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Authors: Culver, Carolynn S., Schroeter, Stephen C., Page, Henry M., and Dugan, Jenifer E.

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Essential Fishery Information for Trap-Based Fisheries: Development of a Framework for Collaborative Data Collection

CAROLYNN S. CULVER*
University of California Cooperative Extension, Sea Grant Extension Program, and Marine Science Institute, University of California–Santa Barbara, Santa Barbara, California 93106-6150, USA

STEPHEN C. SCHROETER, HENRY M. PAGE, AND JENIFER E. DUGAN
Marine Science Institute, University of California–Santa Barbara, Santa Barbara, California 93106-6150, USA

Abstract.—The availability of up-to-date information for managing marine resources is limited worldwide. In California, lack of data is hindering the execution and evaluation of two recent state laws, the Marine Life Management Act and the Marine Life Protection Act. The inability to meet the objectives of these laws is particularly acute for large cryptic benthic species (e.g., crabs, lobster, and prawns) that support valuable trap fisheries. Such species are not readily quantified by conventional methods and thus are not usually included in existing monitoring efforts. We explored the integration of data collection with ongoing commercial crab fishing activities to address this information gap and developed sampling regimes that provided accurate estimates of at-sea catches that could show the status of crab populations. Crab catches sampled in port represented only a subset of the catch at sea owing to selective harvesting of the catch (i.e., sorting) and thus would be a poor estimator of wild stocks. We developed a framework for addressing data accuracy and validity, data management and sharing, incentives, compensation, and long-term funding. Our findings suggest that data collection programs in which fishermen, managers, and scientists collaboratively design, collect, and analyze data are well suited for trap fisheries, particularly those that include multiple species or practice high rates of selectivity. The resulting recommendations for ensuring that the process is transparent and that the data are accurate and integrated into management include having (1) well-defined goals and appropriate, scientifically sound data collection methods, (2) hands-on training for participants, (3) validation of the collected data, (4) well-defined procedures for handling confidential data, (5) an adequate funding source, and (6) timely and consistent reviews of the data with subsequent actions as needed. This program offers a sound solution for obtaining comprehensive fishery information in a more cost-effective manner than is currently available.

Large mobile invertebrates (including crabs, shrimp–prawns, and lobsters) form the basis of valuable trap fisheries worldwide (Leet et al. 2001). These animals also play an important role in the ecological functioning of nearshore ecosystems (e.g., food chain support). Despite their value and ecological importance, data are often lacking for these species largely because they are cryptic, mobile, patchily distributed, and often nocturnal. Because of these characteristics, sampling approaches currently in use to monitor benthic communities (e.g., quadrat sampling) do not accurately sample this suite of species and this large group of invertebrates is essentially ignored in existing monitoring programs.

A review of California's marine fisheries (Leet et al. 2001) identifies the lack of biological data needed for managing these commercially important species, particularly that for rock crabs *Cancer* spp., which includes three different species. Notably, monitoring of cryptic species was identified by the Channel Islands National Marine Sanctuary Research Activities Panel (2005) as a primary area of research that is lacking in existing monitoring programs for marine resources of the region. Fishery landings, one form of fishery-dependent data, are often the only information available for management of trap fisheries, including the rock crab fishery. Unfortunately, using fishery landings data to make management decisions is problematic because many factors (e.g., economic, environmental, regulatory) influence fishing effort and subsequent landings. Thus, landings data alone do not provide reliable indicators of resource condition and status.

The management and sustainability of California's valuable trap fisheries is currently hindered by a lack of information and effective methods for collecting data on large cryptic species. Although California's Marine Life Management Act requires the development of

Subject editor: Glen Jamieson, Pacific Biological Station, British Columbia, Canada

* Corresponding author: c_culver@lifesci.ucsb.edu

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fishery management plans based on essential fishery information, such information is sparse for trap fisheries. Furthermore, little data are available to identify and evaluate the efficacy of marine protected areas (MPAs), as directed by the Marine Life Protection Act, hindering implementation of ecosystem-based management. Fishing communities are also beginning to suffer from the lack of data in the face of increasing consumer and public demands for information on the sustainability of fisheries in seafood purchase and consumption.

Collaborative data collection programs offer a cost-effective approach to address these pressing information and management needs. Both managers (e.g., California Department of Fish and Game [DFG]) and fishermen have expressed an increased interest in the development of collaborative data collection programs that can provide essential fisheries information for managing and illustrating sustainability of California fisheries. The need for new data collection approaches is supported by the current realization that managers and affiliated monitoring groups lack the funds and staff to collect these data, and data other than fishery landings are needed to assess and ensure the sustainability of the resources.

Collaborative data collection programs that engage fishermen in the collection of essential fisheries information for the purpose of long-term management on a broad scale is a relatively new approach to fisheries management. Other countries have successfully implemented this approach for management (Starr and Vignaux 1997; Parma et al. 2003). Attempts to develop similar types of programs for California fisheries (e.g., market squid *Loligo opalescens*, red sea urchin *Strongylocentrotus franciscanus*, spiny lobster *Panulirus interruptus*, red abalone *Halioitus rufescens*; Schroeter et al. 2009a; K. Barsky, California Department of Fish and Game, personal communication; C. Miller, California Lobster and Trap Fisherman's Association, personal communication; D. B. Pleschner-Steele, California Wetfish Producers Association, personal communication; C. S. Culver, personal observation) have met with varying degrees of success. Overall, however, the California programs have fallen short of providing data that are integrated into the management process. Based on our observations, this shortcoming is because of issues with sampling design, trust in the accuracy of the data, and the lack of a widely acceptable means for sharing the data. Concerns over compensation and the long-term stability and funding of these programs have also been raised.

We investigated these and other issues associated with developing a successful collaborative data collection program in California using the rock crab fishery of the Santa Barbara Channel region as a model system. The southern California rock crab fishery was ideal for our investigations because (1) this fishery includes multiple species (three species of rock crabs) that occupy a range of habitats (soft bottom, soft–hard bottom interface, hard bottom), thus offering the greatest potential for extrapolation of study findings to other species and areas; (2) fishing season is year-round, thereby maximizing the time available to gather data; and (3) a core group of local crab fishermen continue to be proactive and supportive of collaborative efforts to improve the management of their fishery.

The objectives of our study were threefold: (1) to determine scientifically robust data collection protocols that could be readily integrated into commercial trapping operations, (2) to test the efficacy of different sampling regimes for providing an accurate estimate of the commercial catch, and (3) to identify potential solutions to three key components of collaborative data collection efforts: accuracy and validation of data, data management and sharing, and incentives, which include compensation (including funding) and the opportunity to participate in management of the fishery.

Importantly, data collection during our project was done for the purpose of profiling the fishery and testing standard methods for collecting essential fisheries information, not for analyzing the fishery. Furthermore, as a pilot project we only discussed issues and potential solutions; we did not assess or test the feasibility of the resulting framework.

Our results provide a framework for the development and implementation of collaborative data collection programs for commercial fisheries in California. We also suggest specific methods and protocols to be considered for trap fisheries to illustrate aspects associated with sampling designs for this type of program. Our findings are broadly applicable to other fisheries and could be adopted to assist the state with management of "data-poor" fisheries and to enhance the sustainability of fishing communities.

Methods

We used a combination of field sampling approaches, meetings, information exchanges, and data analyses to examine potential sampling designs and a framework for a collaborative data collection program.

Field Sampling Protocols

We obtained general information concerning the crab fishery and evaluated potential methods and protocols to obtain essential fishery information through the sampling of catches at sea and in port from April through August 2008. Our study was conducted in fishing grounds of the northern Santa Barbara Channel region, along the mainland coast from Carpinteria to Point Conception and at the northern Channel Islands where the majority of crab landings ($\geq$75%) are obtained for the region. Data were collected from both pre- and postharvest catches, which are also referred to as the "at-sea" and "in-port" catches, respectively. At-sea catch represents the actual catch of all traps serviced by the fishermen at sea, whereas in-port catch is the portion of the catch retained by the fishermen and landed at port for market. We analyzed data for three species of rock crabs: red rock crab *Cancer productus*, brown rock crab *C. antennarius*, and yellow rock crab *C. anthonyi*.

At-sea sampling.—At-sea sampling of commercial crab catches included the collection of both general data from all traps and more detailed data from a subset of traps. Mean catch per trap and total catch were determined from general data recorded by fishermen on the number and species of crabs that were captured from all of the traps. Data were also recorded on the number and species of crabs released back into the sea. From a selected subset of traps, data were collected on the sex and size (carapace width [CW]) of individuals captured and, when applicable, the reason the crab was released back to sea. Crabs were measured on a fish board to the nearest 0.5 cm at the widest part of the crab (the ninth lateral tooth for red and yellow rock crabs, and the eighth lateral tooth for brown rock crabs).

Because recording data on the entire catch at sea is not feasible for long-term data collection efforts, we compared the accuracy of three subsampling approaches in estimating the mean number of crabs caught per trap by species for each trapline. In the first approach, a subsample of traps within stratified catch levels set a priori by the fishermen (high, medium, and low) were sampled. These levels were based on the anticipated average catch level for a given site and season. Within each of the three catch levels, four traps were sampled for a total of 12 traps. One trap of each catch level was sampled from each quarter section of the trapline. In the second approach, a subsample of 12 traps spaced haphazardly along the traplines were sampled. In the third approach, a subsample of four traps spaced haphazardly along the traplines were sampled. This sampling approach was adapted from a subsampling protocol recommended for lobsters by Starr and Vignaux (1997).

In-port sampling.—The number of individuals of each species of crab was recorded for all receivers (i.e., plastic containers used to store crabs at port). In addition, for haphazardly selected receivers, sex and size (CW) of individual crabs were recorded for the first 30 individuals of each species of crab. Crab size was measured to the nearest 0.1 mm using a digital vernier caliper at the widest part of the crab as described above.

Development of a framework.—Through a series of monthly meetings with our fishing partners, we explored three key framework components: (1) accuracy and validation of data, (2) data management and sharing, and (3) incentives, compensation, and funding. These components were identified by us as areas where a defined and broadly accepted structure was needed in order to support integration of collected data into the management process in California. For example, data collected by fishermen, volunteers, or others not trained in science are often criticized for not being scientifically sound and accurately taken, and thus not often used to inform management. Because the collaborative approach we were investigating engages many individuals in data collection, we needed to address these concerns. Likewise, we know there is reluctance within the fishing community to share data with manager and others. This obviously needs to be overcome in order to integrate collected data into management. Compensation is also of considerable debate, as is the means for paying for long-term data collection efforts.

To address data accuracy and validity, we explored scientifically robust procedures and protocols that could be clearly defined and readily carried out by our fishing partners with minimal chance for individual interpretations. This required discussion about the scientific method and the need for taking accurate data in a repeatable manner that did not vary among fishermen. It also required discussing individual fishing operations to make sure all participants could integrate the developed procedures and protocols into their operations. Once the procedures and protocols were developed, hands-on training was used to ensure methods did not vary by fishing partner. Validation of the data were accomplished through in-port sampling.

Discussions regarding the other two components—data management and sharing and incentives, compensation and funding—included reviews of procedures used in other California data collection programs (squid, sea urchin, lobster, and abalone), their applicability to the rock crab fishery, and identification of other potential options for addressing these components. Participants in collaborative data collection programs for the other California species were consulted with and attended some of the meetings. We also occasionally consulted with the DFG to gain insight into the department's needs and requirements

TABLE 1.—Numbers of rock crabs sampled from mainland coast and island fishing grounds. The percentage of the catch represented by each species at a particular location is indicated in parentheses. Sample size refers to the number of catches sampled.

		Rock crab species			
Location	Sample size	All species	Brown	Red	Yellow
Mainland coast					
At sea	8	11,736	33 (0.3)	1,780 (15.2)	9,923 (84.5)
In port	8	7,684	23 (0.3)	1,467 (19.1)	6,194 (80.6)
Islands					
At sea	2	1,716	202 (11.8)	1,502 (87.5)	12 (0.7)
In port	2	1,426	201 (14.1)	1,218 (85.4)	7 (0.5)

for engaging in collaborative data collection programs. Topics discussed for data management and sharing included (1) who would manage the collected data, (2) where the data would be housed, (3) how confidential data would be handled, and (4) how data would be shared with others. Topics discussed regarding incentives, compensation, and funding were (1) what incentives were most important to participants of the program; (2) whether compensation should be provided and, if so, how much; and 3) how long-term funding could be obtained to cover the costs of such a program.

Data Analyses

Comparison of sampling methods.—We compared species composition, sex composition, and size distributions of at-sea and in-port catches. Species composition was determined from the data taken for the entire catch from all the traps sampled at sea or all of the receivers sampled in port. Sex composition and size frequencies were calculated from the subsamples taken from selected subset of traps of the at-sea catch and from selected receivers sampled from the in-port catch. We analyzed for differences in species composition, sex composition, and size distribution between the at-sea and in-port catches of the various species using chi-square statistics (Zar 1999). Sampling protocols with means falling within the 95% confidence intervals of the catch for "all traps" were considered good estimators, all others considered as under- or overestimating the catch.

Development of a framework.—To evaluate how accurately the methods and procedures were implemented by individual fishermen, we compared data recorded by our fishing partners at sea on the retained catch to the data we collected in port for the same catch. The percent difference between the at-sea and in-port data were calculated for the total counts per species retained. We also analyzed the support of our fishing partners for various options to address the key framework components by surveying and calculating the percentage of support for each option. To better understand the importance of certain incentives to fishermen participating in data collection efforts, fishermen ranked their responses based on a scale of 1–3, 1 being the least important and 3 being the most important.

Results

Sampling Effort

A total of 16 catches were sampled at sea by five fishermen. Nine of the catches were from traps deployed along the mainland coast, the remaining seven catches coming from the offshore islands. An average of 70 traps were serviced per catch, ranging from 24 to 103 traps (19,116 crabs sampled). Of these 16 at-sea catches, 10 were also sampled in port (Table 1), 8 catches coming from the mainland coast and the other 2 from the offshore islands. Detailed data (see Methods) were collected on a subsample of these 10 catches (Table 2).

Comparison of At-Sea and In-Port Samples

Species composition.—Species composition varied significantly between at-sea and in-port samples of mainland coast catches ($\chi^2 = 51.53$, $P < 0.0001$; Figure 1). A higher proportion of yellow rock crabs (84.6% versus 80.6%) and a lower proportion of red rock crabs (15.2% versus 19.1%) occurred in the at-sea samples than in the in-port samples. There was no difference in these proportions for brown rock crabs,

TABLE 2.—Numbers of rock crabs subsampled from mainland coast and island fishing grounds.

	Rock crab species			
Location	All species	Brown	Red	Yellow
Mainland coast				
At sea	1,493	12	117	1,364
In port	1,482	18	441	1,023
Islands				
At sea	258	23	235	0
In port	584	131	447	6

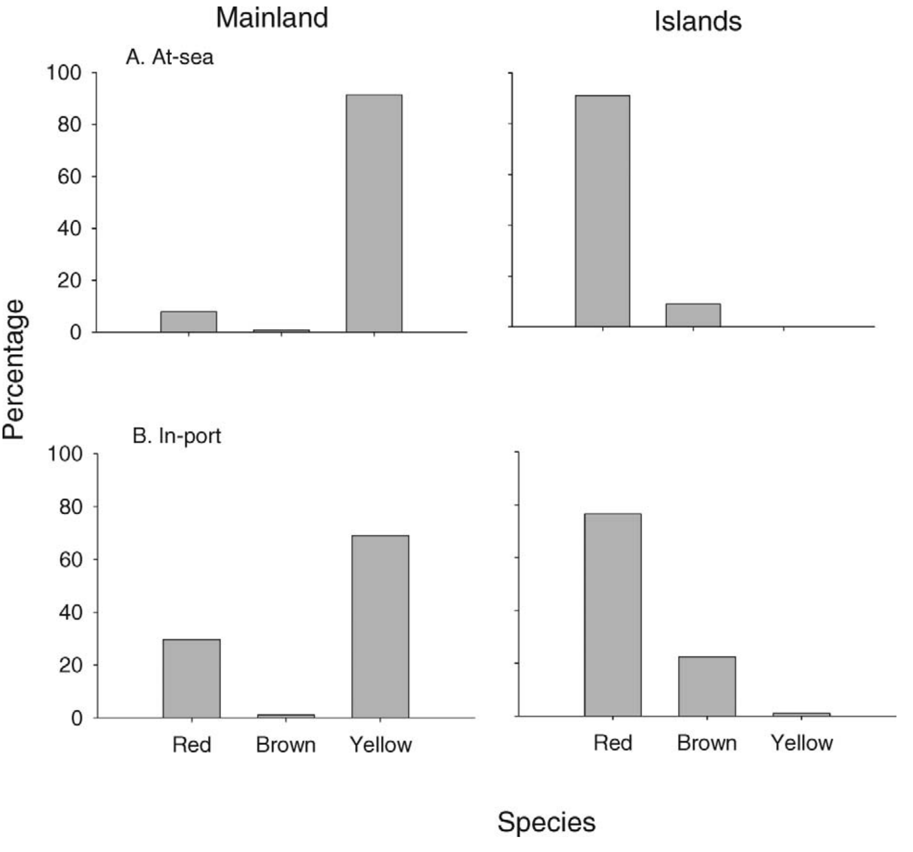

FIGURE 1.—Species composition of rock crabs sampled from commercial catches along the mainland coast and the offshore islands of the Santa Barbara Channel **(A)** at sea (i.e., sampled directly from traps at sea) and **(B)** in port (from retained at-sea catches sampled in port).

which comprised less than 0.5% of the species composition in both cases. In contrast, the species composition of at-sea and in-port samples of island catches was similar ($\chi^2 = 4.241$, $P > 0.12$; Figure 1). Red rock crabs dominated both types of samples from the islands (87.5% at sea versus 85.4% in port), with considerably fewer brown rock crabs (11.8% versus 14.1%). There were no differences for yellow rock crabs, which made up less than 1% of island catches.

Sex ratio.—For mainland catches, at-sea samples had a significantly higher percentage of female yellow rock crabs than in-port samples (60.3% versus 52.4%; $\chi^2 = 14.7$, $P < 0.0001$; Figure 2C). Sex ratios did not differ significantly among at-sea and in-port samples for brown ($\chi^2 = 2.301$, $P = 0.13$; Figure 2B) or red ($\chi^2 = 2.759$, $P = 0.10$; Figure 2A) rock crabs. This result was likely due to the low statistical power associated with small sample sizes (Table 2) for the brown rock crabs as there was a clear trend toward fewer female crabs for the in-port samples. For island catches, at-sea samples had a significantly higher percentage of female brown rock crabs than in-port samples (34.8% versus 12.2%; $\chi^2 = 7.575$, $P = 0.006$; Figure 2B). For red rock crabs, the sex ratios were similar (about 40% females) for at-sea and in-port samples ($\chi^2 = 0.013$, $P = 0.910$; Figure 2A). Too few yellow rock crabs were obtained from island catches to conduct similar analyses.

Size distribution.—For catches from the mainland coast, at-sea samples yielded a significantly higher percentage of smaller yellow crabs (<130 mm CW) than in-port samples ($\chi^2 = 102.77$, $P < 0.0001$; Figure 3C). No difference in the size distribution of crabs sampled at sea versus in port were observed for either red ($\chi^2 = 7.28$; $P = 0.13$) or brown ($\chi^2 = 5.07$; $P = 0.08$) rock crabs from the mainland coast (Figure 3A, B). The majority of red rock crabs from the mainland ranged in size from 108 to 170 mm, with very few sub–legal-size (<108-mm) individuals. In contrast, brown rock crabs were smaller in size (<150 mm) and sublegal individuals comprised 25% of the at-sea

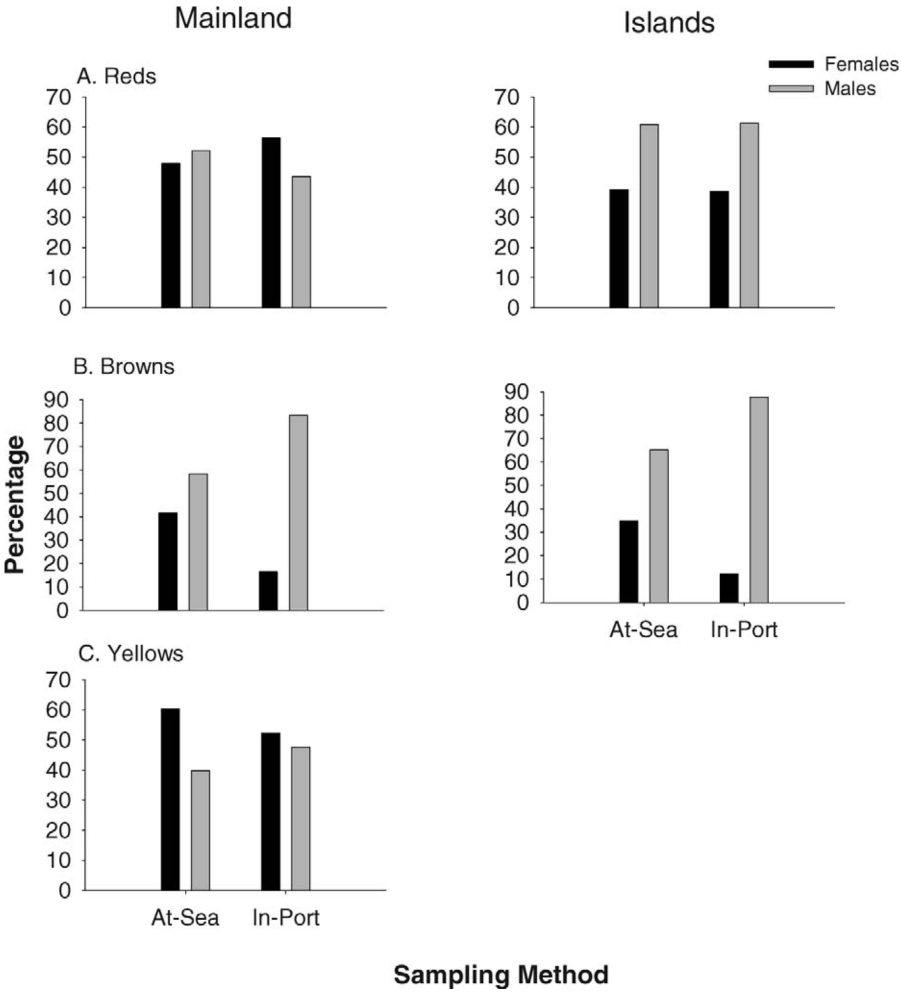

FIGURE 2.—Sex composition of **(A)** red, **(B)** brown, and **(C)** yellow rock crabs sampled from commercial catches along the mainland coast and the offshore islands of the Santa Barbara Channel. The scales vary; the data on yellow rock crabs from island catches are not shown owing to their paucity.

samples, although the sample size was small for this species.

For crab catches from the islands, the size distributions for red and brown rock crabs did not differ significantly among at-sea and in-port samples (red: $\chi^2 = 7.93$, $P = 0.16$; brown: $\chi^2 = 5.30$, $P = 0.07$: Figure 3A, B). Red rock crabs from the islands ranged between 130 and 190 mm in size. In contrast, the majority of brown rock crabs ranged in size from 108 to 150 mm. Only one sublegal (<108-mm) rock crab—a brown rock crab—was obtained in the island samples. Too few yellow rock crabs were obtained from the islands to conduct these analyses.

Discarded crab proportions and composition.—Overall, 39.7% of the crabs obtained along the mainland coast were discarded alive at sea. The percentages of discarded and retained crabs differed significantly among species for mainland coast catches ($\chi^2 = 70.16$, $P < 0.0001$; Figure 4), with the highest percentage of discards for yellow rock crabs (43.6%), followed by brown rock crabs (38.5%), and then red rock crabs (12.6%). The majority of yellow (64.5%) and red (92.0%) rock crabs were discarded because the shell or limbs were considered soft and unsuitable for the market (Figure 5A, C). Yellow rock crabs that were smaller than legal size (17.4%) or gravid (15.9%) were also discarded. Only a few brown rock crabs were obtained from the mainland catches ($n = 13$), and all individuals ($n = 5$) were returned because they were smaller than legal size (<108 mm CW; Figure 5B).

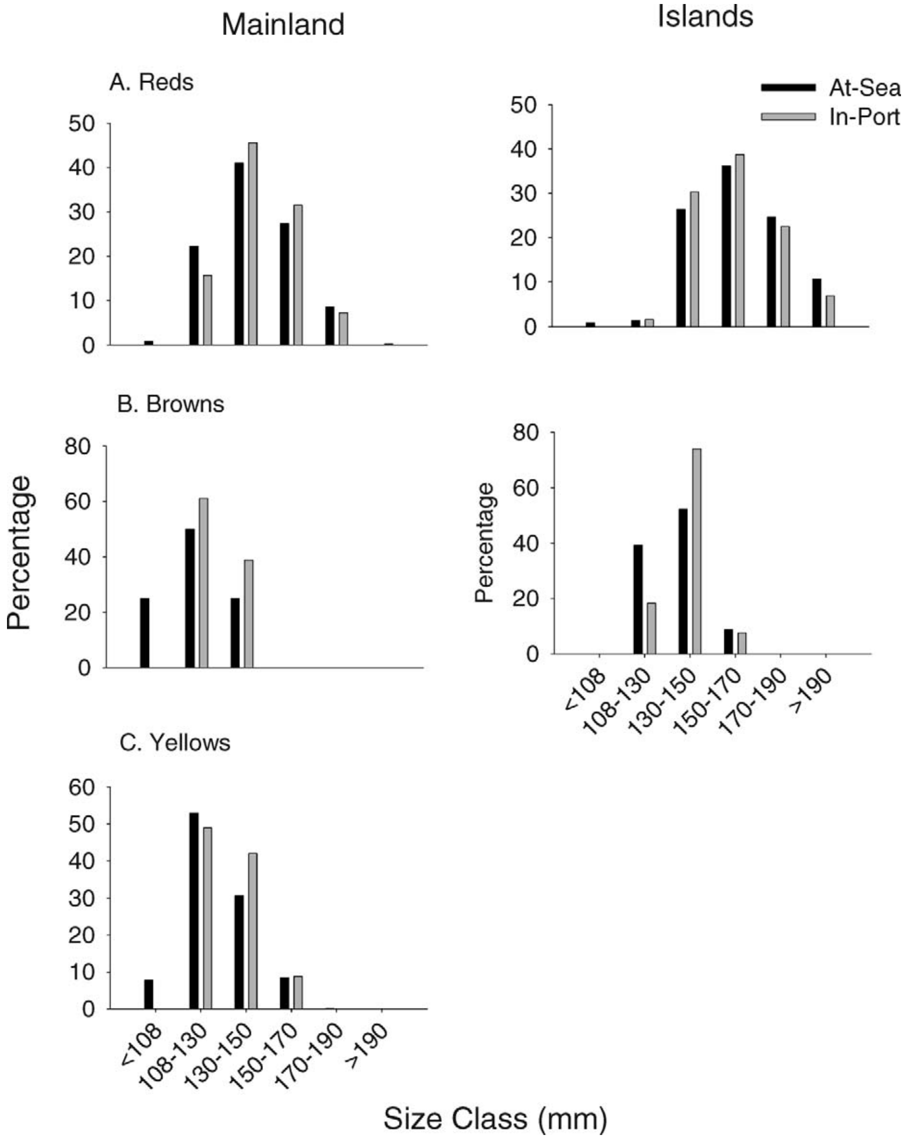

FIGURE 3.—Size distribution of **(A)** red, **(B)** brown, and **(C)** yellow rock crabs sampled from commercial catches along the mainland coast and the offshore islands of the Santa Barbara Channel. The scales vary; the data on yellow rock crabs from island catches are not shown owing to their paucity.

For the island catches, 28.5% of the crabs sampled overall were discarded alive at sea. The percentage of discarded crabs did not differ significantly between red and brown rock crabs ($\chi^2 = 0.053$, $P < 0.818$; Figure 4), with a majority of crabs (red: 71.7%; brown: 70.7%) retained from island catches. Soft condition of the crabs was noted as the primary reason for discarding both species (red: 41.9%; brown: 39.0%), but crabs were also often discarded because of discoloration, other shell imperfections (red: 33.6%; brown: 19.5%), or loss of one or both claws (red: 23.4%, brown: 24.4%; Figure 5). Too few ($n = 2$) yellow rock crabs were obtained in both at-sea and in-port samples from the islands to include in analyses, one crab being retained for market and one returned to sea because it had shell imperfections.

Stratified traps sampling protocol.—Catch levels varied between mainland and island catches. Nearly half (46%) of the traps of mainland coast catches contained 10–25 crabs per trap, another third of the

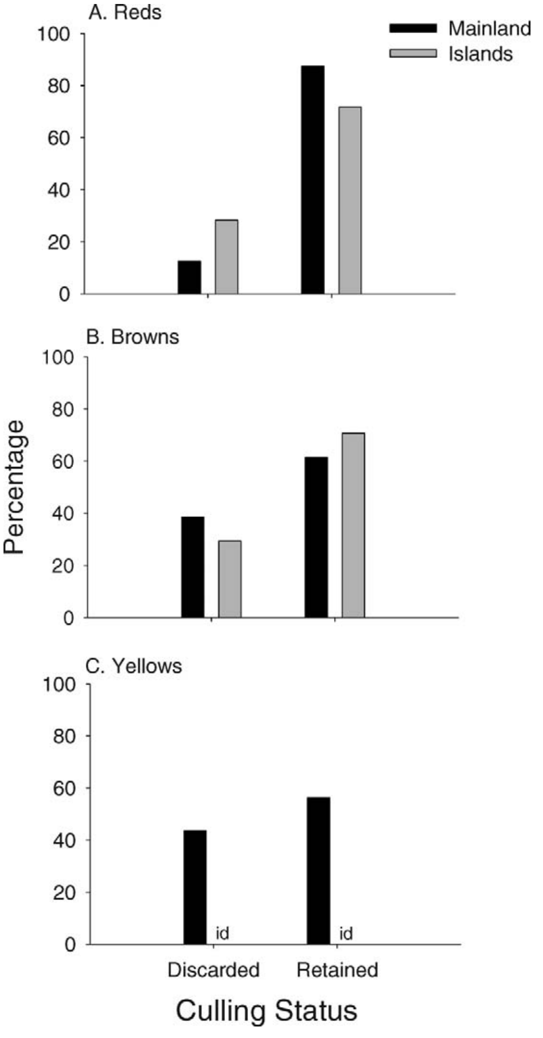

FIGURE 4.—Percentages of **(A)** red, **(B)** brown, and **(C)** yellow rock crabs from commercial catches that were discarded at sea and retained for market; id = insufficient data.

traps having more (>25) crabs. A small percentage (17%) of the traps had few (<10) crabs (Figure 6). The low catch level for mainland coast catches averaged 9 crabs per trap, ranging from 2 to 19 crabs per trap (Figure 6). An average of 22 crabs per trap occurred in traps assigned to the medium catch level, ranging from 7 to 40 crabs per trap. The high catch level for mainland coast catches averaged 35 crabs per trap, ranging from 20 to 54 crabs per trap.

Over half (54%) of the traps of island catches contained less than 10 crabs per trap (Figure 6). Almost all remaining traps (41%) contained 10–25 crabs per trap. Very few traps (4%) contained more than 25 crabs per trap in island catches. Traps assigned to the low catch level for island catches averaged six crabs per trap, ranging from 2 to 15 crabs per trap (Figure 7). The medium catch level averaged 13 crabs per trap, a minimum of five crabs and a maximum of 38 crabs per trap being included in this category. An average of 22 crabs per trap occurred in traps assigned to the high catch level, ranging from 10 to 48 crabs per trap.

Effect of sampling protocols on estimates of catch.— For mainland coast catches, sampling 12 traps per line provided the best estimate of the mean number of crabs per trap for brown rock crabs, a majority of the estimates (78%) being within the 95% confidence limits of the actual mean value (Figures 8, 9). The two times that this sampling protocol resulted in an over- or underestimate they were only slightly outside the confidence intervals (Figure 8). Catches of red and yellow rock crabs were equally accurately estimated using either the 12-trap or the stratified-trap design, estimates falling within the 95% confidence limits for 67% of the catches (Figures 8, 9). However, the degree to which these estimates were outside of the confidence intervals was generally small for only the 12-trap protocol, whereas the stratified sampling method greatly over- or underestimated the true (i.e., all-trap) mean for several samples. The four-trap protocol uniformly performed more poorly than the other two protocols, many of the estimates being well outside of the confidence intervals for the actual value (Figures 8, 9).

For island catches, the 12-trap sampling protocol was most accurate in estimating the mean number of red crabs per trap (Figures 8, 9), providing accurate estimates for 71% of the catches. In contrast, the stratified sampling protocol provided extremely poor estimates of the mean number of red rock crabs per trap, 71% of the estimates overestimating this value. The four-traps-per-line sampling protocol was only slightly better than the stratified method at estimating red rock crab catch for island samples, often (57%) underestimating crab catch. Two of the sampling protocols—12 and 4 traps per line—were similarly accurate (86%) in estimating the mean number of yellow rock crabs per trap, whereas the stratified sampling protocol significantly overestimated this value for two of the samples (Figures 8, 9). This was not the case for estimates of brown rock crabs from island catches, where the stratified traps provided accurate estimates of crab catch for the majority (86%) of samples. The 12-traps-per-line sampling protocol provided less-accurate estimates (57%) of brown rock crab catch, albeit the majority of the under- and overestimates being only slightly outside the confidence intervals. The four-traps-per-line sampling protocol was much less accurate (29% of means falling within the 95% confidence interval for all traps) than the other two sampling

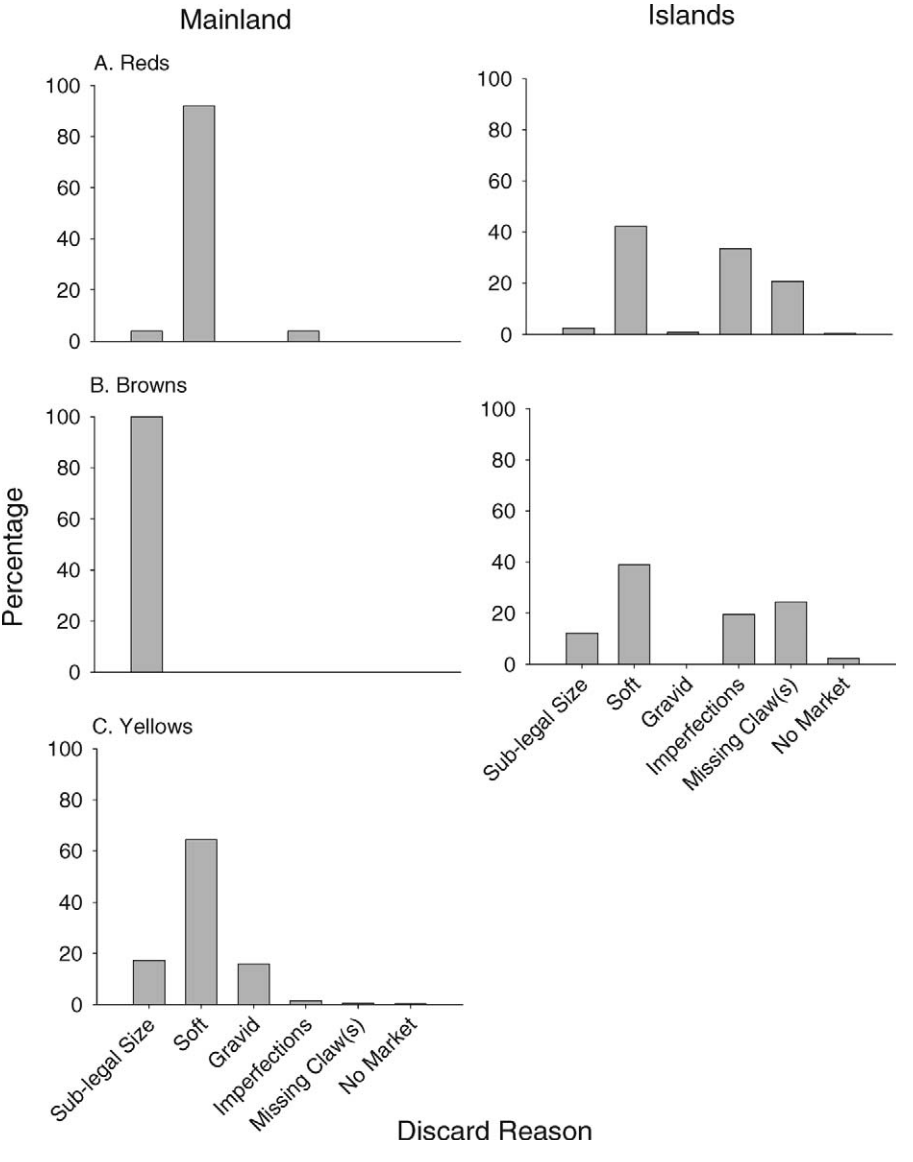

FIGURE 5.—Percentages of **(A)** red, **(B)** brown, and **(C)** yellow rock crabs from commercial catches that were discarded at sea for various reasons.

protocols, and there were both under- and overestimates that were sometimes quite significant.

Overall, for all species from both the mainland and islands, the four-trap and stratified protocols were outside of the 95% confidence interval of the all trap samples about 58% and 40% of the time, respectively, compared with the 12-trap samples that were outside of the 95% confidence interval only about 29% of the time. Notably, the degree to which these protocols over- and underestimated the catch for all traps was far smaller for the 12-trap protocol.

Development of a Framework

Accuracy and validation of data.—We obtained accurate data through the development of categories of information that were clearly defined and easily determined for crabs, including species, sex, whether an individual was retained or released back to sea, and the reason for discard. We also developed and incorporated the use of tools that minimized the potential for errors and variability in execution and made the data collection easier and faster for the participant. Most notably, instead of requiring crabs to

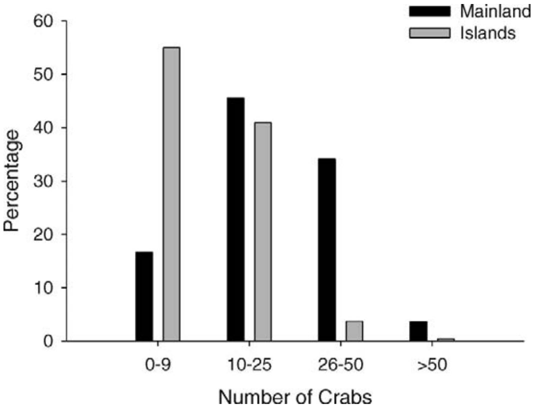

FIGURE 6.—Frequency distribution of the number of crabs per trap in at-sea catches.

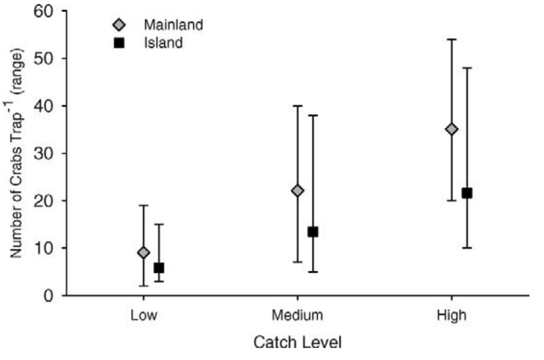

FIGURE 7.—Number of crabs per trap for stratified catch levels. The bars represent the minimum and maximum numbers of crabs per trap assigned to each level.

be measured with a caliper, we provided measuring boards typically used for fish. Our fishing partners evaluated the best locations for mounting the boards on their boats to increase convenience and ease of handling and measuring the crabs at sea. We also provided multistation hand tally counters to increase the accuracy of crab counts and discards for each species.

A comparison of the data collected by fishermen at sea for retained crabs with the data collected by us in port revealed that data were being collected accurately. The counts of the number of crabs kept at sea and brought to port differed, on average, from the number of crabs counted in port by only 3.5% for all samples. Two of the first round of samples were higher than the others (7.5% and 8.8%), and if these are removed from the analysis the counts differed by only 2.3%, ranging from 1.8% to 2.7% per sample.

Data management and sharing.—Our fishing partners fully (100%) supported the use of a third party in all aspects of data management, including data entry and analysis, and the housing and release of data. This type of system is used by other California data collection programs because of an unwillingness to share the data directly with managers. However, it was recognized that while this approach reduces the concerns of the fishermen, it does not address the needs of managers because the data are not readily available to them and thus cannot be integrated into management—the very reason for collecting the data. We identified the need for further discussions with managers to understand their requirements and needs for data management and sharing, including identification of "acceptable" third parties.

Our fishing partners (100%) expressed concern about the release of sensitive data (e.g., fishing locations) and the potential misuse of collected data by others. To address the first concern, we discussed the use of the "rule of three" (National Marine Fisheries Service 2006), a method widely used in fisheries and other disciplines. This rule requires that data be reported only in summary format (no raw data), and only when three or more data points are grouped together. This minimizes the chance for revealing confidential information about an individual's fishing activities. To illustrate use of the rule of three, we grouped catch information from this study by the broad categories of "mainland" and "island" catches to reach compliance with the rule. Three or more fishermen did not work in a similar area, covering a smaller spatial scale. Listing sampling effort on a finer spatial scale (e.g., by a specific island or mainland coastal site) would have revealed confidential information about an individual's fishing activities.

We also discussed the housing of sensitive data in a "confidential database" in which the data of concern would be coded and then placed into a "shared" database. For example, the highly sensitive geographic data on fishing locations could be converted into identification numbers for a broad area (similar to block numbers). Global Positioning System coordinates would still be needed for correctly identifying the initial location, assigning it to the appropriate broad location, and for allowing more detailed analyses when appropriate. However, these sensitive data could be treated as such and stored in a separate database, security measures being taken to minimize their unwanted release. This type of system that included the rule of three and coding of sensitive data were supported by all fishing partners.

We identified several steps that could be taken to minimize the potential misuse of data, including (1) requiring written details about the intended use of the

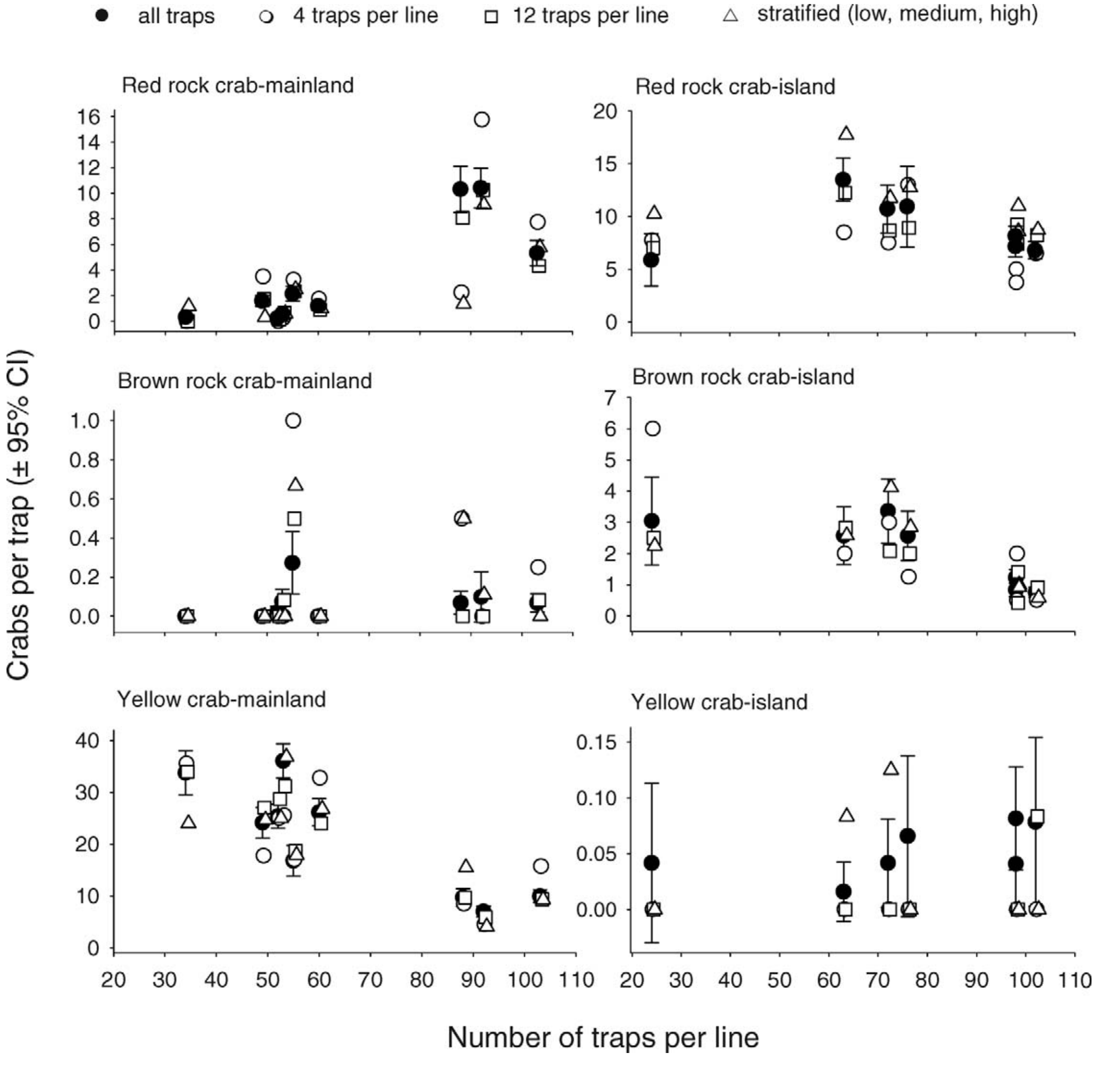

FIGURE 8.—Crab abundance estimates based on three sampling protocols compared with the actual catch from all traps; scales vary.

data prior to its release, (2) clearly defined statements about what analyses are appropriate for the available data, (3) defined limitations regarding the use of data for inappropriate analyses that may be anticipated, and (4) requiring review of the analyses and reports for their appropriateness prior to their release. Some ongoing programs, including one for the fishery for California spiny lobster *Panulirus interruptus*, have already incorporated some of these measures, including the development of a subcommittee for reviewing all requests for data and any reports generated from the data (C. Miller, personal communication). Our fishing partners fully (100%) supported the use of their existing fishing association for organizing such a subcommittee in a manner similar to the spiny lobster program.

Incentives, compensation, and funding.—Within our group of fishing partners, all (100%) indicated that a primary incentive for their involvement in a future collaborative data collection program was the ability to acquire data, allowing for more-efficient harvesting strategies that maximize profitability and resource sustainability (an average ranking of 3 in terms of importance). They were also very supportive of a data collection effort to facilitate science-based resource management versus a "precautionary" approach, the majority (80%) of participants rating this as very important. For those fishing along the mainland coast,

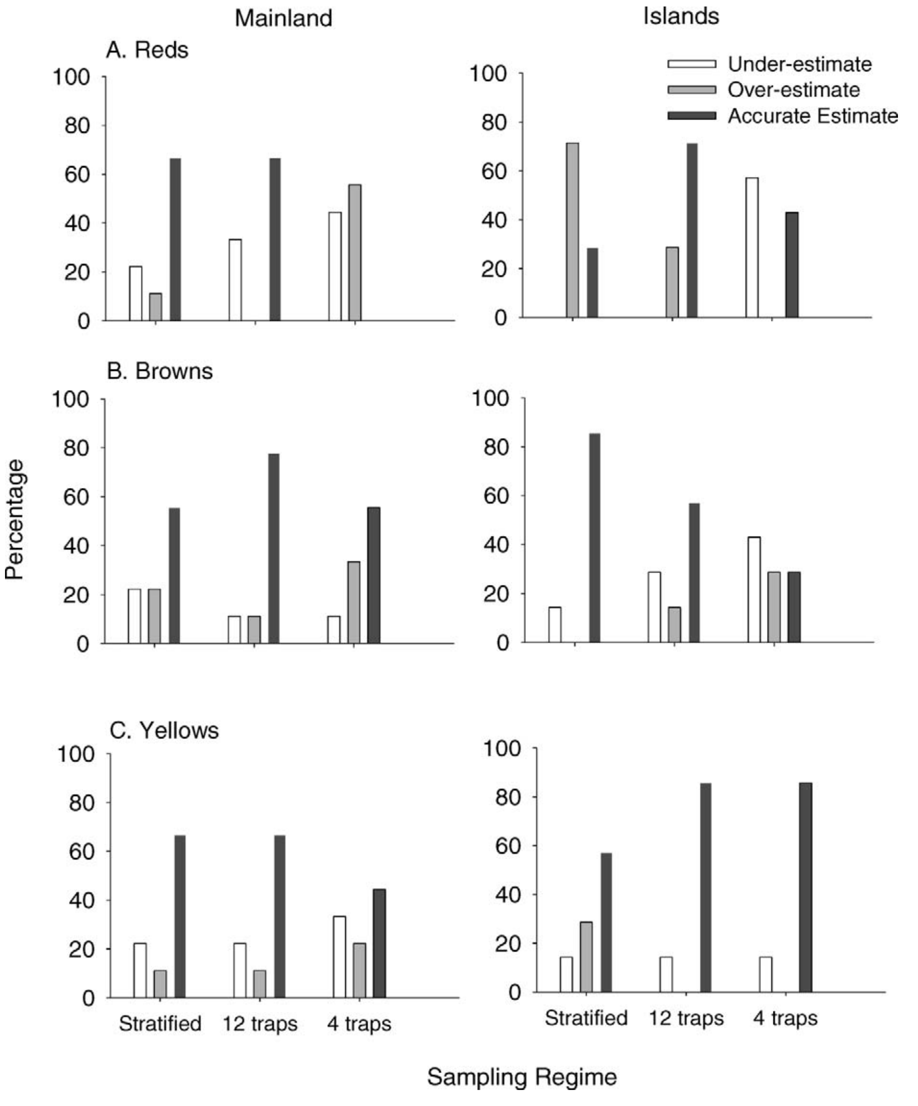

FIGURE 9.—Comparison of the accuracy of three sampling protocols for estimating the catch of rock crabs from commercial catches. The sample size was 9 for mainland catches, 7 for island catches.

collection of data was highly desired (average ranking = 3) for use in site selection, evaluation, and monitoring of upcoming planned coastal marine protected areas. Those fishing at the offshore islands found this incentive to be less desirable (average ranking = 1) because MPAs had already been established where they were fishing. Of low consideration (average ranking = 1.5) was the incentive of obtaining additional income for collecting data; they would all rather fish than collect data. One other incentive identified by our fishing partners was the ability to obtain detailed data about their individual catches that they could use for their personal business. We provided reports on individual catches to the associated fisherman, as well as provided an overview of the grouped data to all fishermen.

All (100%) fishing partners strongly supported the need for compensation to cover the expenses associated with collecting data. For this study, we agreed on an amount that covered the expenses of additional crew, fuel, and extra time at sea. Fishermen participating in our program lost fishing time when collecting data on their catch. They also noted an increase in fuel costs when collecting data due to the longer hours at sea. Further, they required the assistance of at least one other person. Those fishing along the coast found they needed two other people to collect data and handle the number of crabs they were catching. Even with this additional help, they often had difficulty completing the data collection and servicing their typical number of traps. Notably, we requested the collection of a fair amount of data for use in evaluating various sampling protocols. This intensive level of data collection would not be required once a program is implemented. With the rapidly increasing fuel costs occurring during this project, we also discussed the need to adjust the amount of compensation for future studies in light of the increased expenses.

Funding to cover long-term collaborative data collection programs was also discussed during our project meetings. In particular, we discussed the pros and cons of using two existing funding mechanisms: an industry-imposed landings tax (used in the sea urchin fishery) or membership fees of industry-based nonprofit associations (used in the squid fishery; Dewees et al. 2004; D. Pleschner-Steele, personal communication). On the positive side, the self-imposed tax system would provide a mechanism for having state oversight for and transparency of the program and for spreading the expense of the data collection program among all fishermen. However, a small percentage of the generated funds would have to be paid to the state as a type of administrative overhead. Also, the funds generated would vary with the annual landings such that lower landings will generate less money at a given tax level. Our fishing partners felt this could be problematic for a fishery that is small and does not generate large landings, such as the rock crab fishery.

Collection of membership fees through a nonprofit organization avoids the problem associated with the amount landed, but we identified other tradeoffs. On the positive side, revenue is not collected by the state and fishermen are more likely to be engaged in a program directly linked to a fishing association. However, others outside the fishing community may have less confidence in data that are collected, housed, and analyzed by a fishing organization. Further, this method requires that sufficient support for the program be generated among members within an association. For fisheries with few participants (restricted access) or participants that are only engaged in the fishery for part, or very little, of the season—like the rock crab fishery—it may be difficult to raise adequate funding through a voluntary association membership.

An alternative approach of having a data collection fee associated with fisheries permits was also explored. It was recognized that this fee would have to be collected and maintained in a separate fund specifically for data collection efforts, thus requiring development of new administrative processes. Further, an economic analysis of the costs associated with the data collection programs would be required to set the fee at a level that would adequately support the data collection efforts. Our fishing partners preferred this mechanism because it included contributions from all participants of the fishery, whether fishing or not or whether engaged in or supportive of the data collection program, because everyone in the fishery would benefit from the additional data.

Discussion

Our results for the southern California rock crab trap fishery suggest that collaborative data collection programs are a useful approach for acquiring essential fishery information that is not presently available for managing data-poor fisheries in California and elsewhere. Importantly, our data indicate that at-sea sampling is needed to provide more accurate information about the rock crab fishery and resource. Port sampling, a method often used to collect information for various types of fisheries, was not adequate for collecting essential information for this fishery because of the selective harvesting practices occurring at sea. Not surprisingly, there is considerable selection during the harvesting process (e.g., 30–50% of the catch from the mainland) to ensure landing of high-quality and high-value products. Crabs are discarded live and not landed for many reasons, the rate of selectivity varying throughout the year and by individual fishermen. These selection practices strongly influenced the type, sex, and size of individual crabs landed in port. Thus, the use of landings data, log books, or port sampling that provide data on only the harvested catch would likely lead to misinterpretations of the fishery and resource.

Implementation of an at-sea data collection program, where the catch is sampled prior to selective harvesting, raises new challenges. In particular, acceptable sampling designs must be integrated with day-to-day fishing practices so that they are not only sound scientifically but also cost-effective for the fishermen. One option to achieve this balance is to subsample traps from a day's catch using a sample size that accurately estimates the entire catch. Sampling of four preselected traps is being used in lobster sampling programs (Starr and Vignaux 1997; C. Miller, personal communication). However, we found that this sampling protocol provided the least precise and least accurate estimates of rock crab catches among the three sampling protocols examined in our study. The only time this method provided a good (yellow rock crab samples from the islands) or moderate (brown rock crabs from the mainland) estimate of the catch was when there were virtually no crabs collected. In all other cases, it was by far worse at providing an accurate estimate than the other two protocols. This, taken in combination with the occurrence of significant under- and overestimates when using this method, indicate that the sampling of just four traps will not be sufficient to accurately estimate the entire catch for the rock crab fishery in the Santa Barbara Channel region or other fisheries with similar catch profiles.

Subsampling 12 traps within three different catch levels ("stratified design" with high, medium, and low abundance of crabs) provided a reasonable estimate of the overall catch for the majority of species and locations. However, the accuracy of this protocol was strongly affected by the assignment of catch level by fishing partners. For example, the extremely poor estimate obtained for red rock crabs from island catches was due to an inappropriate assignment of catch levels to the three categories for these catches. The majority of traps (55%) contained very low numbers of crabs (<10 per trap), but in many cases traps with high catches (>10 crabs per trap) were categorized a priori as medium or even low catch levels. Consequently, the catch was overestimated when using the values obtained from the stratified traps. Similarly, the error of assigning an inappropriate catch level explained other over- and underestimates for this sampling method. For future efforts, collection of data on the catch levels per trap from particular areas prior to intensive data collection could be used to define appropriate high, medium, and low catch levels.

The protocol of sampling 12 traps also generally provided a good estimate of the overall catch. Estimates of catches of brown crabs at the islands were the least accurate, although only slightly outside of the 95% confidence intervals. In fact, all of the over- and underestimates calculated using this sampling protocol were just outside of the 95% confidence intervals. This finding suggests that while this estimate may vary somewhat, it was overall fairly consistent and reliable as an estimate. Based on these data and the issues associated with the a priori selection of traps of high, medium, and low catch levels, we recommend a protocol of sampling 12 traps for future data collection programs for rock crabs and for fisheries with similar catch profiles (i.e., high number of traps used or large number of individuals per trap). A more general guideline for sampling may be that no less than 10–15% of the traps should be sampled. Evaluations of catches in other trap fisheries using this protocol will help assess how widely this sampling design may be applied.

Additional research is required to more thoroughly define other aspects of the sampling design. In particular, the frequency and timing of sampling still needs to be determined. We also need to identify the number of participants necessary on a regional and statewide basis to obtain data on an appropriate spatial scale while protecting issues of confidentiality. Profiling fishing activities conducted by those that are willing to collect data will help determine when, where, and how often fishermen might be engaged in data collection efforts.

Program Framework

There is still a need to develop well-defined guidelines and design additional infrastructure and administrative procedures to advance the implementation of collaborative fisheries data collection programs in California. These additional steps are not viewed as obstacles but simply as hurdles that, once cleared, will facilitate the wide adoption of this method. Key elements that we recommend for California-based programs include (1) scientifically sound goals, with associated data collection methods and protocols that are accepted by the DFG and others; (2) hands-on training and recertification programs for participants; (3) validation of the collected data; (4) well-defined procedures for handling confidential data; (5) sufficient compensation and an adequate funding source; and (6) timely and consistent reviews of the data, with subsequent actions as needed.

As with any research and monitoring effort, there must be a clearly defined goal for why data are being collected and how they will be used. That is, there should be agreement on how the fishery will be analyzed before data collection efforts begin. This first step will drive the development of the data collection protocols, identifying those data that are needed to meet the goal(s) of the program.

Once a goal has been agreed upon, the use of independent, scientific peer-review of methods and protocols is recommended for illustrating transparency and gaining support from all interested parties. This is particularly important for long-term monitoring efforts and data that will be used for specific management actions, as in this case. In fact, a peer review process was used for a collaborative data collection effort that will inform evaluation of the potential reopening of a commercial abalone fishery in south-central California (Culver, personal observation). Methods and protocols should be well defined, easy to follow, and readily and easily integrated into fishing activities, which will be best achieved through collaborative development with fishing partners. Hands-on training courses will ensure that each participant clearly understands and performs the necessary tasks. Annual recertification courses could also be used to illustrate that participants are using the appropriate protocols and methods. A minimum of an annual validation of the data as a type of certification for each data collector may also improve the acceptability of the program. Validation events could occur more frequently; however, this may be an unnecessary expense if data collection methods and protocols are well defined and easily carried out. The sampling program used in our study was designed with these issues in mind, and accurate data were collected and validated through in-port sampling.

Fishery data, no matter how accurate, are of limited utility unless they are made available to and incorporated into the management process. While the DFG has indicated support for and often participated in discussions of ongoing programs, no formal agreements supporting the data collection efforts or actual integration of the data into fisheries management have apparently occurred. In some cases, more data may be needed before the information is useful for management. In other cases, data sharing and analyses have not been worked out. No matter what the shortcoming, the lack of formal approval by the DFG of the program design in writing (e.g., memorandum of understanding) early in the process may hinder use of the data for management if there is no buy-in to the program.

Meeting the needs of both groups for managing and sharing the data will require new infrastructure and administrative steps. First, data will need to be housed at a specified location that is agreed upon by all parties. Second, a person will need to be appointed for quality assurance and quality control of the data. Given the trust issues existing between fishermen and managers in California as well as elsewhere, it is likely a third party may have to be designated for this task, as is evident in ongoing collaborative data collection programs. However, discussions regarding "acceptable" third parties are critically needed. Third, procedures for identifying, completing, and reviewing data analyses (with identification of follow-up actions in accordance with the results) will need to be developed on a fishery-by-fishery basis. While this has often been left to the person overseeing the data, it will be critical to collaboratively define the ultimate goals of the data collection effort upfront and identify the appropriate data to be collected and methods for analysis. This step is essential for ensuring that the data are used and incorporated into the management process, allowing for adaptive management.

Additional administrative procedures will also be needed to address issues of compensation. The amount of compensation that fishermen may receive for collecting data are currently unresolved, and it is an issue of considerable debate. Some, but not all, data collection programs in California have provided compensation in undisclosed amounts for participants. Adoption of this management method more broadly in California may require development of guidelines for determining a standardized level of compensation for such programs. Recognizing that costs will vary from program to program because of differences in the required sampling effort, these guidelines could simply define the types of expenses that may be considered for compensation. Amounts of compensation for each type of expense could also be outlined, a mechanism for updating the amounts based on changing financial conditions.

Obtaining and distributing funds for a collaborative data collection effort can be achieved through various mechanisms. Based on our results, we recommend having a fee added to fisheries permits with the added funds earmarked for data collection efforts. This fee would likely vary from fishery to fishery, being dependent on the sampling design (including the number of participants, the frequency of sampling, and the agreed-upon compensation for collection efforts).

Application of Program

Implementation of a collaborative data collection program as we describe here could be broadly applied to numerous trap-based fisheries to extend collection of essential fishery information to other cryptic benthic species. Identifying the number of traps typically serviced and the expected catch levels for the traps will be required to determine whether the sampling design (12 traps) recommended by our results would be adequate for these fisheries. Other components of the program may also need to be adapted for specific fisheries. For example, fisheries with confined seasons (e.g., lobsters) may require more frequent collection of data while the fishery is open. Alternatively, approval of collection of data by specific participants when the fishery is closed may be needed; this may be best integrated with the training and recertification processes of the data collection programs. The number of participants needed should also be evaluated on a fishery-by-fishery basis because of the varying spatial scales of the fisheries.

One important consideration is whether commercial traps could provide data useful for ecosystem-based monitoring as well as fisheries. Species targeted by trap fisheries are predators that potentially have important communitywide effects, and thus knowledge of their distribution and abundance would offer data important for ecosystem-based evaluations. Our study recorded relatively little bycatch associated with commercial crab traps, suggesting the use of this gear may be limited for sampling nontarget species. Catches are likely limited by the size, shape, and location of the trap entrance and escape ports. Clearly, different types of traps are used to catch specific target commercial species. This fact further supports the need for a new or modified trap design that can adequately sample multiple species if ecosystem-based monitoring is desired. Alternatively, underwater video recorders could potentially be used to assess a broader range of animals approaching or moving in and out of the traps. Other cryptic benthic organisms are undoubtedly attracted to the traps, but they either cannot get in through the trap entrance or they leave the trap through the escape ring prior to the trap being serviced. Use of underwater video cameras may offer a methodology for assessing populations and communities of cryptic benthic organisms while avoiding the sampling biases inherent in traps. Combining various sampling techniques may also provide a means for enhancing the utility of commercial traps for monitoring marine systems. In particular, monitoring settlement with appropriate substrates provides a fishery-independent measure of stock health (Schroeter et al. 2009b). This type of monitoring could easily be incorporated into fishing activities.

Similar data collection programs could also be developed for fisheries that employ different gear (e.g., dive, hook–pole and line, trawl), protocols being adapted to the fishing practices. These programs would be particularly useful for fisheries targeting species that are not included in existing monitoring programs or to support new, emerging fisheries. In the latter case, a different funding mechanism might be required if a specific permit is not required for the emerging fishery or if there are few participants in the fishery.

Costs and Benefits

Collaborative data collection programs have clear advantages over many other data collection methods. As many have noted (Parma et al. 2003; Schroeter et al. 2009a, b), engaging fishermen in the collection of data greatly enhances the amount of information that can be collected within a small amount of time and over a large spatial scale. Fishermen are at sea much more frequently than managers or researchers. As long as the data are accurate and trusted, everyone—fishermen, managers, scientists, and the public—will benefit from having more information for use in managing fisheries and marine resources in general. Equally beneficial is the vast knowledge of the ocean environment and specific organisms that fishermen can contribute to the design of a program and interpretation of resulting data. For example, many fishermen have observed the influence of certain environmental parameters on their catch. Incorporating ways to measure these parameters in a data collection program could help evaluate these observations and may potentially reveal factors that should be considered in interpreting the collected data. Importantly, collaborative data collection programs can provide data over a longer time scale. Once established and running, such a program will provide data as long as the fishery exists. This is highly valuable given the long-term and often episodic effects of shifting ocean regimes on marine populations. Engaging fishermen in the collection of data may also reduce the ecological impacts by taking advantage of activities that are already ongoing. Clearly, this type of program will enable communities to become more involved in the management of their local fisheries.

The economic benefits and costs of collaborative data collection to managing agencies and the fishing industry will differ from those of other data collection methods. Managers will benefit by obtaining access to more data using fewer state resources (e.g., personnel, analyses, vessels, some supplies). These data will have greater spatial and temporal coverage than could be feasibly obtained directly by the agency. Fishermen would bear much more of the economic burden, having to contribute time to not only collect the data but also to participate in discussions of data analyses and interpretations. Using the recommended framework, they would also sustain much of the financial burden of the program. Nonetheless, by contributing their knowledge and skills to the collection of more comprehensive and current data than are presently available to fishery managers, they will realize benefits from long-term sustainability of the fisheries they rely on for their livelihood.

Conclusions

We have illustrated the feasibility of using collaborative data collection programs for obtaining essential fisheries information for trap fisheries. These data may prove useful not only for managing fisheries, but also for evaluating MPAs and ecosystem health. The framework provided could be adapted more broadly to include fisheries of all types. Broad application of collaborative data collection programs in California will depend on the ability of managers, fishermen, and scientists to work together and develop programs that integrate scientifically robust and efficient protocols and associated training with a framework that supports long-term quality data management and sharing of results with decision makers such that the data are incorporated into the management process. While hurdles still exist, management of valuable marine resources would clearly benefit from careful development and implementation of collaborative data collection programs.

The timing may be well suited for adopting this method as a management tool because the state is considering the development of a Collaborative Fisheries Research Institute (Gamman and Poncelet 2008). A new institute could be ideal for addressing the administrative, infrastructure, and regulatory procedures needed for successful application of collaborative data collection programs, including a mechanism for (1) collecting and distributing funds to cover the costs of the program, (2) gaining state support and endorsement that the programs are scientifically robust and the data will be used for management, (3) permitting collection of data during closed seasons or in light of other restrictions, and (4) developing guidelines regarding handling of confidential data, sharing of data, and compensation. If such an institute was developed, it could also act as a catalyst by providing funds necessary to bring collaborators together to develop and test effective and efficient sampling methods and protocols.

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