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Source: Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 2009(2009) : 230-243

Published By: American Fisheries Society

URL: https://doi.org/10.1577/C08-037.1

*Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 1:230–243, 2009

DOI: 10.1577/C08-037.1



# Moving from Data Poor to Data Rich: A Case Study of Community-Based Data Collection for the San Diego Red Sea Urchin Fishery

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*Abstract*.—Responding to the need for management of California's nearshore fisheries mandated in state law by the Marine Life Management and Marine Life Protection acts, the San Diego Watermen's Association (SDWA), which includes divers that target local red sea urchins *Strongylocentrotus franciscanus*, initiated a community-based data collection program in 2001. In collaboration with independent scientists and biologists from the California Department of Fish and Game, the SDWA developed an ongoing program to gather, organize, and analyze both fishery-dependent and fishery-independent data on the local red sea urchin fishery. The goal of the program is to collect data that will support periodical stock assessments needed for sustainable management of existing nearshore fisheries (including red sea urchins) as well as the kelp forest ecosystem on which these fisheries depend. Here, we discuss sampling designs, methods for determining data quality (bias and precision), and methods for detecting change, and we provide some examples of results from the ongoing community-based data collection program. We also report on (1) the design and implementation of scientifically valid sampling protocols; (2) data quality assurance and control collaboratively conducted with scientists and resource agency biologists; (3) calibration studies to determine accuracy and precision and the magnitude of detectable changes in red sea urchin populations; and (4) visualization and dissemination of data and results and incremental changes in protocols that would facilitate the monitoring of associated biological communities. Finally, we discuss keys for success in this cooperative-based data collection program and its implications for stock assessment and management of the red sea urchin fishery in California.

The dominant tradition in fisheries management in the United States and other developed countries has evolved from the theory of fisheries management developed in Europe and largely codified in a book by Beverton and Holt (1957). This history is well described by Smith (1994). The key elements have been the identification of the "unit stock" and the regulation of fishing mortality to achieve maximum sustainable yield on that stock. Most fisheries agencies have tried to develop long-term indices of abundance based on survey data, and these surveys form the core of most fisheries management programs in the federal waters of the United States.

It has long been recognized that these approaches are inappropriate for sedentary species, especially invertebrates (Orensanz and Jamieson 1998), where populations are often highly spatially structured and the unit stock may be very small (Caddy 1975; Orensanz et al. 2005). Their population dynamics are dependent on environmental conditions, which change even within small distances, and on ecological interdependencies,

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Received November 7, 2008; accepted May 21, 2009
Published online December 31, 2009

both intra- and interspecific, which regulate demographic variations at small spatial scales (e.g., meters; Caddy 1975; Orensanz 1986; Orensanz and Jamieson 1998). Growth, survival, fecundity, and settlement are usually shaped by food quality and availability and are strongly related to the complexity of the substrate (e.g., as a cover for predators; Caddy 2007). Therefore, life history traits of sedentary invertebrates show fine-scale variations associated with specific locations and environmental gradients (Caddy 1975; Orensanz et al. 1998; Prince 2005). In addition, management regulations for sedentary resources have mainly involved use of statewide size limits rather than total allowable catches.

There is now considerable interest in small-scale management of many marine resources (Castilla and Defeo 2005; Gunderson et al. 2008), which might involve area-specific size limits, effort, or total allowable catch controls and possibly stocking or reseeding for invertebrates. This emphasis on spatial structure requires the need to identify appropriate spatial scales for data gathering, analysis, and management of exploited sedentary or low-mobility invertebrate stocks. As stated by Caddy (1989), the need for spatially complex biological information is inversely related to a species' mobility during different life stages. Monitoring and management of dozens or even hundreds of individual stocks are well beyond the capacity of federal or state agencies (Prince 2005), leading to data-poor fisheries situations. Various forms of co-management with local stakeholders have been suggested as the mechanism to achieve small-scale management (Castilla and Defeo 2001; Orensanz et al. 2005), similar to what has been done in the artisanal fisheries of Chile (Castilla et al. 1998), Japan (Yamamoto 1995), and Oceania (Johannes 2002), among others.

Fishery-independent estimates of density, abundance, and size structure of exploited populations are a valuable tool for stock assessment and sustainable management. For nearshore sedentary invertebrates, including red sea urchins *Strongylocentrotus franciscanus*, these estimates are typically obtained by diver counts along transects or in quadrats. Owing to high levels of spatial and temporal variability in red sea urchin populations, collection of data useful for fishery and ecosystem management may require more resources than are typically available for agencies tasked with such management (Kalvass and Taniguchi 1991; Kalvass 1997; Parnell et al. 2006). In recent years, a possible solution to this problem has been to enlist fishery members in a cooperative data collection program (Starr and Vignaux 1977). In this respect, Prince (2003, 2005) has proposed extensive use of commercial fishermen as data collectors in order to gather enough information at appropriate scales to support fine-scale management. The San Diego Watermen's Association (SDWA) has developed a sampling protocol that allows working divers to collect random samples of sea urchin density and size distributions during the course of normal harvesting operations. These samples are intended to capture the relevant spatial variability that typically occurs within kelp forests. The idea behind this protocol is to collect accurate "random" samples throughout the Point Loma kelp bed in areas subject to the full range of harvesting intensity and variations in red sea urchin density and size structure. Since each sample requires relatively little effort, it is possible to accumulate many samples throughout the kelp bed during any given year. If these samples produce accurate estimates of density (number per unit area) and abundance (population or stock size), then it is possible to make both accurate and precise estimates of changes in these parameters from year to year. Combining density estimates with size data will enable estimates of changes in whatever size-class is of interest, including young-of-the-year and harvest-sized individuals.

Estimates of both accuracy and precision are critical in evaluating sampling data used for stock assessments. Whereas precision (i.e., the degree of closeness of repeated estimates) of a given sampling protocol can be determined from repeated sample points, estimates of accuracy (the degree of closeness to the true value being estimated) require sampling in locations where abundance is known without error. Estimating precision is relatively straightforward given sampling data. Accuracy is much more difficult to estimate since it requires knowledge of the true value of the quantity being estimated and can be problematic, particularly when dealing with populations of nearshore benthic invertebrates like sea urchins, which have highly clumped spatial distributions.

Our objective for this article was to describe the approach used by San Diego red sea urchin divers to collect fishery-dependent and fishery-independent data at fine temporal and spatial scales. Four additional protocols were implemented in order to compare accuracy, precision, and effort required to measure density and abundance with those of the standard protocol at six sites within the Point Loma kelp bed. These sites encompass the full range of red sea urchin densities and spatial patchiness observed throughout the entire kelp bed. The analyzed protocols include the one regularly used by the SDWA, three modifications of this protocol, and the one used by the California Department of Fish and Game (CDFG; CDFG 2004). Finally, conclusions about how the data collection program will be used for stock assessment and management of the red sea urchin in California are discussed.

## Methods

*Calibration*.—We estimated the accuracy of the four sampling protocols by comparing their estimates to either (1) a large number of samples taken uniformly or (2) complete censuses at sites consisting of square plots ranging from 2,500 to 40,000 m$^2$ (0.6–9.9 acres) in area. We also estimated the precision of the various protocols and expressed it in two ways: (1) the number of spatial samples required to detect a 20% reduction in red sea urchin abundance with a significance level of 0.20 and power of 80% and (2) the margin of error, expressed in density (e.g., U.S. Census Bureau 2006; Wombold 2008), for specified sample sizes with a significance level of 0.20 and power of 80%. The locations of the calibration plots and a schematic diagram of sampling layouts for the different sampling protocols are given in Figures 1 and 2. Table 1 summarizes plot characteristics and the percentage of total plot area sampled by the different protocols, which are described below.

*Estimating the true density*.—To determine the accuracy of density estimates, it is necessary to know the true density value. We obtained this by choosing square plots of known areas on the sea floor (ranging from 2,500 to 40,000 m$^2$ [from 0.6 to 9.9 acres]) and counting all red sea urchins that could be seen without turning over substrates in large, uniform subsamples (comprising 15–100% of the total plot area; see below). Although we did not explicitly estimate the proportion of truly cryptic individuals, we assumed that this number was likely small since the bottom topography in the study plots consisted primarily of bedrock reef with various amounts of single-layered patches of boulders and cobbles. We then sampled these plots by using various protocols described below and compared these sample estimates to the "true" (censused) value to estimate accuracy.

Several methods were used to delineate and census the sites. In all of them, the corners of the plots were marked by weights or weighed lobster traps. Marked lines or meter tapes were then stretched between two parallel edges of a plot (usually the offshore and inshore edges). Additional marked lines or meter tapes were extended perpendicular to these two baselines at regular intervals, resulting in a grid of contiguous subplots (Figure 2). Counts were then made at regular intervals on both sides of these perpendicular lines using 1.5- or 2.0-m fiberglass rods as a scale (Figure 2; Table 2). Initially (at sites A and B, Figure 1), the perpendicular band transects did not encompass the entire plot area. Subsequently, lines perpendicular to the base lines were arranged so as to form parallel, 5-m-wide bands that covered the entire plot area (Figure 2). Initially, the lines delineating plots and subplots were put in place by divers on the bottom. Subsequently, lines were laid out by first attaching them to weighted lobster traps, which were deployed from the surface and then adjusted on the bottom by divers. This latter procedure greatly reduced the time required to delineate plot boundaries.

*Sampling protocols*.—The following four sampling protocols were examined: SDWA protocols 1, 2, and 3 and the CDFG Cooperative Research and Assessment of Nearshore Ecosystems (CRANE) protocol (hereafter, CDFG/CRANE).

*SDWA protocol 1*.—The SDWA protocol 1 (hereafter, SDWA-1) consisted of a 10- × 4-m band transect "randomly" positioned at a sampling or harvest site. A 10-m lead line was attached to the anchor or to a weight dropped prior to harvesting, and its direction (azimuth) was determined by the lay of the anchor line (Figure 2). In practice, this resulted in a haphazard distribution of transect directions relative to the shoreline or isobaths. The predominant wind direction in the San Diego area is from the northwest (about 45° to the shoreline); therefore, approximately 60% of all transects lay in the northwest direction. The remaining 40% of transects varied in directions ranging from north and south (parallel to the shoreline) to west (perpendicular to the shoreline). All individuals were counted in a 2-m swath on either side of each transect. During data collection, the first 30 individuals encountered were collected and their test diameters were measured to the nearest 0.1 mm. Size data were not included in the calibration study.

*SDWA protocol 2*.—The SDWA protocol 2 (SDWA-2) rapidly censused plots by counting contiguous strips of varying widths that covered the entire plot and that were delineated with lead lines and weights. This method was a variation on the original censuses that resulted in increased efficiency of the methods for delineating contiguous subplots in a calibration area.

*SDWA protocol 3*.—The SDWA protocol 3 (SDWA-3) consisted of counts made over the entire calibration plot that were done in the same manner as was used by two of the investigators to assess numbers over large areas during harvesting operations. This method involved counting red sea urchins in an estimated area and so introduces two potential sources of error: counting error and error in estimating the area. Typically, the area of harvest at a dive site is estimated by using a known length of air supply hose as a scale. This protocol required less time than the SDWA-2

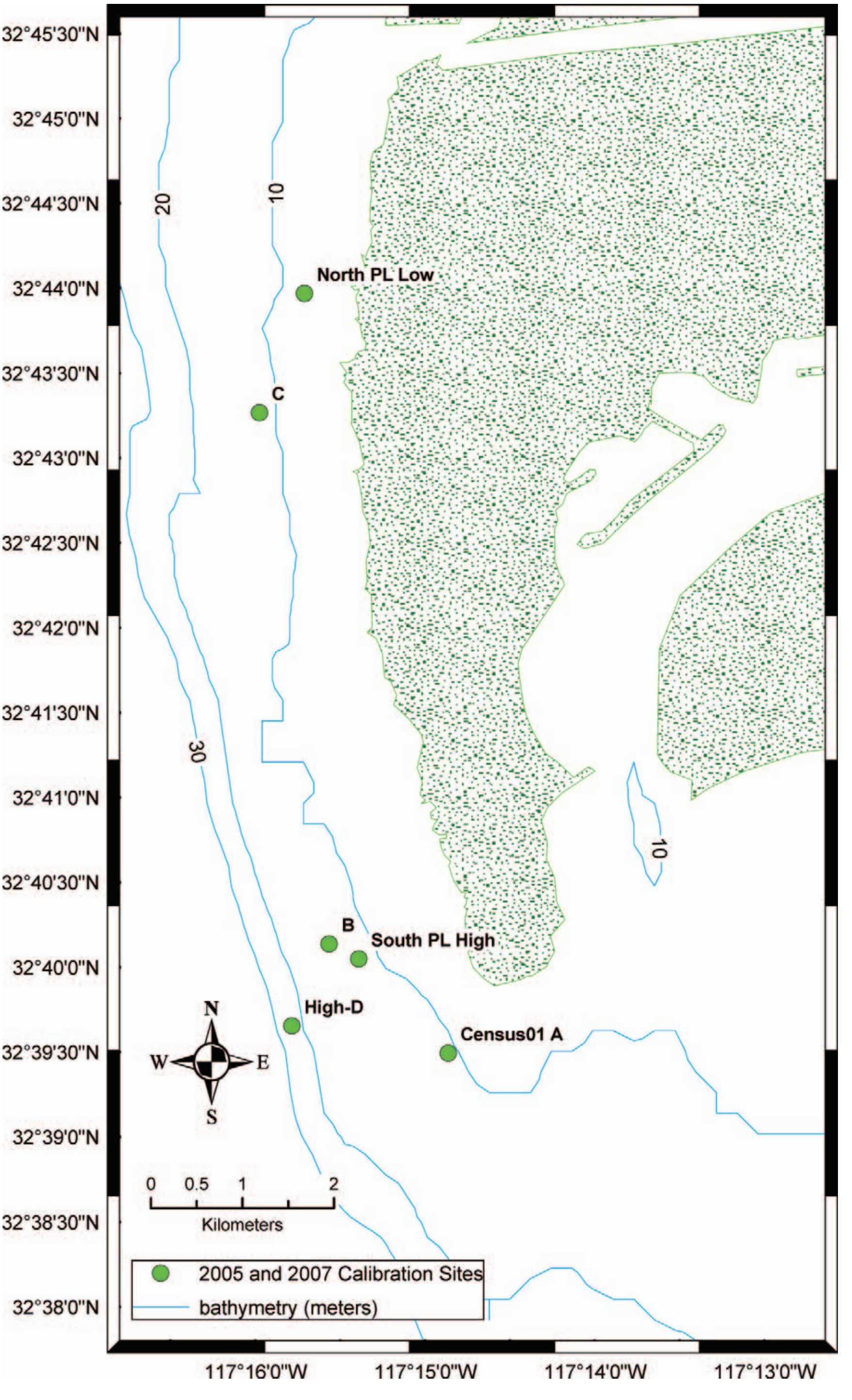


FIGURE 1.—Schematic map of calibration study sites for red sea urchin data collection in San Diego, California (see Table 1 for site definitions).

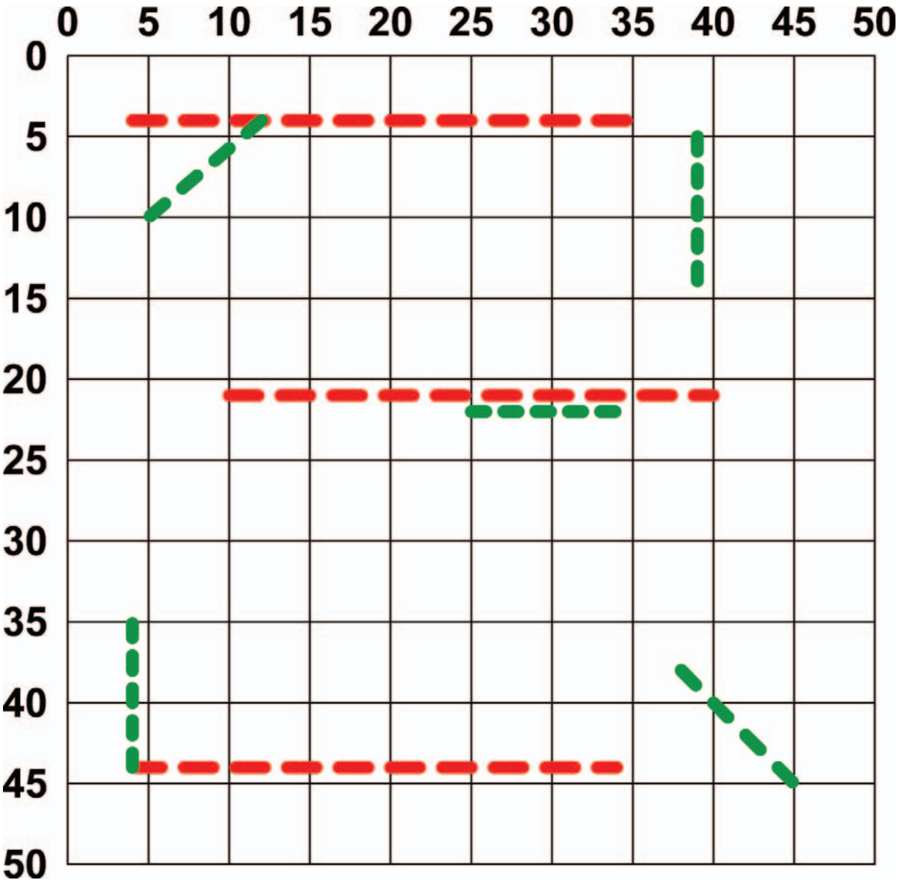


FIGURE 2.—Schematic drawing of sampling layout for census or large, uniform samples of red sea urchins. The green dotted line represents the San Diego Watermen's Association sample; the red dotted line represents the California Department of Fish and Game's Cooperative Research and Assessment of Nearshore Ecosystems sample. The diagram shows a 50- × 50-m plot with grid points (delineated in the field by measuring tapes and marked lines) at 5-m intervals. The census counted all red sea urchins in each subsquare.

protocol because it did not depend on first delineating counting areas; it was used on a single calibration plot.

*CDFG/CRANE*.—The CDFG/CRANE protocol consisted of 30- × 2-m transects divided into three 10-m segments. Each transect was oriented along the isobath, which in the Point Loma kelp bed generally resulted in an orientation parallel to the shore. Species that occurred in high densities (which included both red

TABLE 1.—Plot sizes and areas ($m^2$) sampled or censused by different protocols (defined in Methods) for collection of red sea urchin data along the coast of southern California. CDFG/CRANE = California Department of Fish and Game/Cooperative Research and Assessment of Nearshore Ecosystems; SDWA = San Diego Watermen's Association; PL = Point Loma; High-D = high densities.

| | | Area ($m^2$) sampled by protocol | | | | |
|---|---|---|---|---|---|---|
| Date | Site code | Plot area | Census | CDFG/CRANE | SDWA-1 | SDWA-2 and SDWA-3 |
| Jun 29, 2005 | Site B | 40,000 | 6,000 | 2,400 | 440 | — |
| Sep 20, 2005 | SITE A | 10,000 | 2,400 | — | 360 | — |
| Aug 9, 2007 | Census01 | 2,600 | 2,600 | 200 | 160 | 2,600 |
| Dec 14, 2007 | North PL low | 2,500 | 2,500 | 180 | 200 | 2,500 |
| Dec 15, 2007 | South PL high | 2,500 | 2,500 | 180 | 200 | 2,500 |
| Jan 18, 2008 | High-D | 2,500 | 2,500 | 180 | 300 | 2,500 |

TABLE 2.—Percent of total plot area censused or sampled by different protocols (defined in Methods). CDFG/CRANE = California Department of Fish and Game/Cooperative Research and Assessment of Nearshore Ecosystems; SDWA = San Diego Watermen's Association; PL = Point Loma; High-D = high densities.

| | | | % of total plot area sampled | | | |
|---|---|---|---|---|---|---|
| Date | Site code | Plot area | Census | CDFG/CRANE | SDWA-1 | SDWA-2 and 3 |
| Jun 29, 2005 | Site B | 40,000 | 15 | 6 | 1.1 | — |
| Sep 20, 2005 | Site A | 10,000 | 24 | — | 3.6 | — |
| Aug 9, 2007 | Census01 | 2,600 | 100 | 7.7 | 6.2 | 100 |
| Dec 14, 2007 | North PL low | 2,500 | 100 | 7.2 | 8 | 100 |
| Dec 15, 2007 | South PL high | 2,500 | 100 | 7.2 | 8 | 100 |
| Jan 18, 2008 | High-D | 2,500 | 100 | 7.2 | 12 | 100 |

sea urchins and purple sea urchins *Strongylocentrotus purpuratus*) were subsampled as follows: if the count exceeded 30 individuals in any of the three 10-m segments, the diver recorded the meter mark at which this occurred, stopped counting, and used the count and the meter length to estimate density in the segment by extrapolation. This extrapolation could produce significant upward bias if red sea urchins are abundant and patchily distributed on a scale less than 10 m, a situation that commonly occurs. To avoid these potential problems, we eliminated the "subsampling" rule. We did, however, maintain the positioning along the isobaths (i.e., parallel to the shore). This positioning rule is a potential source of bias because the substrate in the Point Loma kelp forest consists of ridges and structures that are parallel to the shore and in which red sea urchins are often concentrated.

Census and sample data were used to estimate accuracy (percentage deviation of sample from census estimates of density) and precision. Protocol precision was examined by comparing the number of samples required to detect a 20% change in density, setting the significance or type I error (probability of a false positive) and type II error (probability of a false negative) at 0.20. Power, the probability of correctly detecting a specified change, is equal to 1.00 minus the type II error (i.e., 0.80). Both precision estimates were based on protocol means averaged by year (2005 or 2007).

*SDWA kelp bed-wide sampling*.—During 2003 through October 23, 2008, data were taken at an average of 314 locations throughout the Point Loma kelp bed (Figures 3, 4). Protocols for collecting fishery-independent data (density and size-frequency) were developed prior to 2004 and implemented in January 2004. During 2004 through 2008, fishery-independent data were collected at an average of 93 locations (range = 32–207; Figures 3, 4). Most data were collected during normal fishing operations, representing samples of the "fishing grounds." However, in 2005, 79 sites were sampled outside of the fished sites for that year.

Beginning in 2004, densities and size distributions of red sea urchins were estimated in 10- × 4-m band transects deployed at sites in the harvest grounds and were sampled prior to harvesting. The position of each site was recorded with a Global Positioning System (GPS) unit with an accuracy of about 3 m. The 10-m transect line was deployed either from the anchor or a buoyed weight thrown overboard prior to any harvesting activities. The direction of the line followed that of the anchor line. All red sea urchins visible without turning substrates were counted, and the first 30 animals encountered were collected and brought to the boat, where their test diameters were measured to the nearest 0.1 mm with vernier calipers. Individuals below harvestable size (82.5 mm) were returned to the sea floor; those above this size were retained in the harvest. The sampling units were positioned without regard to red sea urchin densities and therefore constituted a random sample within the harvest grounds. In 2005, additional samples were taken in areas not harvested during that year.

In addition to fishery-independent data, a number of fishery-dependent data were recorded and linked to the GPS location. These included the following variables: number harvested; weight (lb) harvested; bottom time (min) required for the harvest; and gonad condition. Finally, a number of environmental measurements were taken, including the following: depth; water temperature; substrate type (e.g., boulder, reef, and cobble); and categorical estimates of the abundance of canopy kelps (largely giant kelp *Macrocystis pyrifera*) and understory brown algae (mainly *Pterygophora californica* and *Laminaria* spp. but also including *Cystoseira osmundacea*, *Desmarestia ligulata*, and *Egregia laevigata*).

Based on discussions with local divers and examination of reef structures from commercially available maps, the Point Loma kelp bed was divided into nine subreefs (Figure 3). Selected fishery-independent and

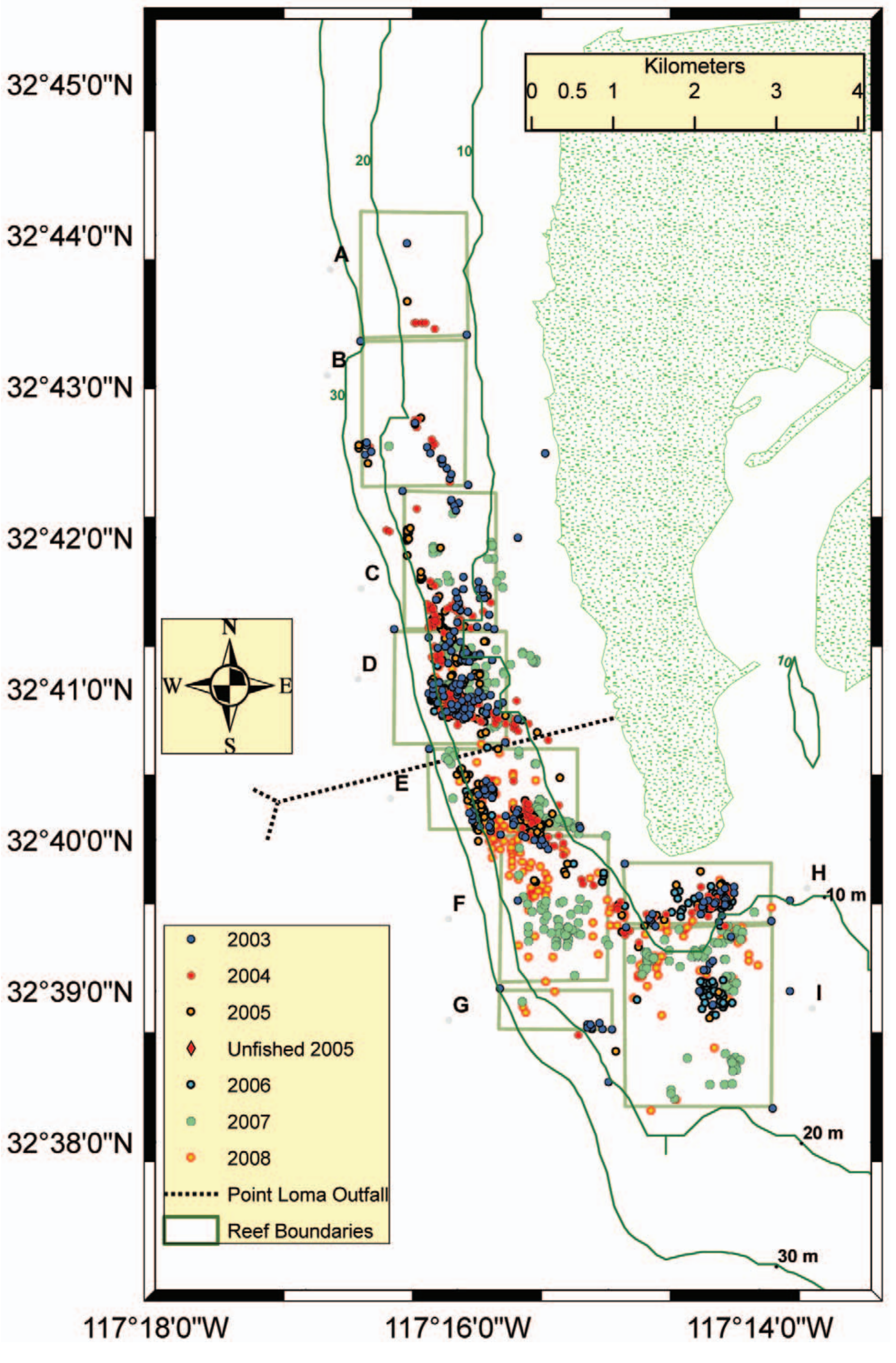


FIGURE 3.—Map of sites sampled by San Diego Watermen's Association divers in the Point Loma kelp forest, California (2003–2008). Red sea urchin size and fishery-dependent data were collected for the entire time series. Collection of data for density estimates began in September 2004. Data outside of harvest areas were collected in 2005.

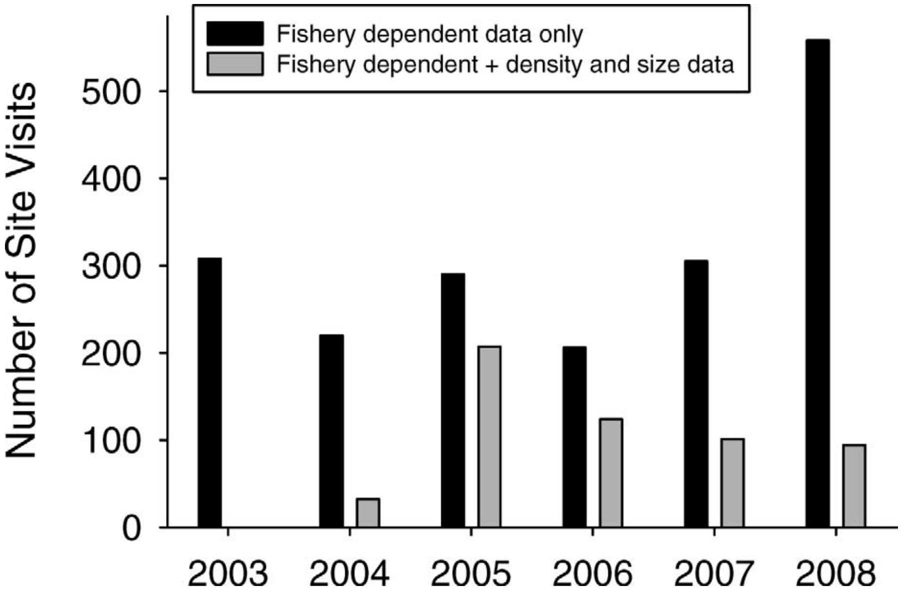


FIGURE 4.—Sample sizes (number of visits) for red sea urchin data collected in the Point Loma kelp forest, California, from 2003 to October 23, 2008. Fishery-dependent data (e.g., catch, effort, roe quality) were collected in areas ranging from 1 to 4 ha (2.5–9.9 acres). Size and density data were collected in 10- × 4-m band transects at a subset of sites.

fishery-dependent data were summarized for each subreef and for the entire kelp bed by year for 2004 to 2008. It is important to note that for most of the time series, the data were collected by a small number (1–3) of divers. A large number of spatial samples were collected in any given year, providing a good indication of general bedwide and subreef trends in red sea urchin densities and size distributions. The same was not generally the case for the fishery-dependent data until 2008, when a substantial proportion of local red sea urchin fishermen began to collect data.

## Results

### *Calibration*

Calibration plot areas varied from 2,500 to 40,000 $m^2$ (0.6–9.9 acres; Table 1). Determination of true densities in two of the plots (sites A and B) were not based on censuses but rather on large, uniform samples that covered 24% and 15% of the total plot area, respectively (Table 2). The remaining four plots were censused (Table 2). Plot densities ranged from 0.037 to 1.468 individuals/$m^2$ (Table 3) and bracketed the range of sampled densities encountered throughout the fished areas of the Point Loma kelp bed (mean = 0.50 individuals/$m^2$; 99.9% confidence limits = 0.35–0.93 individuals/$m^2$; based on 382 samples taken during 2004 through 2007).

The ranking of protocols from highest to lowest mean accuracy (percentage deviation from censused value) was as follows: SDWA-3, SDWA-2, CDFG/CRANE, and SDWA-1. On average, both CDFG/CRANE and SDWA-1 underestimated true densities

TABLE 3.—Total red sea urchin density along the southern California coast by date, site, and protocol (defined in Methods). CDFG/CRANE = California Department of Fish and Game/Cooperative Research and Assessment of Nearshore Ecosystems; SDWA = San Diego Watermen's Association; PL = Point Loma; High-D = high densities.

| | | Density (number/$m^2$) by protocol | | | | |
|---|---|---|---|---|---|---|
| Date | Site code | Census | CDFG/CRANE | SDWA-1 | SDWA-2 | SDWA-3 |
| Jun 29, 2005 | Site B | 0.363 | 0.470 | 0.359 | — | — |
| Sep 20, 2005 | Site A | 0.594 | — | 0.278 | — | — |
| Aug 9, 2007 | Census01 | 0.212 | 0.140 | 0.194 | 0.346 | 0.380 |
| Dec 14, 2007 | North PL low | 0.037 | 0.072 | 0.015 | 0.038 | — |
| Dec 15, 2007 | South PL high | 1.468 | 1.411 | 0.780 | 1.500 | — |
| Jan 18, 2008 | High-D | 0.951 | 0.289 | 1.630 | 0.760 | — |

TABLE 4.—Bias (percentage deviation from census value) in red sea urchin density by date, site, and protocol (defined in Methods). CDFG/CRANE = California Department of Fish and Game/Cooperative Research and Assessment of Nearshore Ecosystems; SDWA = San Diego Watermen's Association; PL = Point Loma; High-D = high densities.

| | | % deviation from census value | | | | |
|---|---|---|---|---|---|---|
| Date | Site code | Census | CDFG/CRANE | SDWA-1 | SDWA-2 | SDWA-3 |
| Jun 29, 2005 | Site B | 0.363 | 22.7 | −1.1 | — | — |
| Sep 20, 2005 | Site A | 0.594 | — | −53.2 | — | — |
| Aug 9, 2007 | Census01 | 0.212 | −51.6 | −8.7 | 63.0 | 80.1 |
| Dec 14, 2007 | North PL low | 0.037 | 48.5 | −59.7 | −5.9 | — |
| Dec 15, 2007 | South PL high | 1.468 | −4.0 | −46.9 | 2.2 | — |
| Jan 18, 2008 | High-D | 0.951 | −229.1 | 71.4 | −20.1 | — |

(by 42.7% and 16.3%, respectively) compared with SDWA-2 and SDWA-3, which overestimated densities (by 9.8% and 80.1%, respectively; Table 4). In contrast to average values, the range of inaccuracy for CDFG/CRANE (−229% to 48.5%) was greater than that of either SDWA-1 or SDWA-2 (SDWA-3 was only conducted once, so evaluation of its performance is limited). The CDFG/CRANE protocol overestimated densities 40% of the time, and SDWA-1 overestimated densities 17% of the time (Table 4).

The ranking of annual protocols from highest to lowest mean precision (based on number of samples required to detect a 20% decline in density with an 80% confidence interval and 80% power) was SDWA-$3_{2007}$, SDWA-$2_{2007}$, CDFG/$CRANE_{2007}$, SDWA-$1_{2005}$, SDWA-$1_{2007}$, and CDFG/$CRANE_{2005}$ (Table 5).

If we scale protocols (ignoring SDWA-3) by precision based on the number of actual samples that either were taken in the past (SDWA samples during 2003 through 2008) or were in the planning stage at the time this article was written (CDFG/CRANE samples taken in the Point Loma kelp bed during the Bight 2008 survey; D. Pondella, Occidental College, personal communication), SDWA-1 is ranked highest, followed by SDWA-2 and CDFG/CRANE (Table 6).

*Summaries of Fishery-Dependent and Fishery-Independent Data*

The density of all sizes of red sea urchins declined by about 50% between 2004 and 2008. This decline did not occur across all subreefs, however; in some subreefs, there were declines followed by increases (most notable in subreef D in central Point Loma and subreef I in south Point Loma). The timing of these changes indicates shifting effort in response to localized declines and recovery in densities (Figure 5A). The patterns for harvestable red sea urchin densities were generally similar, but the overall decline from 2004 to 2008 was less than that observed for total red sea urchin density (Figure 5B).

Densities of young-of-the-year red sea urchins showed marked spatial and temporal patchiness. There were two recruitment peaks (i.e., 2004 and 2006) between 2004 and 2008. In 2004, recruitment occurred in central and south Point Loma, whereas in 2006 recruitment was highest in the subreefs in south Point Loma (Figure 5C).

In contrast to the fishery-independent data, the fishery-dependent data were more synchronous among subreefs. Catch was flat through 2006 and then increased through 2008, largely due to increased catches in the southern subreefs (G, H, and I; Figure

TABLE 5.—Average and standard deviation (SD) of red sea urchin density (number/$m^2$) by protocol (defined in Methods) and year; bias (percentage deviation from census value); samples (*n*) required to detect 20% decline with 80% confidence and 80% power; and margin of error (MOE; in units of number/$m^2$) based on an 80% confidence interval and 80% power. Data from the High-D site (sampled Jan 18, 2008) were combined into the 2007 data. CRANE = Cooperative Research and Assessment of Nearshore Ecosystems; SDWA = San Diego Waterman's Assocation.

| Year | Protocol | Mean | SD | *n* | Census | Bias (%) | *n* for effect sizes = 20% | MOE |
|---|---|---|---|---|---|---|---|---|
| 2005 | Census | 0.48 | 0.16 | 2 | — | — | 9 | 0.02 |
| 2007 | Census | 0.67 | 0.66 | 4 | — | — | 72 | 0.24 |
| 2005 | CRANE | 0.23 | 0.48 | 47 | 0.48 | −51.4 | 298 | 0.10 |
| 2007 | CRANE | 0.35 | 0.61 | 19 | 0.67 | −47.0 | 213 | 0.13 |
| 2005 | SDWA-1 | 0.32 | 0.59 | 20 | 0.48 | −32.6 | 232 | 0.05 |
| 2007 | SDWA-1 | 0.49 | 0.92 | 31 | 0.67 | −26.4 | 248 | 0.07 |
| 2007 | SDWA-2 | 0.65 | 0.63 | 7 | 0.67 | −3.2 | 70 | 0.12 |
| 2007 | SDWA-3 | 0.38 | 0.00 | 2 | 0.67 | −42.7 | 2 | 0.00 |

TABLE 6.—Average and standard deviation (SD) of red sea urchin density (number/$m^2$) by protocol (defined in Methods) and year; detectable effect sizes (% ES) and margins of error (MOE; in units of number/$m^2$) based on projected sample sizes with an 80% confidence interval and 80% power. Data from the High-D site (sampled Jan 18, 2008) were combined into the 2007 data. CRANE = Cooperative Research and Assessment of Nearshore Ecosystems; SDWA = San Diego Waterman's Assocation.

| | | | | | | Projected | | |
|---|---|---|---|---|---|---|---|---|
| Year | Protocol | Mean | SD | *n* | Census | *n* | % ES | MOE |
| 2005 | Census | 0.48 | 0.16 | 2 | — | 20 | 13 | 0.03 |
| 2007 | Census | 0.67 | 0.66 | 4 | — | 20 | 43 | 0.14 |
| 2005 | CRANE | 0.23 | 0.48 | 47 | 0.48 | 16 | 89 | 0.10 |
| 2007 | CRANE | 0.35 | 0.61 | 19 | 0.67 | 16 | 75 | 0.13 |
| 2005 | SDWA-1 | 0.32 | 0.59 | 20 | 0.48 | 120 | 28 | 0.05 |
| 2007 | SDWA-1 | 0.49 | 0.92 | 31 | 0.67 | 120 | 29 | 0.07 |
| 2007 | SDWA-2 | 0.65 | 0.63 | 7 | 0.67 | 20 | 38 | 0.12 |
| 2007 | SDWA-3 | 0.38 | 0.00 | 2 | 0.67 | 120 | 1 | <0.01 |

5D). Effort generally increased over time, again largely due to high increases in southern subreefs G–I (Figure 5D). While overall catch per unit effort (CPUE) generally remained flat over the time series, it increased in the southern subreefs (particularly F and I), reflecting large increases in catch rates coupled with smaller rates of increase in effort from 2006 to 2008 (Figure 5F).

Finally, we compared our measure of CPUE (lb/h) with two fishery-independent measures (total density and harvestable density). Although CPUE was positively related to both measures, it is not considered a good predictor of density ($r^2$ = 0.06 and 0.05, respectively; Figure 6).

## Discussion

The four sampling protocols tested in this study differ significantly in both their accuracy and precision. The SDWA-3 was the most precise protocol, but this assessment was based on a single calibration, overestimating the true density by 80%. Of the remaining protocols, SDWA-2 was potentially much more accurate and precise than either SDWA-1 or CDFG/CRANE. The latter two protocols are similar with regard to average accuracy and precision (CDFG/CRANE is on average slightly less accurate and precise than SDWA-1); however, CDFG/CRANE had a much greater range of positive (overestimating error) and negative (underestimating error) bias than SDWA-1.

Considering only precision and accuracy, both SDWA-1 and SDWA-2 are superior to CDFG/CRANE, SDWA-2 being the best predictor. When deciding how to allocate effort between SDWA-1 and SDWA-2, however, there are important logistical considerations. Advantages of SDWA-1 are that the cost per sample is low and that it can be quickly taught to divers to carry out with high confidence in quality assurance and control. The SDWA-2 protocol, while more accurate and precise than SDWA-1, has higher unit cost and requires special training and experience. The SDWA-3 protocol was the most precise, but accuracy was poor and in a nonconservative direction (80% overestimate). To be effectively used, the SDWA-3 protocol will require dedicated resources for training, quality assurance, and implementation. In the meantime, all divers in the SDWA can be quickly taught SDWA-1. This protocol and its small unit cost assure the long-term continuity of the data collection program, and it can be used as a complement to the SDWA-3 protocol after the latter has been fully developed and implemented.

In summary, the calibration studies indicate that the SDWA protocols are superior to the CDFG/CRANE protocol for collection of density (and thus abundance) data on red sea urchins and can, in combination, produce estimates of total red sea urchin densities with known accuracy and high to very high precision. Analysis of these data over a 5-year time period illustrates feasibility of this community-based program of data collection to provide information that can be used to assess the health of the fishery and suggest adaptive harvesting strategy to ensure sustainability. The SDWA illustrates another critical advantage of the community-based approach, the ability to continually collect data on a yearly basis as opposed to infrequent snapshots. This is particularly important for the red sea urchin fishery, where the distribution, abundance, and harvestability of the target population are closely tied to the availability of a food resource, the giant kelp. This kelp resource can fluctuate significantly on annual to decadal time scales in response to oceanographic conditions associated with El Niño/La Niña and Pacific decadal oscillations. The significant fluctuations in recruitment and total population density observed in the 5-year time scale of the present study argue for a sustained annual data collection program. This was one of the recommendations by Hilborn et al. (2007), who used several methods and the SDWA data collected

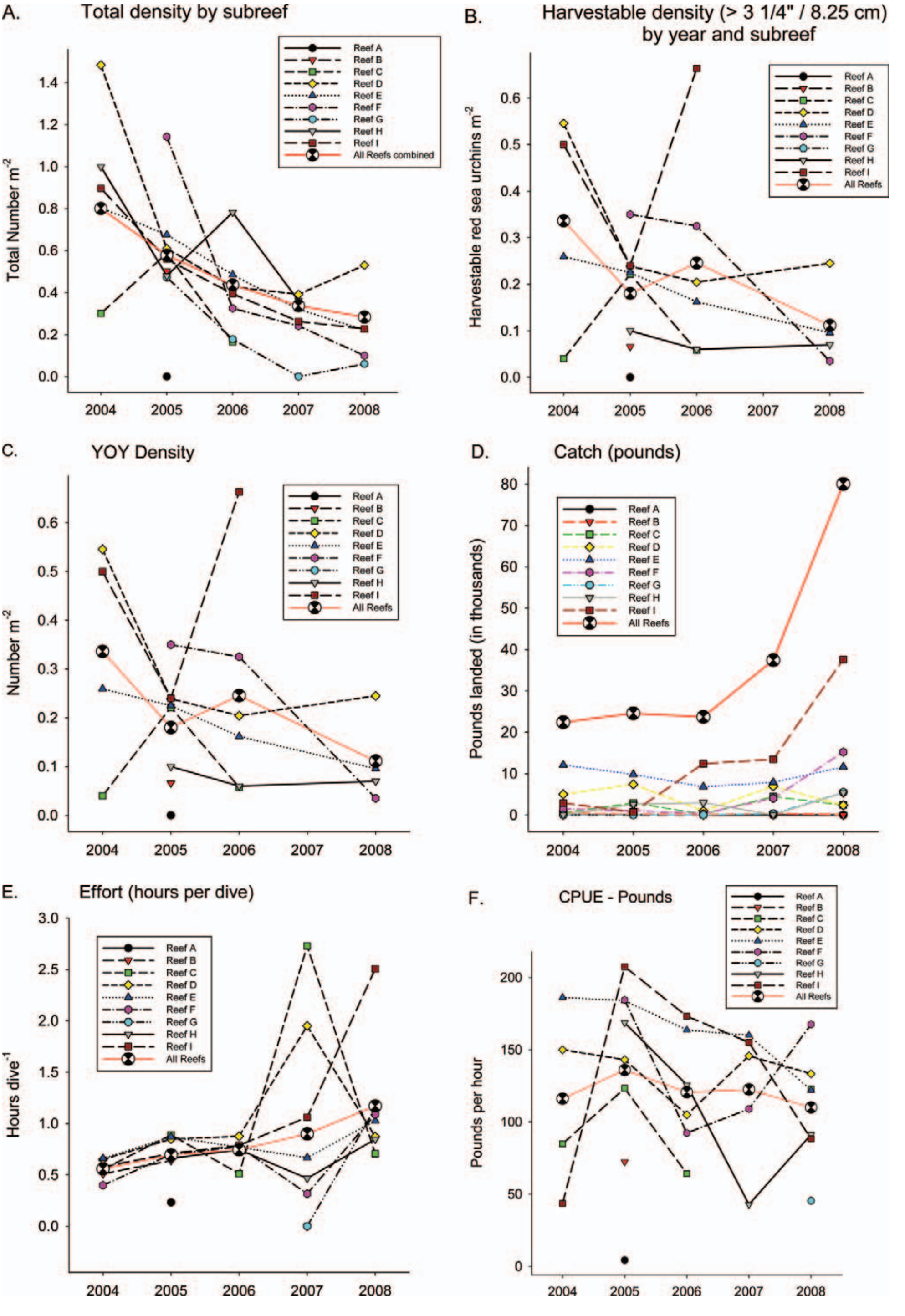


FIGURE 5.—Variables describing red sea urchins sampled off the coast of southern California by year and subreef (see Figure 3 for locations of subreefs): **(A)** density (number/$m^2$) of all sizes; **(B)** density of harvestable individuals (>3.25 in or 8.25 cm); **(C)** density of young-of-the-year (YOY; 1.1 in or 2.8 cm) individuals; **(D)** total catch (lb); **(E)** average effort (h/dive); and **(F)** catch per unit effort (CPUE; lb/h).

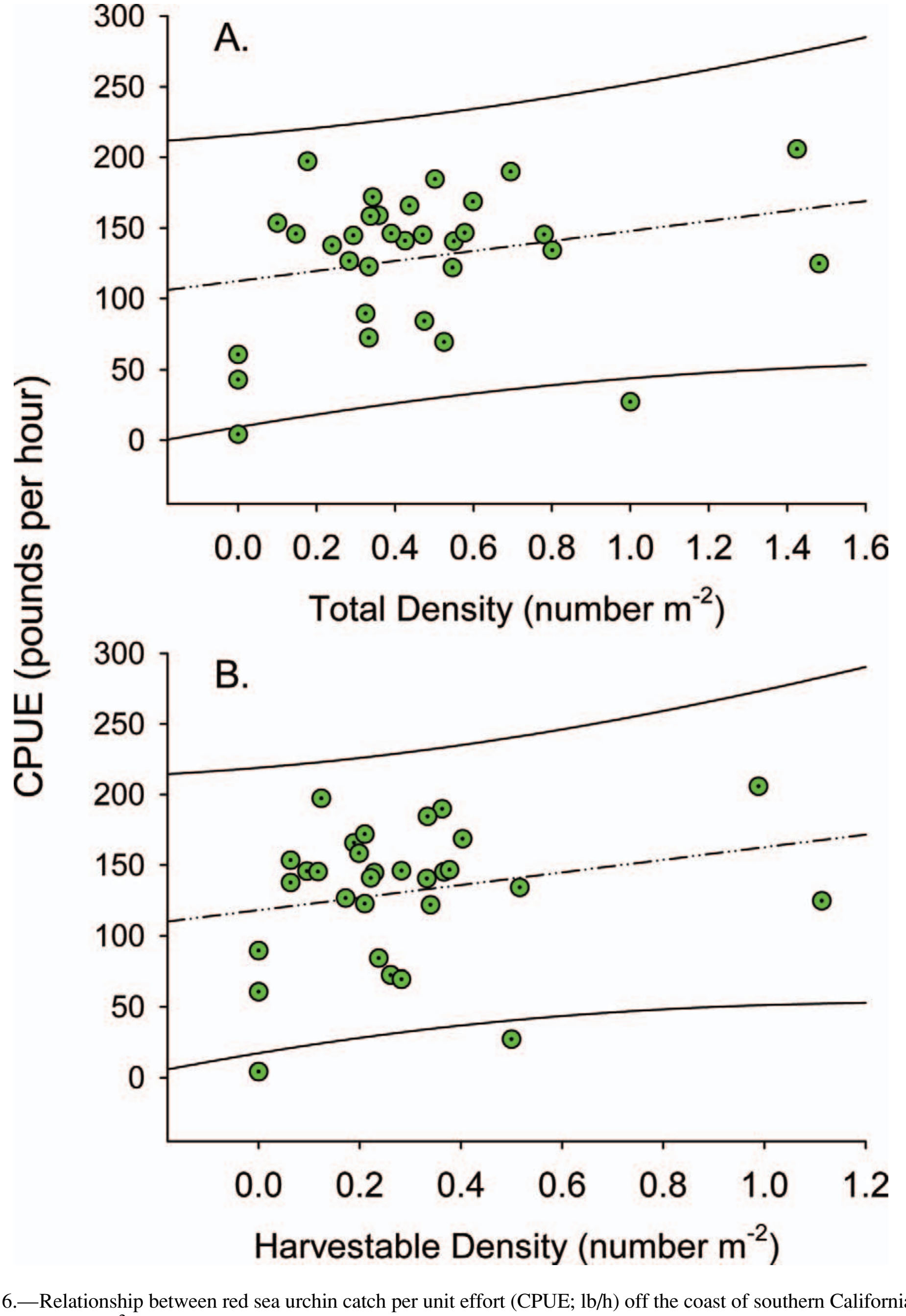


FIGURE 6.—Relationship between red sea urchin catch per unit effort (CPUE; lb/h) off the coast of southern California and **(A)** total density (number/$m^2$) or **(B)** density of harvestable individuals (>82.5 mm). Dashed lines indicate best linear fit; solid lines indicate 95% prediction confidence intervals.

through 2006 to assess trends in abundance and net productivity of the red sea urchin resource in the Point Loma kelp forest. Their analysis concluded that the fishery was sustainable; however, there were major uncertainties based on the fact that divers continued to harvest seemingly too many large red sea urchins, suggesting extremely low fishing mortality rates inconsistent with observed fishing effort. Two possible mechanisms to account for this discrepancy were (1) the influx of individuals from truly nonfished areas and

(2) growth rates that were much higher than had been observed in previous studies. To investigate these possibilities, Hilborn et al. (2007) suggested that in addition to continued monitoring of trends in abundance and length, targeted surveys outside the fishing grounds and growth studies should be conducted. Furthermore, a fine-scale spatial heterogeneity in red sea urchin life history traits (growth: Ebert et al. 1999; Morgan et al. 2000; mortality: Morgan et al. 2000; recruitment: Ebert et al. 1994; gonad development: Rogers-Bennet et al. 1998) affecting their population dynamics implies that significant increases in data requirements and analysis complexity are needed for proper stock assessments and management plans (Butterworth and Punt 1999; Hobday and Punt 2009). Considering how time-consuming and costly it would be to gather information at a proper scale in assessment and management of this type of resource, community-based data collection programs are promising tools.

Finally, we conclude that even though there are many examples of this type of data collection program worldwide, several key factors were responsible for the success in quality and continuity in the San Diego red sea urchin fishery program: (1) a relatively small group of fishermen harvesting a relatively small area for a long period of time; (2) the formation of the SDWA, giving strong community cohesion, good communication, and effectiveness in bringing funds for research activities, educational programs, and development of markets; (3) strong leadership among several members of the community and a sense of trust in external consultants; (4) a mutual understanding and cooperation among the management agency, scientists, and fishermen in designing, implementing, and executing the sampling protocols; and (5) the recognition of this program by the community as a first step towards community-based fishery management, where fishermen have a prime responsibility for stewardship and management, including taking part in decision making for every aspect of management, such as access, harvesting, compliance and enforcement, research, and final product marketing.

## Acknowledgments

We thank Mitch Hobron, Dave Datz, and Mike Neil (sea urchin divers and members of the SDWA); John Duffy (formerly with CDFG); and Pete Kalvass (CDFG senior biologist) for help in the design of the calibration experiments and implementation in the field. Kristine Barsky, Ian Taniguchi, Matt Kay, and Briana Brady of CDFG collected CRANE samples during the 2005 studies. Mark Page provided helpful comments on drafts of the report.

## References

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Fishery Investigations Series II Marine Fisheries Great Britain Ministry of Agriculture Fisheries and Food 19(2):1–533.

Butterworth, D. S., and A. E. Punt. 1999. Experiences in the evaluation and implementation of management procedures. ICES Journal of Marine Science 56:985–998.

Caddy, J. F. 1975. Spatial model for an exploited shellfish population, and its application to the Georges Bank scallop fishery. Journal of the Fisheries Research Board of Canada 32:1305–1328.

Caddy, J. F. 1989. Marine invertebrate fisheries: their assessment and management. Wiley, New York.

Caddy, J. F. 2007. Marine habitat and cover: their importance for productive coastal fishery resources. Oceanographic Methodology Series. UNESC Publishing, Paris.

Castilla, J. C., and O. Defeo. 2001. Latin American benthic shellfisheries: emphasis on co-management and experimental practices. Reviews in Fish Biology and Fisheries 11:1–30.

Castilla, J. C., and O. Defeo. 2005. Paradigm shifts needed for world fisheries. Science 309:1324–1325.

Castilla, J. C., P. Manriquez, J. Alvarado, A. Rosson, C. Pino, C. Espoz, R. Soto, D. Oliva, and O. Defeo. 1998. Artisanal "Caletas" as units of production and co-managers of benthic invertebrates in Chile. Canadian Special Publication of Fisheries and Aquatic Sciences 125:135–146.

CDFG (California Department of Fish and Game). 2004. Cooperative Research and Assessment of Nearshore Ecosystems (CRANE) Program. Available: www.dfg.ca.gov.

Ebert, T. A., J. D. Dixon, S. C. Schroeter, P. E. Kalvass, N. T. Richmond, W. A. Bradbury, and D. A. Woodby. 1999. Growth and mortality of red sea urchins *Strongylocentrotus franciscanus* across a latitudinal gradient. Marine Ecology Progress Series 190:189–209.

Ebert, T. A., S. C. Schroeter, and J. D. Dixon. 1994. Settlement patterns of red and purple sea urchins (*Strongylocentrotus franciscanus* and *S. purpuratus*) in California, USA. Marine Ecology Progress Series 111:41–52.

Gunderson, D. R., A. M. Parma, R. Hilborn, J. M. Cope, D. L. Fluharty, M. L. Miller, R. D. Vetter, S. S. Heppell, and H. G. Greene. 2008. The challenge of managing nearshore rocky reef resources. Fisheries 33(4):172–179.

Hilborn, R., N. L. Gutiérrez, and S. C. Schroeter. 2007. Report on stock assessment for the San Diego Watermen's Association, San Diego, California.

Hobday, D., and A. E. Punt. 2009. How much spatial structure can data for rock lobster off Victoria, Australia support? New Zealand Journal of Marine and Freshwater Research 43:373–385.

Johannes, R. E. 2002. The renaissance of community-based marine resource management in Oceania. Annual Review of Ecology and Systematics 33:317–340.

Kalvass, P. E. 1997. The California red sea urchin, *Strongylocentrotus franciscanus*, fishery: catch, effort, and management trends. U.S. National Marine Fisheries Service Marine Fisheries Review 59(2):1–17.

Kalvass, P., and I. Taniguchi. 1991. Relative abundance and size composition of red sea urchin, *Strongylocentrotus franciscanus*, populations along the Mendocino and Sonoma County coasts, 1989. Marine Resources Division Administrative Report, Number 91–3, California Department of Fish and Game, Sacramento.

Morgan, L. E., L. W. Botsford, S. R. Wing, and B. D. Smith. 2000. Spatial variability in growth and mortality of the red sea urchin, *Strongylocentrotus franciscanus*, in northern California. Canadian Journal of Fisheries and Aquatic Sciences 57:980–992.

Orensanz, J. M. 1986. Size, environment, and density: the regulation of a scallop stock and its management implications. Canadian Special Publication of Fisheries and Aquatic Sciences 92:195–227.

Orensanz, J. M., A. M. Parma, G. Jerez, N. Barahona, M. Montecino, and I. Elias. 2005. What are the key elements for the sustainability of "S-Fisheries"? Insights from South America. Bulletin of Marine Science 76:527–556.

Parnell, P. E., P. K. Dayton, C. E. Lennert-Cody, L. A. Rasmussen, and J. J. Leichter. 2006. Marine reserve design: optimal size, habitats, species affinities, diversity, and ocean microclimate. Ecological Applications 16:945–962.

Prince, J. D. 2003. The barefoot ecologist goes fishing. Fish and Fisheries Series 4:359–371.

Prince, J. D. 2005. Combating the tyranny of scale for haliotids: micro-management for micro-stocks. Bulletin of Marine Science 72:557–577.

Rogers-Bennet, L., W. A. Bennet, H. C. Fastenau, and C. M. Dewees. 1998. Spatial variation in red sea urchin reproduction and morphology: implications for harvest refugia. Ecological Applications 5:1171–1180.

Smith, T. D. 1994. Scaling fisheries: the science of measuring the effects of fishing, 1855–1955. Cambridge University Press, Cambridge, UK.

Starr, P. J., and M. Vignaux. 1977. Comparison of data from voluntary logbook and research catch-sampling programmes in the New Zealand lobster fishery. Marine and Freshwater Research 48:1075–1080.

U.S. Census Bureau. 2006. Accuracy of the data (2006). Available: www.census.gov/acs/www/Downloads/ACS/accuracy2006.pdf.

Wombold, L. 2008. Examining error. ArcUser (Spring2008):8–11.

Yamamoto, T. 1995. Development of community-based fishery management system in Japan. Marine Resource Economics 10:21–34.