sample a greater number of sites, we focused our comparative analyses on 13 sites (sections of reef where transects were conducted) that were sampled by both the Bight and RCCA programs in 2008 (Fig. 1). Some sites were sampled multiple times throughout the year, so sampling events were selected to minimize the number of days between sampling visits by the two programs (Table 2). Furthermore, comparisons were limited to data collected in common between the two programs, so only data from bottom transects were considered. The mean depth of the bottom fish transects was used to match a stratum from the Bight program (typically inner and middle) to the inshore and offshore depth strata in the RCCA sampling scheme. The shallower

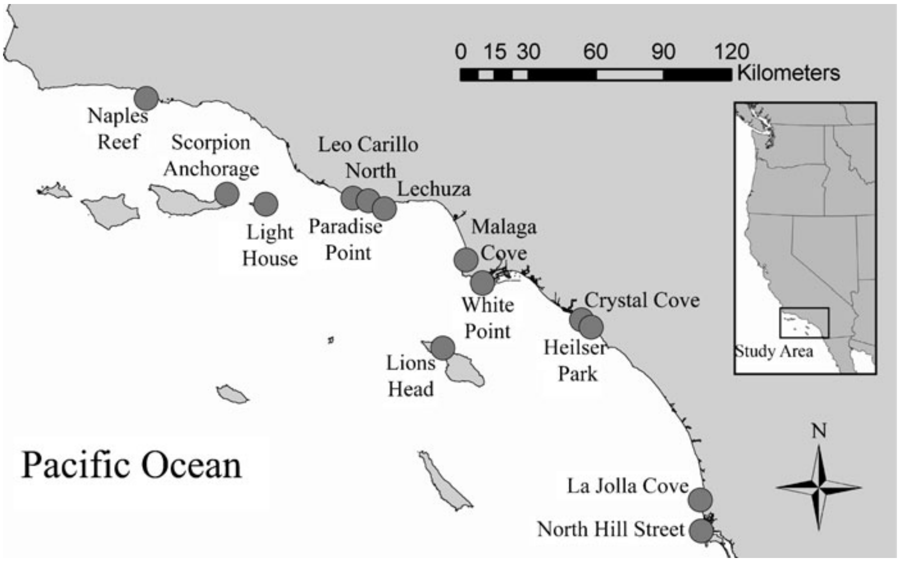


Fig. 1 The 13 sample sites located throughout the Southern California Bight. The *inset* shows the region in relation to the western coast of North America. Site abbreviations are in Table 2

Table 2 Comparisions of transect depth and site sampling date at the paired sites and strata between the RCCA and Bight sampling programs

Sampling site	Abbreviation	RCCA		Bight		Δ date	Δ depth
		Sample date	Stratum	Sample date	Stratum	RCCA-Bight	RCCA-Bight
Crystal Cove	CC	12/2/2008	Inner	11/7/2008	Inner	25	−1.2
			Outer		Outer		−6.6[a]
Malaga Cove	MC	4/27/2008	Inner	7/7/2008	Inner	−71[a]	−1.8
			Outer		Mid		−3.6[a]
Light House	IH	11/5/2008	Inner	10/23/2008	Inner	24	0.1
			Outer	10/1/2008	Outer		−2.8
Leo Carillo North	LC	9/6/2008	Inner	10/30/2008	Inner	−54	1.7
			Outer		Mid		−1.5
Lechuza	LZ	9/6/2008	Inner	10/21/2008	Mid	−45	−1.5
			Outer		Outer		−2.3
Paradise Point	PP	9/6/2008	Inner	10/30/2008	Inner	−54	1.8
			Outer		Mid		−0.9
Heisler Park	HP	12/11/2008	Inner	11/15/2008	Inner	26	2.8
			Outer		Mid		−0.7
Lions Head	LH	11/24/2008	Inner	9/4/2008	Inner	81[a]	4.3[a]
			Outer		Mid		1.0
La Jolla Cove	LJ	7/26/2008	Inner	11/2/2008	Inner	−99[a]	2.8
			Outer		Mid		0.3
Naples Reef	NR	10/18/2008	Inner	10/20/2008	Inner	−2	−1.9
			Outer		Outer		−0.2
North Hill Street	NHS	9/13/2008	Inner	10/31/2008	Inner	−48	−0.4
			Outer		Mid		0.1
Scorpion Anchorage	SA	10/29/2008	Inner	8/12/2008	Inner	78[a]	0.9
			Outer		Inner-Mid		−1.6
White Point	WP	9/27/2008	Inner	9/25/2008	Inner	2	2.6
			Outer		Mid		−0.3

Δ date and Δ depth are the RCCA value—that of the Bight value. As such, negative values indicate a deeper transect or later sampling date at the respective Bight site-stratum

[a] Value exceed a difference between sampling programs of 3-m depth or 60 days

strata will be referred to as the inner strata and the deeper strata as the outer depth strata (Table 2). Comparisons were also limited only to the list of fish and benthic fauna measured by RCCA (Online Resource 2). Any data from un-matched Bight strata (typically outer and deep strata) and from midwater or canopy transects were excluded from our analyses, as they did not have comparable data within the RCCA dataset. Though encrusting/sessile invertebrate cover and algae composition/abundance data are measured by both programs, these data were excluded from the present analyses.

Data analysis

The physical structure of the reefs was compared as measures of vertical relief, which were reported categorically as flat (0–10 cm), low (10 cm–1 m), moderate (1–2 m), and high (>2 m), and as substrate types of sand, cobble, boulder, or bedrock. These data were compared using a Mantel–Haenszel Chi-Square analysis of mean frequency along replicate transects within a stratum, using SAS v9.2 (Stokes et al. 2002). Community structure of the fish and benthic invertebrates were compared with a one-way analysis of similarity (ANOSIM) with dataset as the treatment variable, using Bray–Curtis similarity values calculated from square-root-transformed abundance data. These data were also graphically analyzed using a non-metric multidimensional scaling (nMDS) ordination plots. All multivariate analyses were done using Primer-e v5 (Clarke and Warwick 2001). For these, and all subsequent comparisons, strata (inner vs. outer) were analyzed separately to reduce the influence of depth on any observed similarities or differences.

Species richness (*S*), Shannon–Weiner Diversity (*H*′) of fish and benthic invertebrates, as well as total fish abundance per transect within each stratum were compared between the two sampling programs using a two-way analysis of variance (ANOVA) in SAS v9.2, with site and dataset as the treatment variables (Littell et al. 2002). Data were transformed when necessary to maintain normality and homoscedasticity of the model residuals. Post-hoc comparisons of Tukey–Kramer adjusted least square means (α=0.05) were done to compare differences between the two sampling programs and site-specific interaction terms. Because of the taxonomic constraints of the RCCA program, all measures of species richness, diversity, and abundance do not reflect the complete fish or invertebrate communities of the reef ecosystems, but only the dominant taxa.

Taxon-specific abundance of the seven most frequently observed/abundant (both programs combined) fish (*Chromis punctipinnis*, *Embiotoca jacksoni*, *Girella nigricans*, *Hypsurus caryi*, *Oxyjulis californica*, *Paralabrax clathratus*, and *Semicossyphus pulcher*) and benthic invertebrates (*Strongylocentrotus purpuratus*, *Strongylocentrotus franciscanus*, large anemones [e.g., *Urticina* spp., *Anthopleura* spp.], *Patiria miniata*, *Muricea* spp., *Pisaster giganteus*, and *Lithopoma* spp.) was compared within each stratum between the two sampling programs using a two-way general estimating equation with site and dataset as the treatment variables in SAS v9.2. The GEE models were fit with a negative binomial distribution to minimize over-dispersion of the data due to the count nature of the data, the large number of zeros in the dataset, and because the variance in each treatment was greater than the mean (Stokes et al. 2002). Post-hoc comparisons of the treatment levels were made with Tukey–Kramer adjusted least square means (α=0.05). Species-specific size distributions of the top seven most abundant and frequently observed fish across all 13 sites were compared using a Mantel–Haenszel Chi-Square analysis between the two programs in the inner and outer depth strata (Stokes et al. 2002). For comparison, the size-class data collected by the Bight program (reported in 1- or 5-cm intervals) were combined into the small (<15 cm), medium (15–30 cm), and large (>30 cm) intervals used by the RCCA program.

Results

Physical habitat

Substrate type was significantly different between the two sampling programs in both the inner and outer strata (Fig. 2), with RCCA reporting a greater incidence of bedrock than the Bight program. Conversely, the Bight program reported greater amounts of sand and boulder habitat, with both programs reporting relatively little amounts of cobble-dominated habitat (Fig. 2a, b). Similarly, there was little agreement in measures of vertical relief between the two sampling programs. In the inner strata, RCCA reported a greater incidence of low and moderate relief habitat, while the Bight program reported a greater incidence of flat habitat. In the outer strata, RCCA reported a greater percentage of low relief habitat, while the Bight program reported more flat habitat along the transects (Fig. 2c, d).

Benthic invertebrates

Both programs reported relatively similar benthic invertebrate communities, though the RCCA data was dominated by the urchins *S. purpuratus* and *S. franciscanus*, whereas abundance in the Bight data was more evenly distributed among species (Tables 3 and 4). The orange sponge *Tethya aurantia* and the stalked tunicate *Styela montereyensis* were the only relatively abundant taxa (~5% of total abundance) observed in the Bight program that were not on the RCCA targeted species list (Tables 3 and 4; Online Resource 2). The benthic invertebrate communities described by the two sampling programs were not significantly different in either the inner and outer strata as indicated by the ANOSIM analysis, which takes into account the abundance and species composition of the entire community on a sample-by-sample

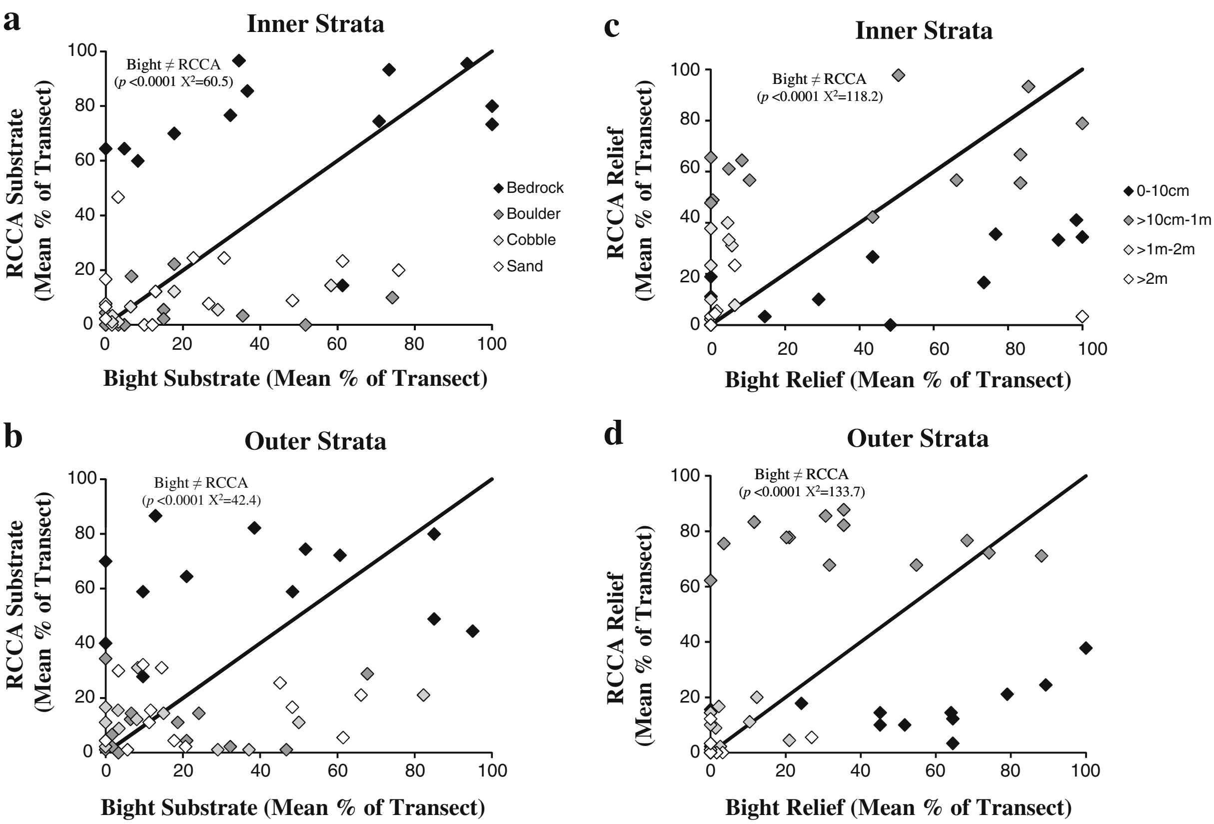


Fig. 2 Paired site-by-site comparisons of substrate (**a** and **b**) and vertical relief (**c** and **d**) measured along transects by the Bight and RCCA sampling programs. The heavy line represents a theoretical 1:1 agreement between the datasets. Results from Mantel–Haenszel Chi-Squire analysis testing differences in mean relief or substrate between the Bight and RCCA sample programs are also presented in each panel

basis (Fig. 3). The very low *R* values (<0.100) in the ANOSIM analyses and the ordination from the nMDS, which had stress values >0.1, are indicative of overlap in species composition between the communities, despite some differences in abundance noted below (Fig. 3).

There were some significant, though inconsistent between strata, differences in the univariate measures of benthic invertebrate community structure between the two sampling programs. Benthic invertebrate species richness was significantly greater for the RCCA in the inner strata, but the outer strata were similar between the programs (Fig. 4a). There were significant differences in the site–dataset interaction from the inner and outer strata because of the greater site-to-site variation in the species richness measured by the Bight program (Fig. 4a). Shannon–Wiener diversity was significantly greater in those communities from the Bight program along the inner transects, but there was no difference in the communities observed by the two programs in the outer strata (Fig. 4b). The significant site–dataset interactions among the inner and outer strata was, like the species richness, a reflection of the greater variability in species diversity among sites observed by the Bight program compared to that observed by the RCCA program (Fig. 4b) and results from the dominance of urchins in the RCCA data, which reduced diversity but does not affect species richness.

There were several differences in the abundance of the dominant benthic invertebrates when taxa were compared individually in both the inner (Table 3) and outer (Table 4) strata. The RCCA program reported significantly more *S. purpuratus* in both the inner ($p<0.0001$) and outer ($p=0.0185$) strata and *S. franciscanus* in the inner strata ($p<0.0001$). The Bight program

Table 3 A comparison of the top seven most frequently observed/abundant benthic invertebrates in the inner strata across both the Bight and RCCA programs and mean abundance (# transect^{-1}) of those taxa that comprised greater than 0.1% relative abundance across the 13 sampling sites

Bight				RCCA				
Species	Mean abundance	Relative abundance (%)	Frequency of occurrence (%)	Species	Mean abundance	Relative abundance (%)	Frequency of occurrence (%)	Difference in abundance
Strongylocentrotus purpuratus	58.35	21.81	75.0	*Strongylocentrotus purpuratus*	305.43	64.01	83.3	RCCA>Bight
Strongylocentrotus franciscanus	53.04	19.83	75.0	*Strongylocentrotus franciscanus*	102.43	21.47	83.3	RCCA>Bight
Anthopleura sola[a]	23.23	8.69	41.7	*Patiria miniata*	15.48	3.24	47.2	RCCA=Bight
Patiria miniata	22.65	8.47	54.2	*Muricea* spp.	10.98	2.30	33.3	RCCA=Bight
Pisaster giganteus	18.73	7.00	83.3	*Lithopoma* spp.	10.52	2.20	44.4	RCCA=Bight
Styela montereyensis[b]	16.88	6.31	33.3	*Megathura crenulata*	7.60	1.59	52.8	
Megathura crenulata	13.58	5.08	45.8	*Pisaster giganteus*	5.97	1.25	58.3	RCCA<Bight
Parastichopus parvimensis	12.15	4.54	25.0	Anemone	4.92	1.03	27.8	RCCA<Bight
Urticina lofotensis[a]	10.92	4.08	8.3	*Parastichopus parvimensis*	4.33	0.91	41.7	
Cypraea spadicea	7.12	2.66	12.5	*Kelletia kelletii*	2.59	0.54	58.3	
Lithopoma undosum[c]	6.88	2.57	58.3	*Centrostephanus coronatus*	2.23	0.47	16.7	
Kelletia kelletii	6.00	2.24	25.0	*Cypraea spadicea*	1.72	0.36	16.7	
Pisaster ochraceous[b]	3.58	1.34	33.3	*Pisaster brevispinus*	1.41	0.30	25.0	
Muricea californica[e]	3.27	1.22	37.5	*Lophogorgia chilensis*	0.51	0.11	8.3	
Tethya aurantia[b]	2.85	1.06	33.3	*Crassedoma giganteum*	0.51	0.11	25.0	
Muricea fruticosa[e]	1.69	0.63	33.3	*Panulirus interruptus*	0.41	0.09	22.2	
Metridium spp.[b]	0.85	0.32	4.2	*Parastichopus californicus*	0.13	0.03	2.8	
Crassedoma giganteum	0.81	0.30	20.8					
Aplysia californica[a]	0.73	0.27	8.3					
Pisaster brevispinus	0.65	0.24	16.7					
Centrostephanus coronatus	0.46	0.17	8.3					
Pachycerianthus fimbratus[a]	0.46	0.17	16.7					
Anthopleura elegantissima[a]	0.38	0.14	8.3					

Table 3 (continued)

Bight				RCCA				
Species	Mean abundance	Relative abundance (%)	Frequency of occurrence (%)	Species	Mean abundance	Relative abundance (%)	Frequency of occurrence (%)	Difference in abundance
Lytechinus anamesus[b]	0.35	0.13	16.7					
Pycnopodia helianthoides[d]	0.35	0.13	8.3					
Urticina spp.[a]	0.31	0.12	12.5					
Lophogorgia chilensis	0.27	0.10	12.5					
Norrisia norrisi[b]	0.27	0.10	8.3					
Panulirus interruptus[b]	0.27	0.10	16.7					

Test results are associated with the species names in the RCCA column. *Dermasterias imbricata*, *Haliotis corrugata*, *Orthasterias koehleri*, *Parastichopus californicus*, *Pugettia richii*, and sheep/decorator crab were also observed, but comprised less than 0.1% relative abundance

[a] Bight taxa grouped together as Anemone for comparison to RCCA data

[b] Taxa observed by Bight program, but not on the RCCA targeted species list

[c] Bight taxa grouped together as *Lithopoma* spp. for comparison to RCCA data

[d] Bight taxa grouped together as Sunflower/Sun Star for comparison to RCCA data

[e] Bight taxa grouped together as *Muricea* spp. for comparison to RCCA data

Table 4 A comparison of the top seven most frequently observed/abundant benthic invertebrates in the outer strata across both the Bight and RCCA programs and mean abundance (# transect^{-1}) of those taxa that comprised greater than 0.1% relative abundance across the 13 sampling sites

Bight				RCCA				
Species	Mean abundance	Relative abundance (%)	Frequency of occurrence (%)	Species	Mean abundance	Relative abundance (%)	Frequency of occurrence (%)	Difference in abundance
Strongylocentrotus franciscanus	48.46	23.25	75.0	*Strongylocentrotus purpuratus*	159.89	54.21	83.3	RCCA>Bight
Strongylocentrotus purpuratus	46.00	22.07	66.7	*Strongylocentrotus franciscanus*	66.66	22.60	88.9	RCCA=Bight
Patiria miniata	28.23	13.54	54.2	*Patiria miniata*	15.69	5.32	61.1	RCCA<Bight
Pisaster giganteus	10.69	5.13	87.5	*Muricea* spp.	12.89	4.37	47.2	RCCA<Bight
Tethya aurantia[a]	9.77	4.69	33.3	*Lithopoma* spp.	11.67	3.95	66.7	RCCA=Bight
Muricea californica[b]	9.65	4.63	66.7	*Pisaster giganteus*	7.46	2.53	77.8	RCCA=Bight
Centrostephanus coronatus	7.65	3.67	12.5	*Kelletia kelletii*	4.36	1.48	63.9	
Pachycerianthus fimbratus[a]	6.31	3.03	16.7	*Parastichopus parvimensis*	2.67	0.90	52.8	
Urticina lofotensis[c]	6.23	2.99	8.3	*Centrostephanus coronatus*	2.49	0.84	19.4	
Styela montereyensis[a]	5.69	2.73	37.5	*Megathura crenulata*	2.46	0.83	50.0	
Parastichopus parvimensis	4.58	2.20	20.8	Anemone	2.13	0.72	30.6	RCCA<Bight
Kelletia kelletii	4.23	2.03	29.2	*Lophogorgia chilensis*	1.95	0.66	19.4	
Megathura crenulata	4.12	1.97	33.3	*Pisaster brevispinus*	1.79	0.61	36.1	
Lithopoma undosum[d]	3.62	1.73	41.7	*Cypraea spadicea*	1.41	0.48	22.2	
Cypraea spadicea	2.77	1.33	16.7	*Panulirus interruptus*	0.79	0.27	13.9	
Anthopleura sola[c]	2.19	1.05	20.8	*Crassedoma giganteum*	0.64	0.22	30.6	
Muricea fruticosa[b]	1.58	0.76	33.3					
Lophogorgia chilensis	1.54	0.74	33.3					
Parastichopus californicus	1.42	0.68	16.7					
Aplysia californica[c]	0.96	0.46	12.5					
Lytechinus anamesus[a]	0.65	0.31	12.5					
Urticina spp.[c]	0.38	0.18	8.3					
Pisaster ochraceous[a]	0.23	0.11	12.5					
Pycnopodia helianthoides[e]	0.23	0.11	8.3					

Test results are associated with the species names in the RCCA column. *Anthopleura elegantissima*, *Asterina armatus*, *Astrometis sertulifera*, *Cancer* spp., *Crassedoma giganteum*, *Cucumaria* spp., *Dermasterias imbricata*, *Haliotis corrugata*, *Linckia columbianuse*, *Metridium* spp., *Orthasterias koehleri*, *Panulirus interruptus*, *Pisaster brevispinus*, *Pugettia producta*, sheep/decorator crab, and sunflower/sun star were also observed, but comprised less than 0.1% relative abundance

[a] Taxa observed by Bight program, but not on the RCCA targeted species list

[b] Bight taxa grouped together as *Muricea* spp. for comparison to RCCA data

[c] Bight taxa grouped together as Anemone for comparison to RCCA data

[d] Bight taxa grouped together as *Lithopoma* spp. for comparison to RCCA data

[e] Bight taxa grouped together as Sunflower/Sun Star for comparison to RCCA data

Fig. 3 nMDS plots of benthic invertebrate communities observed by Bight and RCCA sampling programs in (**a**) inner and (**b**) outer strata. Results of ANOSIM analyses, where sampling program (Bight vs. RCCA) was the treatment variable, are also presented. All calculations were based on Bray–Curtis similarity values calculated from square-root-transformed species abundances

reported significantly greater abundances of anemones from the inner ($p<0.0001$) and outer ($p=0.0008$) strata, *P. miniata* in the outer strata ($p<0.0186$), *Muricea* spp. from the outer strata ($p=0.0119$), and *P. giganteus* from the inner strata ($p=0.0006$). There were no differences in the abundances of *Lithopoma* reported by the two programs nor *P. miniata* and *Muricea* spp. from the inner strata, or *P. giganteus* from the outer strata. At four of the five sites where there were large differences in depth or sample date (Table 1), there were some differences in the abundance of at least one of the dominant benthic invertebrates between the programs, but there were no consistent patterns in those site-specific differences.

Fish

There were even fewer differences for the fish than there were for the benthic invertebrates collected by the two sampling programs and the goby *Lythrypnus dalli* was the only numerically dominant fish species observed by the Bight program that was not on the RCCA species list (Tables 5 and 6). The ANOSIM indicated that there were statistically significant differences in the community composition of the fish observed by the Bight and RCCA sampling programs in both the inner and outer strata, but with low R values (<0.100). This is consistent with the nMDS ordination plots (Fig. 5a and b), which showed no clear visual separation of the communities sampled by either program and had large stress values (>0.20).

There was significantly greater species richness of the fish observed along transects from the inner strata by RCCA than by Bight, but there was no statistical difference observed between the two programs in the outer transects (Fig. 4c and d). Additionally, the site–dataset interaction term was significant for the inner and outer strata, indicating greater site-to-site variability in species richness observed by the Bight program compared to the RCCA (Fig. 4c). RCCA also observed fish communities with significantly greater Shannon–Weiner diversity along transects from both the inner ($p=0.0058$) and outer ($p=0.0372$) strata. The site–dataset interaction was also significant in the inner ($p=0.0085$) and outer ($p=0.0052$) strata, again due to the greater site-to-site variability within the Bight dataset (Fig. 4d).

There were no significant differences in the total abundance ($\log_{10}+1$ transformed) of fish observed by the Bight and RCCA sampling programs along transects from either the inner ($p=0.1213$) or outer ($p=0.3267$) strata, though there were significant differences among the site–dataset interaction term for total fish abundance for both the inner ($p<0.0001$) and outer ($p=0.0014$) depth strata. This was due primarily to greater site-to-site variance in total abundance observed by the Bight program. Of the seven most abundant species of fish observed across

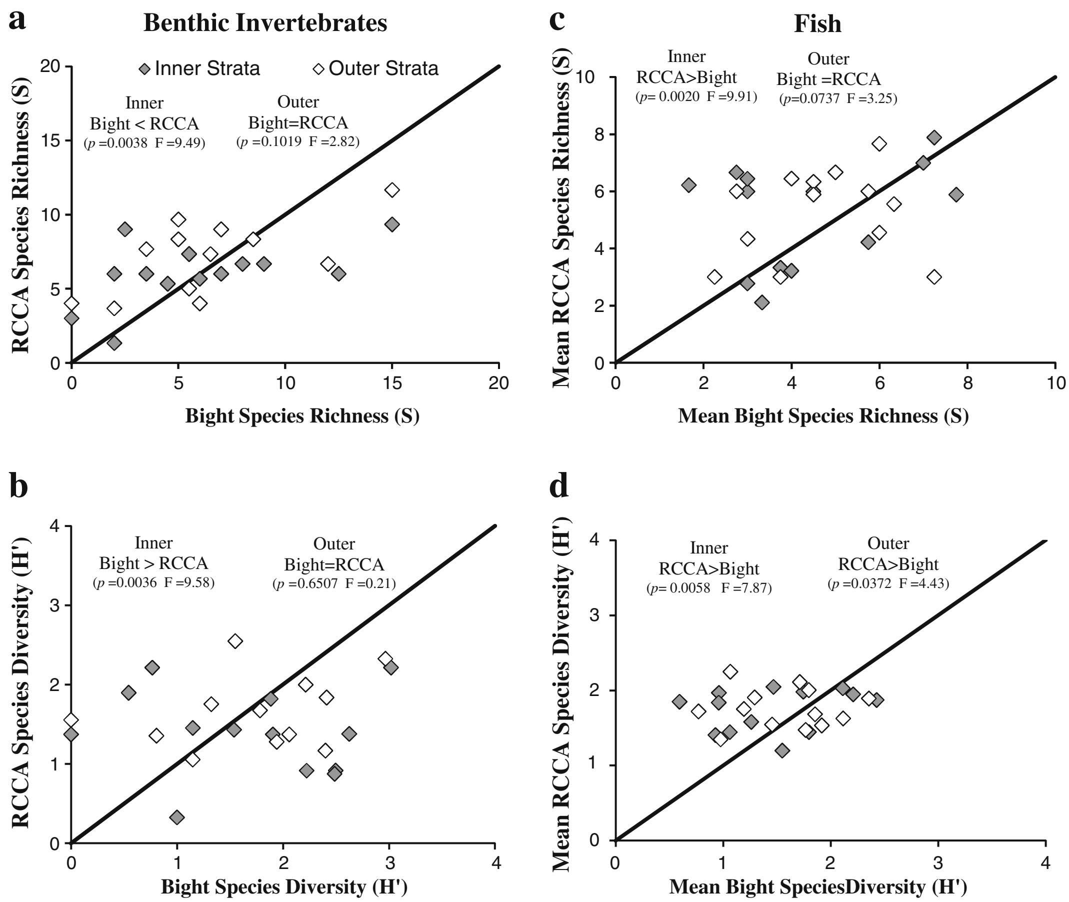


Fig. 4 Comparison scatter plots of mean species richness (S) (**a** and **c**) and mean species diversity (H') (**b** and **d**) for benthic invertebrate and fish communities observed by the CRANE and RCCA sampling programs. Dataset results from a two-way ANOVA, with site and dataset as treatment factors, are presented for each stratum. The *solid line* represents a 1:1 agreement between the datasets. Species richness and diversity values are based upon only those species on the RCCA species lists, not the entire community of rocky reefs

all 13 sites, only *G. nigricans* and *H. caryi* differed significantly between the two programs (Tables 5 and 6). The RCCA program observed more *G. nigricans* along transects from both inner and outer depth strata than did the Bight program. The Bight program observed more *H. caryi* along transects from the inner strata.

The size distribution of fish observed by the two programs across all seven species differed significantly (p=0.0007) in the inner strata, but not in outer strata (p=0.5564). When the individual species were analyzed separately, there were no consistent differences between the two programs (Fig. 6). There were significant differences in the size distributions of *C. punctipinnis* and *O. californica* from the inner strata, where the Bight program reported smaller fish than the RCCA, but this difference was not apparent in the outer strata. There were also differences in the distribution of *P. clathratus* and *S. pulcher* from both strata, where the Bight program reported larger fish than the RCCA program. There were no statistical differences in the size frequencies for the other species.

Discussion

We found differing degrees of agreement between the two sampling programs for the three sampling elements, with the greatest agreement for the fish,

Table 5 A comparison of the top seven most frequently observed/abundant fish from the inner strata across both the Bight and RCCA programs and mean abundance (#transect^{-1}) of those taxa that comprised greater than 0.1% relative abundance across the 13 sampling sites

Bight				RCCA				
Species	Mean abundance	Relative abundance (%)	Frequency of occurrence (%)	Species	Mean abundance	Relative abundance (%)	Frequency of occurrence (%)	Difference in abundance
Oxyjulis californica	20.19	32.70	63.5	*Chromis punctipinnis*	14.09	39.50	50.4	RCCA=Bight
Sardinops sagax[a]	19.23	31.14	1.9	*Oxyjulis californica*	8.22	23.04	83.8	RCCA=Bight
Chromis punctipinnis	7.98	12.92	28.8	*Hypsypops rubicundus*	2.32	6.51	50.4	
Paralabrax clathratus	2.38	3.86	65.4	*Paralabrax clathratus*	2.09	5.84	64.1	RCCA=Bight
Embiotoca jacksoni	2.23	3.61	53.8	*Embiotoca jacksoni*	2.07	5.80	53.0	RCCA=Bight
Paralabrax nebulifer	1.77	2.87	19.2	*Halichoeres semicinctus*	1.79	5.01	48.7	
Hypsurus caryi	1.71	2.77	25.0	*Semicossyphus pulcher*	1.65	4.62	48.7	RCCA=Bight
Semicossyphus pulcher	1.21	1.96	30.8	*Girella nigricans*	1.57	4.41	26.5	RCCA>Bight
Brachyistius frenatus[a]	1.10	1.78	17.3	*Paralabrax nebulifer*	0.62	1.75	14.5	
Hypsypops rubicundus	1.00	1.62	38.5	*Hypsurus caryi*	0.40	1.13	22.2	RCCA<Bight
Oxylebius pictus[a]	0.63	1.03	19.2	*Rhacochilus vacca*	0.19	0.53	14.5	
Atherinopsis californiensis[a]	0.48	0.78	1.9	*Sebastes atrovirens*	0.18	0.50	9.4	
Halichoeres semicinctus	0.46	0.75	21.2	*Rhacochilus toxotes*	0.12	0.34	8.5	
Girella nigricans	0.23	0.37	11.5	*Embiotoca lateralis*	0.10	0.29	6.8	
Rhacochilus vacca	0.23	0.37	13.5	*Anisotremus davidsonii*	0.09	0.24	3.4	
Phanerodon furcatus[a]	0.21	0.34	11.5	*Sebastes carnatus*	0.04	0.12	4.3	
Sebastes atrovirens	0.13	0.22	11.5	*Sebastes auriculatus*	0.03	0.10	2.6	
Cymatogaster aggregata[a]	0.08	0.12	3.8					

Test results are associated with the species names in the RCCA column. *Anisotremus davidsonii*, *Balistes polylepis*, *Heterodontus francisci*, *Heterostichus rostratus*, *Lythrypnus dalli*, *Medialuna californiensis*, *Ophiodon elongatus*, *Paralichthys californicus*, *Scorpaenichthys marmoratus*, *Sebastes carnatus*, *S. chrysomelas*, *S. flavidus*, *S. mystinus*, *S. serranoides*, *S. serriceps*, and *Scorpaenichthys marmoratus* were also observed, but comprised less than 0.1% relative abundance

[a] Species observed by Bight program, but not on the RCCA targeted species list

Table 6 A comparison of the top seven most frequently observed/abundant fish from the outer strata across both the Bight and RCCA programs and mean abundance (#transect^{-1}) of those taxa that comprised greater than 0.1% relative abundance across the 13 sampling sites

Bight				RCCA				
Species	Mean abundance	Relative abundance (%)	Frequency of occurrence (%)	Species	Mean abundance	Relative abundance (%)	Frequency of occurrence (%)	Difference in abundance
Chromis punctipinnis	11.29	28.54	44.2	*Oxyjulis californica*	12.09	30.68	77.8	RCCA=Bight
Oxyjulis californica	6.98	17.65	63.5	*Chromis punctipinnis*	11.53	29.27	53.0	RCCA=Bight
Paralabrax clathratus	4.65	11.76	71.2	*Paralabrax clathratus*	3.16	8.03	80.3	RCCA=Bight
Lythrypnus dalli[a]	3.65	9.24	7.7	*Hypsypops rubicundus*	2.74	6.94	48.7	
Semicossyphus pulcher	2.33	5.88	53.8	*Halichoeres semicinctus*	2.32	5.88	46.2	
Paralabrax nebulifer	1.77	4.47	30.8	*Girella nigricans*	2.01	5.10	26.5	RCCA>Bight
Hypsurus caryi	1.73	4.38	21.2	*Semicossyphus pulcher*	1.74	4.43	53.8	RCCA=Bight
Hypsypops rubicundus	1.54	3.89	40.4	*Embiotoca jacksoni*	1.63	4.14	47.0	RCCA=Bight
Brachyistius frenatus[a]	1.31	3.31	9.6	*Hypsurus caryi*	0.80	2.04	20.5	RCCA=Bight
Embiotoca jacksoni	1.04	2.63	44.2	*Paralabrax nebulifer*	0.40	1.02	22.2	
Rhacochilus vacca	0.67	1.70	17.3	*Embiotoca lateralis*	0.36	0.91	10.3	
Halichoeres semicinctus	0.56	1.41	28.8	*Rhacochilus vacca*	0.21	0.52	14.5	
Oxylebius pictus[a]	0.48	1.22	13.5	*Rhacochilus toxotes*	0.15	0.39	7.7	
Medialuna californiensis[a]	0.46	1.17	7.7	*Sebastes atrovirens*	0.10	0.26	6.8	
Girella nigricans	0.33	0.83	13.5	*Anisotremus davidsonii*	0.07	0.17	2.6	
Phanerodon furcatus[a]	0.21	0.53	5.8					
Sebastes atrovirens	0.10	0.24	9.6					
Rhinogobiops nicholsii[a]	0.08	0.19	5.8					
Caulolatilus princeps[a]	0.06	0.15	3.8					
Sebastes caurinus	0.06	0.15	5.8					
Rhacochilus toxotes	0.04	0.10	3.8					
Sebastes auriculatus	0.04	0.10	3.8					
Sebastes carnatus	0.04	0.10	3.8					
Sebastes serranoides[b]	0.04	0.10	3.8					

Test results are associated with the species names in the RCCA column. *Atherinopsis californiensis*, *Cephaloscyllium ventriosum*, *Cymatogaster aggregata*, *Heterodontus francisci*, *Leiocottus hirundo*, *Myliobatis californica*, *Scorpaenichthys marmoratus*, *Sebastes carnatus*, *S . caurinus*, and *S . chrysomelas* were also observed, but comprised less than 0.1% relative abundance

[a] Species observed by Bight program, but not on the RCCA targeted species list

[b] Bight species grouped together with *Sebastes flavidus* for comparison to RCCA data

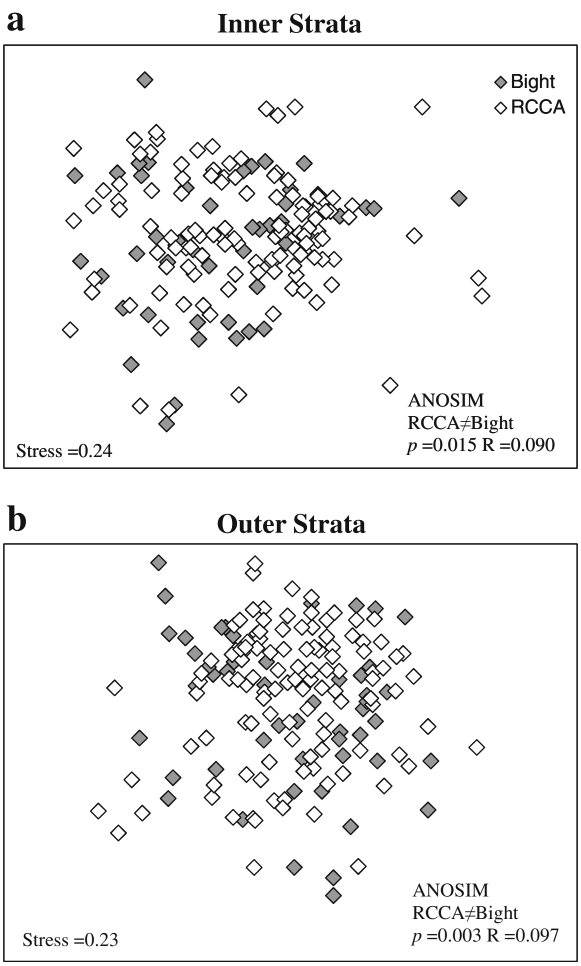


Fig. 5 nMDS plots of fish communities observed by Bight and RCCA sampling programs in (**a**) inner and (**b**) outer strata. Results of ANOSIM analyses, where sampling program (Bight vs. RCCA) was the treatment variable, are also presented. All calculations were based on Bray–Curtis similarity values calculated from square-root-transformed species abundances

lesser agreement for the benthos and poor agreement for the physical habitat descriptors. These differences are likely related to three types of error or bias in the data and in our analyses. The difference in the physical habitat variables likely result from procedural differences in how the two programs select their transect starting point and direction, which can bias the micro-habitats (e.g., boulder fields or sandy patches) that are sampled. RCCA haphazardly selects starting locations on rocky substrate and then the direction of a transect to follow along the depth contour, while the Bight transects start at the boat anchor and follow pre-determined compass headings. The RCCA transect selection allows for active selection of more "interesting" habitats (i.e., greater relief or structural complexity) by volunteer divers, which would account for the greater amounts of bedrock and boulder substrates with greater relief in the RCCA dataset. This bias in the underlying substrate of the reefs would be most directly reflected in the composition of the benthic invertebrate community, given their relatively sessile nature and that many of the species are actually anchored to the substrate. Though most species of fish that were observed tend to be found in greater numbers in more complex habitats (e.g., Stephens et al. 2006), they are much more mobile and therefore have less fidelity to a reef location at the scale of a 30-m transect than the invertebrates would (e.g., Ordines et al. 2005; Topping et al. 2006). Consequently, the differences in physical habitat observed between the two programs would be more likely to produce the observed differences in benthic invertebrates between the programs than differences in the fish community, which were not observed.

Another procedural difference between the Bight and RCCA sampling designs that could explain some of the observed differences is how they estimated the abundance of high density invertebrates and the size-spectra of fish. The extrapolation procedure and the spatial scale used by the RCCA (50 individuals→30 m) and Bight (30 individuals→10 m) likely influenced the estimates of the most abundant benthic invertebrates. With organisms that have patchy distributions, like urchins, counting a limited number and extrapolating to a larger area or length (i.e., variable area subsampling) can produce erroneous estimates of total abundance when a high density patch is encountered (e.g., Schroeter et al. 2009). Though both the Bight and RCCA programs use this approach, the smaller distances and multiple measures per transect used by the Bight program lessen the error associated with extrapolating across patchy distributions compared to the RCCA protocol and create a divergence in the abundance estimates of the two programs. Similarly, the way the two programs estimate the size of fish (fine- and coarse-grained) may account for some of the differences that were observed for the larger, more mobile taxa. It also bears noting, that the greater number and finer-grain size classes of the Bight contain more information that can be essential for estimating fish population structure/

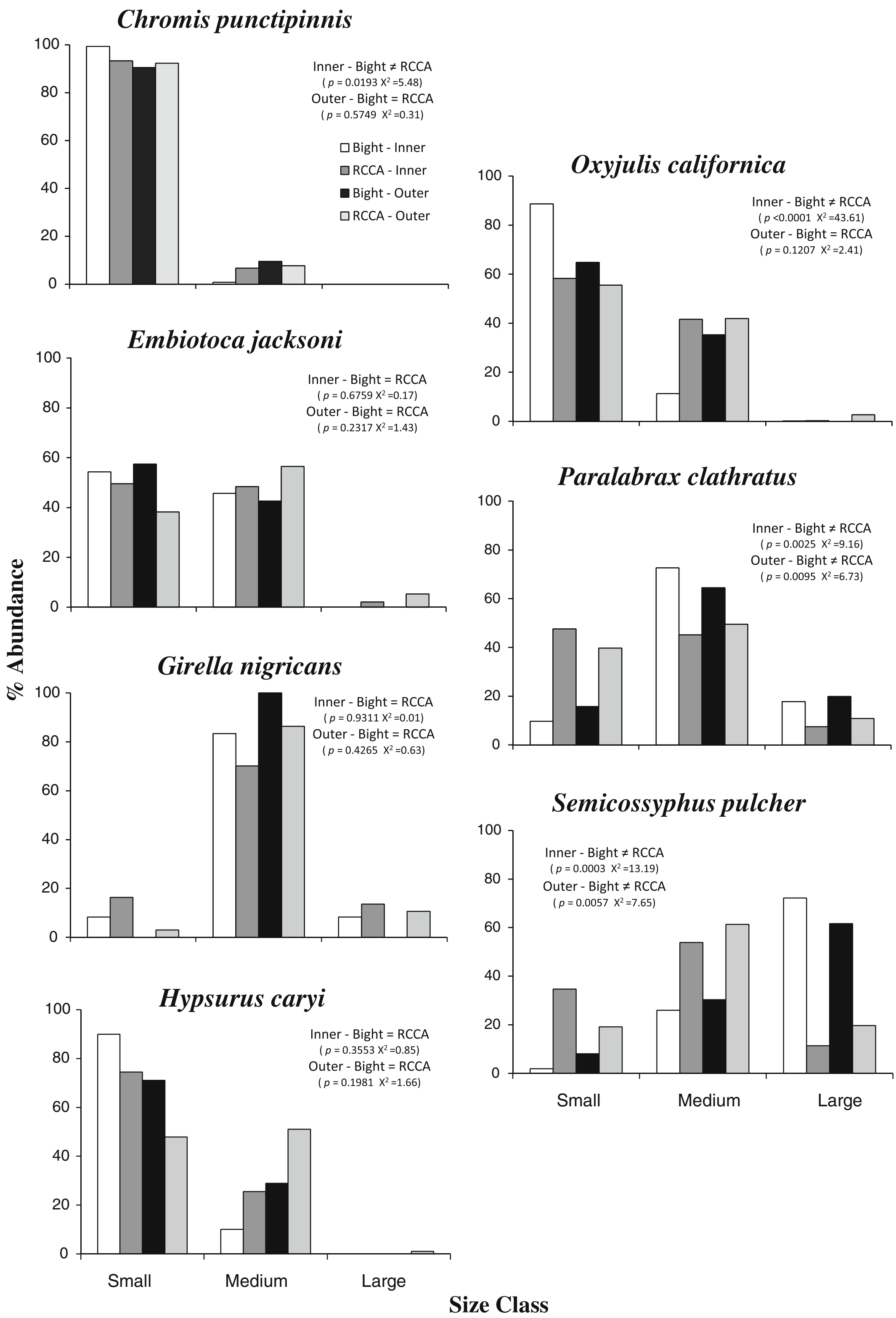
productivity and biomass (e.g., Pauly and Morgan 1987) and assessing the habitat quality of rocky reefs (i.e., Bond et al. 1999; Oakes and Pondella 2009).

A second underlying cause for observed differences between RCCA and the Bight program could be related to observer error in the datasets. Previous studies (Halusky et al. 1994; Mumby et al. 1995) have demonstrated that trained volunteers, particularly those with less experience, are less accurate than trained professionals in taxonomic identifications and the sorting of data into size classes. RCCA volunteers are not novice SCUBA divers and they undergo a thorough training, testing, and certification process (Dawson and Shuman 2009), but there is still typically a mix of experience levels among divers conducting the surveys. In contrast, the Bight program consistently used the same set of divers who have multiple years of scientific diving experience and conduct surveys more frequently than typical volunteer divers (Caselle pers. comm.; Pondella pers. comm.). This could explain some of the fish size differences we observed since some RCCA divers would be less experienced in correcting for underwater parallax, particularly under varying surge and visibility conditions. The variable experience levels may also account for some of the variability among species identifications and estimates. Two particular examples would be: *G. nigricans*, which typically schools in the midwater, was observed in greater numbers by the RCCA divers suggesting an expansion of the sampling window; or *H. caryi*, a taxon that is easily confused with other surfperches and/or missed. Variability in diver experience and lack of repetition could also have led to some of the greater diversity observed in the RCCA dataset, since less experienced divers may actively seek out the rare and more interesting species. Moreover, the errors associated with individual divers can be additive, as RCCA typically uses multiple divers for sampling different replicate transects on a given reef, whereas all replicates are typically surveyed by two pairs of divers across multiple reefs in the Bight sampling.

A third source of the difference between the two programs could be related to our study design. This comparative study was conducted in a post-hoc manner, assembling data that were not synoptically collected, but were from the same reef. This led to both small-scale spatial and temporal differences in site pairings, but we were able to address them. The two programs sampled most of the sites within an average of 31 days from each other, but four sites were sampled more than 60 days apart (Table 2). Patterns in both fish and benthic invertebrates (species richness, diversity, and abundance) were compared between the programs at these four sites, but there was no apparent influence of the time between sampling in the differences between the RCCA and Bight programs at these four sites compared to the others. There also exists the possibility that the two programs were sampling different parts of a given reef, particularly as the RCCA divers typically accessed the reef by swimming out from shore, while the Bight sampling was done from anchored boats. We were unable to test the geospatial aspect specifically due to a lack of precise latitude–longitude data in the RCCA dataset, but we were able to compare the influence of depth on the fish and benthic invertebrate data. Most of the transects were an average of 1.3 m in depth from each other within a given depth stratum, but the difference between three sets of transects were greater than 3 m. However, site-specific differences in the fish and benthic invertebrate communities were not consistently different at those sites compared to those that were closer together in depth. As such, we believe the differences in time and depth that arose from our study design had minimal influence on our comparisons, but the geospatial location on the reef had unknown impact. This type of error, much like the transect bias, would most severely affect the physical habitat characterization and then the subsequent influence this would have on characterizing the benthic invertebrate and fish communities.

When the results of our study are considered as a whole, there was reasonable agreement between the data collected by the two programs and the observed differences were likely a product of biases and error inherent to the sampling programs (methodological differences) and our analyses (post-hoc, non-synoptic nature of the study). In the development of this study, the RCCA program has expressed a desire to modify its protocols where possible to increase the accuracy

Fig. 6 Relative abundance of the seven most abundant/frequently observed species of fish reported by the Bight and RCCA programs from the inner and outer strata. Differences in size distribution were compared using a Mantel–Haenszel Chi-Square analysis, the results of which are presented in each panel ▶


Chromis punctipinnis
Inner - Bight ≠ RCCA
(p = 0.0193 X² =5.48)
Outer - Bight = RCCA
(p = 0.5749 X² =0.31)
Bight - Inner
RCCA - Inner
Bight - Outer
RCCA - Outer
Oxyjulis californica
Inner - Bight ≠ RCCA
(p <0.0001 X² =43.61)
Outer - Bight = RCCA
(p = 0.1207 X² =2.41)
Embiotoca jacksoni
Inner - Bight = RCCA
(p = 0.6759 X² =0.17)
Outer - Bight = RCCA
(p = 0.2317 X² =1.43)
Paralabrax clathratus
Inner - Bight ≠ RCCA
(p = 0.0025 X² =9.16)
Outer - Bight ≠ RCCA
(p = 0.0095 X² =6.73)
Girella nigricans
Inner - Bight = RCCA
(p = 0.9311 X² =0.01)
Outer - Bight = RCCA
(p = 0.4265 X² =0.63)
Semicossyphus pulcher
Inner - Bight ≠ RCCA
(p = 0.0003 X² =13.19)
Outer - Bight ≠ RCCA
(p = 0.0057 X² =7.65)
Hypsurus caryi
Inner - Bight = RCCA
(p = 0.3553 X² =0.85)
Outer - Bight = RCCA
(p = 0.1981 X² =1.66)
% Abundance
Small
Medium
Large
Size Class

and precision of its data. The results suggest that some changes to the RCCA procedures are advisable if data collected by volunteer and professional scientists are to be integrated; particularly the use of a pre-determined, random transect selection procedure by RCCA and a more precise reporting of transect location. However, any decision about the extent to which data from these programs can be merged ultimately depends on the intended use of the data. If the management of an ecosystem as a whole (either structurally or functionally) is of primary interest, than monitoring programs like the Bight, PISCO, or CRANE programs that collect a wide variety of detailed biological and physical data would be most appropriate. The sampling reductions to accommodate volunteers (e.g., elimination of the midwater habitat and outer transects and a more limited targeted species list) will preclude extensive use of RCCA data. Conversely, if management and monitoring of select components of the rocky reef ecosystem (e.g., community dominants or stress tolerant/indicative taxa) is of primary interest, than the RCCA data collection may be an effective manner for achieving such assessments. Our analyses and those of others (e.g., Fore et al. 2001; Pattengill-Semmens and Semmens 2003; Leopold et al. 2009) suggest that trained volunteers can be taught the appropriate skills to produce similar data to professional scientists, as long as there is sufficient guidance and supervision, a rigorous sampling scheme, and that the taxonomic scope of the work is constrained. The minor procedure modifications to the RCCA program identified in this paper have already been implemented and will enable the managers of Southern California's rocky reef ecosystems to use the data collected by the trained volunteers of the RCCA program in concert with those data collected by professional scientists.

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