Comparisons of Sampling Methods for Surveying Nearshore Fishes: Collaboration between Fishermen, CDFG, and University Scientists

Final Report to the Commonweal Ocean Policy Program

by

Rick Starr, University of California Sea Grant Extension Program
Mark Carr, University of California Santa Cruz
Ashley Greenley, Moss Landing Marine Labs
Dan Malone, University of California Santa Cruz

25 October 2006

Summary and Implications

The California Marine Life Management Act and Marine Life Protection Act have created an increased interest in the development of fine-scaled fishery management plans. Currently, however, little information exists with which to manage fisheries in relatively small sections of the coast. One way to gather data appropriate for fine-scale management is to use a variety of information sources and sampling methods. We have been working with fishermen, and university and agency scientists since 2003 to compare various surface fishing and SCUBA sampling methods, and learn more about population sizes and movements of nearshore fishes.

Primary Results

- In a 1 hour-long time period, two SCUBA divers were able to complete 6 transects (30 m long), and fishers were able to deploy and retrieve 10 sets of sticks or traps.
- SCUBA surveys accounted for more species (31) than all fishing gear combined (18), but fishing gear caught some species that were not seen by divers.
- Stick fishing gear recorded the second largest number of species (16), including three species that were not sampled by either traps or handlines.
- All of the species that were caught with fishing gear are commercially important, but some recreationally important species were not sampled by fishing gear (e.g., sea perches and sheephead) with the sampling effort employed in this study.
- Estimates of rank order of relative abundance of commercially important species were different for each type of sampling gear.
- SCUBA gear required the fewest number (11) of samples to account for the nine most abundant fished species, whereas fishing gear ranged from 48-182 samples to account for the nine species.
- The number of samples required to obtain a greater than 95% probability of seeing at least one individual lingcod ranged from 26 samples (30 m transect) for SCUBA gear, 29 samples (1 hour fishing) for handlines, 95 samples (1 stick) for sticks, and 503 samples (1 trap) for traps.
- The number of samples required to obtain a greater than 95% probability of seeing at least one individual cabezon ranged from 44 samples for SCUBA gear, 161 samples for traps, and 274 samples for sticks. Cabezon were not caught on handlines.
- Estimates of catch per hour (CPUE) from commercial fishing gear in nearshore kelp and shallow rock habitats were highly variable.
- Estimates of relative abundance were influenced by swell height. There was an inverse correlation between swell height and CPUE estimates.
- After 16 sampling days, we observed no evidence of a statistically significant relationship among estimates of CPUE for any combinations of sampling methods.
- Sticks and traps caught relatively more bottom-oriented species, whereas handline and SCUBA sampling recorded a higher proportion of species such as blue and black rockfishes that inhabit the middle of the water column.
- Habitat and depth influenced significantly the relative differences in CPUE generated by different sampling methods.
- Within a location, SCUBA and fishing gear methods yielded similar estimates of mean lengths of most species (for fishes over 20 cm long).
- Estimates of mean length of species differed significantly between the two study sites.

- Where differences in mean lengths were observed among locations, they were observed similarly by all sampling methods.
- SCUBA sampling resulted in broader estimates of size distributions than fishing methods, both above and below the mean.
- The combined fishing and diver mark-recapture analysis resulted in the highest population estimates for the semi-pelagic species such as blue rockfish, kelp rockfish, and olive-yellowtail rockfish in the north (low-relief) site and for 6 of 9 species at the south site. No cabezon or kelp greenling were recaptured or re-sighted, thus, expansions of diver densities was the only method of obtaining an estimate of population size for these two species.
- Fish tagged with dart tags in each study site were not seen or caught outside the tagging site.
- Most fish tagged with acoustic transmitters exhibited relatively little movement.

General Conclusions and Implications

- Many of the species observed by SCUBA that were not sampled by fishing gear were not fished species, but are important if a management goal is to characterize the nearshore assemblages for purposes of ecosystem-based management.
- Because of differences in the area (volume) sampled by each method, SCUBA sampling requires fewer samples to obtain an estimate of the true structure of the fish assemblage in nearshore rocky reef or kelp habitats.
- It takes less time and fewer samples to arrive at an estimate of the assemblages of commercially important fishes with SCUBA than with fishing gear. For example, to arrive at the 11 samples needed to account for the 9 most abundant commercial species, it would take 2 hours of SCUBA sampling compared with 7, 16, and 18 hours with sticks, handlines and traps, respectively.
- To our surprise, SCUBA surveys were more effective at encountering lingcod and cabezon than fishing gear than we previously believed. Nonetheless, fishing gear is more efficient at sampling some species (e.g., grass rockfish, wolf eel). For this reason, a sampling program that uses both fishing gear and SCUBA sampling will likely result in the most comprehensive description of nearshore assemblages.
- We have not yet found a significant correlation among the CPUEs of different sampling methods, suggesting that CPUE estimates of individual species will have to be generated independently by each of the sampling methods. It is possible that such correlations could be identified with greater sampling effort. However, to do so would require a very large, coordinated sampling effort among divers and fishers.
- The estimates of CPUE generated by the different sampling methods were significantly influenced by habitat and depth. Thus, a CPUE generated by one sampling method in one habitat cannot be compared directly with another CPUE estimate generated by a different method in a different habitat.
- The mean lengths of species were similar among sampling methods, and the size frequency distributions estimated by fishing gear were not significantly different. However, for many species, the size frequency distribution estimated by SCUBA differed from the fishing gear. This has important implications if a size or age structured model is used to estimate population abundance of nearshore species.

- For bottom dwelling species, the highest estimates of abundance were obtained from fishing gear. This makes sense given the focus of the fishing gear on the bottom.
- For semi-pelagic species, the combined estimates of fishing and diver surveys generated the highest tag-recapture estimates of population abundance. This also makes sense as fishing gear is limited in the number of individuals that can be caught per sample, whereas divers can count hundreds of fish at a time. This ability of divers to count large numbers at one time also has the effect of reducing the tagged to untagged ratio and thus increasing the population estimates of schooling fishes.
- For most species, the population estimates based on expansions of diver densities were smaller than tag-recapture estimates of abundance. However, the expansion of diver densities provided the only estimates of population size for cabezon and kelp greenling because neither species was recaptured nor re-sighted in sufficient quantities to generate Schnabel tag-recapture estimates of abundance.
- Abundance estimates generated by expansion of diver densities had greater precision (i.e., tightest 95% confidence intervals) than any tag-recapture estimate. The precision of abundance estimates generated by fishing gear was greatest when tag-recapture information from all fishing gear was combined.
- The precision of abundance estimates was greater in the high-relief study site than in the low relief site for handline and SCUBA gear. This may reflect greater habitat patchiness resulting in more patchy species distributions in the low relief area.
- In contrast to stick and trap sampling, spatial patterns of CPUE (i.e., north vs. south site) generated by SCUBA and handline methods more frequently reflected similar differences as those seen in abundance estimates (from tag-recapture data) between the two sites. This suggests that the CPUE estimates generated by handlines and SCUBA are more accurate indicators of relative abundance than either sticks or traps. However, this result varies by species.
- Both the tag-recapture data and acoustic tagging data showed that the species we studied have high fidelity to the study sites.

Introduction

In June 2002, the Pacific Fishery Management Council (PFMC) closed ocean waters south of Cape Mendocino, California to the harvest of all shelf rockfish species between depths of 20 – 100 fathoms because of the population status of a few depleted stocks. The inshore and offshore boundaries of the rockfish conservation area (RCA) have changed annually, but since that time, there has been no commercial or sport fishing for benthic species on the continental shelf in waters deeper than 20 – 30 fathoms. As a consequence of creating the RCA, however, fishing pressure on species in waters shallower than 20 fathoms has greatly increased. These shallow water species are managed by the state of California.

The California Marine Life Management Act (MLMA) requires the California Department of Fish and Game (DFG) to actively manage nearshore fisheries to ensure conservation of nearshore species, reduce bycatch, protect habitat, and obtain estimates of abundance. Additionally, the development of MPAs in California requires an understanding of community structure and populations on a fine geographic scale. A problem, however, is that little information exists with which to estimate abundance or trends in abundance of nearshore species, and it is difficult to develop appropriate regional management plans without sufficient information about fish population sizes. Despite the lack of information about nearshore species, the MLMA requires that DFG develop fishery management plans that are based on the best available scientific information.

Typically, fishery managers use fishery-dependent data and/or fishery independent surveys to estimate population sizes of marine species. Currently, however, relatively little fishery-dependent or independent information is available to evaluate nearshore fish populations. The DFG has started to collect landings, logbook, and other fishery-dependent information, but it will be many years before sufficient fishery data are collected to determine trends in catches or catch rates along the coast. In recognition of the need for more immediate information, the DFG, in conjunction with other marine scientists, developed a standardized protocol for visually assessing nearshore fishes and invertebrates. The visual surveys, conducted by SCUBA divers, are designed to provide information about relative abundance of species occurring in rocky habitats from about 5 – 20 m deep.

The strategy of combining fishery-dependent and fishery independent information is intriguing, but contains several logistical challenges. The primary challenge is to understand the relationships among spatial and temporal variability and the biases associated with each sampling gear. As both fishery-dependent and independent information are collected, it is important to understand what the data represent, i.e., how the different sampling techniques relate to one another, how they are affected by environmental variation, and how they vary in time and space. Ideally, all sampling methods would provide similar trends in density or abundance, even though the numerical values might be different. If the sampling methods produce similar trends, then a scaling factor could be developed and applied for each method to standardize results among methods.

Before a scaling factor can be developed, however, it is necessary to determine if the sampling methods produce similar trends. One key consideration for the comparison of species composition, abundance, or CPUE estimates generated by different sampling methods is whether their relative sampling efficacy differs among depths or habitat types. For example, if estimates of fish abundance by both fishing gear and SCUBA surveys decline in habitats with greater kelp density or topographic complexity, then a scaling factor could be developed to estimate the numbers of fish divers would see in any area sampled by fishing gear. Conversely, if estimates of fish abundance by SCUBA divers decline in habitats with greater kelp density or topographic complexity, while estimates of CPUE from fishing gear do not, the relative estimates generated by these methods will vary among sites that differ in depth or habitat. In this case, estimates of population characteristics would need to be corrected or scaled for each of these habitat-specific differences among the sampling methods. Recognizing these differences in relative sampling efficacy among habitats and depths would be critical to integrating estimates of species composition, abundance and CPUE across habitats and depths to generate regional estimates of stock dynamics.

In 2003, we conducted a study that was funded by Commonweal Ocean Policy Program to compare estimates of CPUE of typical nearshore commercial fishing operations and estimates of fish density derived from SCUBA surveys. In collaboration with the DFG and two nearshore commercial fishermen, we conducted standardized fishing and diving operations at similar habitats in Carmel Bay for 16 days. Our 2003 study showed that surfaced based sampling and divers surveys each had strengths, weaknesses, and biases for the objective of estimating species, size composition, and relative abundance of nearshore species. The study also showed that catch rates of different gear types are highly variable over short time scales, often due to oceanographic conditions such as wave height. This high variability makes it difficult to combine both SCUBA density estimates and fishing CPUE to establish trends in relative abundance on a coast-wide basis, because many more sampling days would be needed to develop a correlation among sampling techniques than is logistically feasible. A key aspect of that study was the intent to compare differences in estimates generated among sampling methods, but not to determine which of the methods provided a more accurate estimate of the true populations. That study was not designed to compare relative accuracy of the estimates.

In 2005, we developed a project to provide information about the relative precision and accuracy of estimates of CPUE and abundance of different sampling techniques in different habitats. In 2005, we designed studies to address two questions:

- Do the relative CPUE of different sampling methods (sticks, traps, handlines, divers) differ by habitat or depth?
- Do surveys conducted with any particular fishing gear or by divers more accurately or precisely estimate abundance of fish in an area, when compared to abundance estimates from mark-recapture surveys?

Our primary objectives in 2005 were to estimate the relative accuracy of CPUE of each sampling method by comparing the relative CPUE of each sampling method with relative abundance estimates generated from mark-recapture surveys. Accuracy was determined by the degree to which patterns of CPUE corresponded with abundance estimates among species, sites and depths. We also examined the relative precision of each sampling method by the error (i.e. variance or standard error) associated with each mean CPUE. Additionally, we investigated the effects of habitat, depth and fish movement in understanding both CPUE and abundance estimates.

To determine whether relative estimates of species composition, abundance, and CPUE generated by different sampling methods vary among habitats, we conducted gear comparisons at two sites that differ markedly in relief and topographic complexity of rocky reef habitat. To determine whether relative estimates of species composition, abundance and CPUE generated by different sampling methods vary with depth, we conducted gear comparisons across the depth range encompassed by the two sampling sites. We also examine the combined effects of habitat and depth on the relative estimates of the three variables.

Methods

Study Site

To determine whether the relative estimates of species composition, abundance and CPUE generated by different sampling methods vary among habitats and depth, we conducted gear comparisons across the depth range encompassed by two sites that differ markedly in relief and topographic complexity of rocky reef habitat. We chose two study sites in Carmel Bay, just west of Carmel, California, that each contain a different type of nearshore habitat, but in the same depth range of 10 – 25 m (Fig. 1). We used multibeam surveys of the sea bottom of Carmel Bay conducted in 2005 by Dr. Rikk Kvitek of the California State University Monterey Bay's Seafloor Mapping Center to identify two study sites with contrasting rocky reef habitat (Fig. 2). The northern site is characterized predominately by low-relief rock habitat, interspersed with coarse sand flats, that contains patches of kelp (*Macrosystis pyrifera*) associated with low (< 2 m) rock outcrops. The southern site is characterized by continuous high-relief (2 – 8 m) granitic rock habitat covered with a dense kelp forest. The northern site is surrounded by expanses of sand bottom on all sides, whereas the southern site is surrounded by contiguous high-relief rocky habitat that extends into the Carmel canyon. The area encompassed by the northern study site is 65,536 m^2 and the area of the southern study site is 35,920 m^2.

Fishing Estimates of Species Composition and CPUE

Surface fishing operations were designed and implemented to meet four specific objectives, (1) work collaboratively with commercial fishermen, (2) gather more information about CPUE of several types of typical fishing gear, (3) place dart tags in captured fishes to enable us to generate tag-recapture estimates of abundances of fishes, and (4) place sonic tags in selected fishes to track movements of fish associated with each study site. We worked with Mr. Giovanni Nevoloso and Mr. Sal Pitruzzello, two fishermen from Monterey who have more than 50 years combined experienced fishing in nearshore habitats. At the start of the project, we discussed the goals of the project with and talked with them about the best ways to achieve our desired objectives. They helped us identify sampling locations, catch and tag fishes, and explained their typical methods of fishing.

We fished for 4 – 6 hours per day (from about 07:30 – 13:30) for a total of 15 days at each study site in July and August, 2005. Each vessel fished at only one site each day and vessels alternated sites each trip. Fishing gear used included traps, handlines, and stick gear. Typically, one vessel fished traps at one of the study sites, while the other fished handlines and sticks at the other site. The commercial fishermen distributed fishing effort throughout the study site each trip, in order to sample each portion of the study site each day. Other than being asked to fish in all parts of the study site, the decisions about where and how to fish were left to the fishermen. Each fisherman used techniques (e.g., bait, soak time, type and number of hooks, traps, or sticks used) commonly used in commercial fishing operations. Handlines consisted of a weight (approximately 1 kg) and two baited hooks on 40 kg-test fishing line. Traps were deployed singly or on a string of two traps, and usually 10 traps were deployed at a time. Sticks were deployed on single lines and buoys and contained 5 hooks per stick. We usually deployed 10 sets of sticks at a time. We typically soaked sticks and traps for an hour. Traps were baited with squid and anchovies, whereas sticks and handlines were baited almost exclusively with squid.

All captured species were measured and released at location of capture. We collected information on species composition, size composition, sex (when possible), and the fishing time and depth at which each unit of gear was fished. Actual depth ranges sampled by the different sampling gears at the north and south sample sites were 6-18 m and 5-20 m for handlines, 6-18 m and 6-26 m for sticks, and 4-18 m and 4-22 m for traps, respectively. Additionally, we placed external dart tags in selected fishes. Dart tags were color-coded based on the type gear used to catch the fish and the location (north or south site) of release.

For stick and trap fishing gear, CPUE was calculated by dividing the number of fish caught on an individual stick or trap by the number of hours the gear was deployed. CPUE of handlines was calculated by dividing the number of fish caught per angler by the time fished. During the study, if the anglers using a handline did not catch fish within the first couple of minutes, the skipper relocated the boat and fishing continued in a different spot, frequently one that was only a few meters away. Often, these short (< 3 min-long) periods were not recorded, or were included as one longer session, which ultimately resulted in very few values of zero for CPUE from handlines and thus higher CPUE estimates.

Diver Surveys of Species Composition and CPUE

Diver surveys were designed and implemented to meet three specific objectives, (1) characterize the habitats of the two sites used in the study, (2) estimate the density and size structure of the fish assemblage at the two study areas using visual strip transects, and (3) generate tag-recapture estimates of abundances of fishes based on the re-sighting of tags by divers.

Each of the two study sites was sampled two times (13 – 16 July 2005) before any fishing occurred, and two times after fishing occurred (15 – 19 August 2005) using a depth-stratified sampling design (Fig. 3). Actual depth ranges sampled by the divers at the north and south sample sites were 9-19 m and 8-21 m, respectively. On each sampling day, pairs of divers surveyed 24 transects, each 30 m long by 2 m wide by 2 m high, and recorded the species and estimated total length (TL) of all non-cryptic fishes (i.e., excluding fishes such as small sculpins and kelpfishes) observed along each transect. One diver searched for fishes along the bottom, while the other surveyed the middle of the water column. This sampling design produced 24 independent replicate estimates of density for each of the two survey periods (pre- and post-tagging). CPUE of SCUBA surveys was calculated as the mean number of fish seen per 60 m^2 transect, i.e., the density of fishes seen on transects.

After the surface tagging of fishes was finished, divers also recorded the numbers of tagged fishes observed. In addition to counting tagged fishes on the visual strip transects, divers conducted haphazard surveys on four other days to estimate tagged-untagged ratios of fishes. On those days (22, 23 August, 28 September, and 5 October), pairs of divers divided each study area into shallow and deep halves and counted tagged and untagged fishes. Divers used dive lights to identify and record the color of each tag. Because the tagging effort included mid-water species, divers surveyed the bottom and middle of the water column separately for tagged fishes.

Population Estimates

We used two methods to estimate population sizes of fishes in each of our study sites. First, we multiplied mean density estimates (fish/60 m^2 transect) from SCUBA visual transects by the area of each study site to obtain population estimates. Each transect provided a measure of variability in space and each dive day provided estimates of variability in time. These analyses enabled us to generate a population estimate with 95% confidence intervals for all species observed in the SCUBA surveys. Second, we used two different mark/recapture methods to estimate population size of the more abundant species inhabiting each study site. We used the single mark/recapture (Petersen) method and the multiple sample (Schnabel) method of estimating population sizes (Krebs 1989). Each method assumes that the population is closed, all animals have the same probability of capture, tagging does not affect catchability, samples are random, and tags are not lost. Our sampling design of tagging in two relatively small areas and sampling over short time intervals enabled us to meet the assumptions of the Petersen and Schnabel methods.

Movement Estimates

We tagged fishes at each site with a different color of dart tag for each gear used to catch fish, and recorded the colors of tags re-captured or sighted by divers at each site. This enabled us to determine if a fish moved between sites. Also, we surgically implanted Vemco, Inc. V13 sonic transmitters in 23 cabezon (*Scorpaenichthys marmoratus*), 7 lingcod (*Ophiodon elongatus*), and 6 grass rockfish (*Sebastes rastrelliger*). Each acoustic tag transmits at a frequency of 69 kHz, and emits a unique ID code at random intervals between 60 and 180 seconds, providing a tag life of more than 2 years. We placed an array of 20 Vemco VR 2 receivers in the eastern portion of Carmel Bay to record signals from tagged fish (Fig. 4). The receivers were placed at the edges of kelp beds and are spaced about 400 m apart to ensure an overlap in receiving range along the outer edge of the kelp.

Analyses

Effects of gear type, habitat, and depth on estimates of species composition

To determine whether estimates of species composition differed among different sampling gears (diver surveys, traps, sticks and handline) and whether these differences varied between habitats and depths, we tested for differences in the species composition (i.e. relative CPUE of species) of adults (> 20 cm TL) of the nine species that were sampled most abundantly across the four sampling methods (cabezon, kelp greenling (*Hexagrammos decagrammus*), lingcod, black rockfish (*Sebastes melanops*), black and yellow rockfish (*S. chrysomelas*), blue rockfish (*S. mystinus*), gopher rockfish (*S. carnatus*), kelp rockfish (*S. atrovirens*), and olive rockfish (*S. serranoides*)). We tested for effects of habitat, depth, and their combined effects on differences in the species composition estimated by different gear types using the gear-by-site, gear-by-depth and gear-by-site-by-depth interaction terms of a multivariate analysis of variance (MANOVA), respectively. To determine the relative number of samples required of each sampling gear to characterize the entire fish assemblage, we calculated the relationship between number of species caught and number of samples for each sampling gear.

Effects of gear type, habitat, and depth on estimates of CPUE

To determine whether relative CPUE differed among gear types and if any differences among gear types varied with habitat and depth, we tested for gear-by-site, gear-by-depth, and gear-by-site-by-depth interactions in univariate analyses of variance (ANOVA) for each of the eight most abundantly sampled species.

In all analyses, depth was treated as a continuous random variable, whereas gear and site were fixed. For each gear type, data were standardized to the mean by dividing each observation by the mean (across all species, depths and both sites) for that gear type. This transformation removed the scale differences among gear types for both the MANOVA and ANOVAs.

Results

Comparison of Estimates of Species Composition Among Gear Types

We fished for a total of 25 boat-fishing days, and caught a total of 2685 fish from 18 different species (Table 1). The total number of fish caught at each site was similar; we caught 1239 fish at the north site and 1446 fish at the south site. The Total Length (TL) of more than 99% of the fish caught was $\geq$ 20 cm. Sticks, traps, and handline gear caught about the same number of species, but the number of individuals of each species caught varied among the gear types (Fig. 5, Table 2). SCUBA divers saw more than twice the number of fish species than were sampled from surface fishing gear (Table 2). Divers counted a total of 11,970 fish from 33 species; 4481 fish from 24 species at the northern (low-relief) site and 7489 fish from 27 species at the southern (high-relief) site. The total number of fish greater than 20 cm long observed on quantitative transects, however, was comparable to the number of fish caught by fishing gear

(Table 1). On transect, SCUBA divers counted 486 fish greater than 20 cm TL at the north site and 854 fish greater than 20 cm TL at the south site. The number of fish seen on transects before and after fishing and tagging operations was similar for all species, except that divers saw twice as many blue rockfish at the north site before than after tagging. The counts of yellowtail (*S. flavidus*) and olive rockfishes were combined because these two species are difficult to distinguish from one another underwater.

Overall, estimates of the species composition of the sampled fish assemblage (i.e. relative CPUE of the nine most abundantly sampled species) differed among the different sampling methods (traps, sticks, handline and divers; Fig. 5,Tables 2 and 3). Sticks and traps caught relatively more bottom-oriented species, whereas handline gear caught a higher proportion of species such as blue and black rockfishes that inhabit the middle of the water column. Interestingly, grass rockfish were only caught in traps (Figs. 5 and 6). The vast majority (72%) of fish recorded by divers was the blue rockfish. This overwhelming representation of one species reduced the estimate of species diversity (H') and evenness (E) by SCUBA relative to the other sampling gears. Excluding blue rockfish, the proportional representation of species was more equally distributed than the other sampling methods, especially between the water column and bottom-oriented species (Table 2: e.g., kelp, black, gopher and olive rockfish and the striped surfperch, *Embiotoca lateralis*). Removing blue rockfish resulted in a higher estimate of species diversity (2.47 vs. 1.28 with blue rockfish) and evenness (0.73 vs. 0.37 with blue rockfish). Thus, diversity and evenness indices were higher than the other sampling methods when blue rockfish was excluded from the estimate (Table 2).

The relationship between sample size and number of species sampled indicates how well all species in an assemblage are being sampled for a given level of sampling and how that changes with increased sampling effort (Fig. 6, Table 4). Of the 15 species caught with fishing methods, SCUBA sampled the most species and Handlines sampled the fewest (15 and 11 species, respectively). Traps required far more samples than any other sampling method to sample a representative number of species caught (nine), and recorded far fewer species for a representative number of samples (50) than any of the other methods, reflected the selectivity of the sampling method (Table 4). It also required far more samples to detect 95% of all the species caught. Of the sampling methods examined, SCUBA recorded on average the highest number of species (12) for a given number of samples (50) and required the fewest number of samples (11) to detect a representative number of species (50), reflecting the higher number of species encountered on a transect sample compared to a stick, trap or handline.

Many fishers and scientists have said that SCUBA sampling methods poorly estimate abundance of cryptic fishes such as cabezon and lingcod. In our study, the number of samples required to obtain a greater than 95% probability of seeing at least one individual lingcod ranged from 26 samples (30 m transect) for SCUBA gear, 29 samples (1 hour fishing) for handlines, 95 samples (1 stick) for sticks, and 503 samples (1 trap) for traps. The number of samples required to obtain a greater than 95% probability of seeing at least one individual cabezon ranged from 44 samples for SCUBA gear, and 161 samples for traps. Cabezon were not caught on handlines.

The species composition (i.e., relative CPUE among species) sampled by each gear type varied between the two sample sites and by depth (Fig. 5 and 7, Table 3; significant site and depth effects). Thus, each sampling method described differences in species composition of the fish assemblage between the sites and across the depth range of both sites. Most importantly however, these differences in the relative CPUE of species among the sampling gears were not consistent between sites or across depths (Fig. 5 and 7, Table 3; significant gear*site and gear*depth interactions). Thus, changes in relative CPUE of species across sites of different relief or depths differed among the sampling gears.

Comparison of CPUE Among Gear Types for Individual Species

Except for blue rockfish, density estimates of all species observed on SCUBA transects were less than 1.1 fish per 60 m^2 transect (Table 5). Blue rockfish densities averaged 3.4 and 7.5 fish/60 m^2 transect at the north and south sites, respectively. CPUE from handline fishing was also much greater for blue rockfish than for other species (Fig. 5). Other species frequently caught were gopher rockfish, black and yellow rockfish, and black rockfish. In addition to the species frequently caught, SCUBA surveys also indicated high densities of kelp greenling, kelp rockfish, and olive/yellowtail rockfishes. Densities of six of the seven most abundant species were higher at the south site.

ANOVA tests reflected strong differences in estimates of CPUE of individual species by different gears at different sites and depths across these sources of variation (Fig. 5 and 7, Table 6). Generally, our ability to detect differences among gear types, sites and depths, and the effects of each of these variables on one another, was great because of the very large number of samples (hence the very small P-values in Table 6). However, the ability to detect such effects varied among species in relation to the number sampled and their patchy distribution; specifically, we were less likely to see differences among gears, sites, and depths for species for which fewer individuals were sampled, such as kelp greenling and black rockfish (Fig. 7, Table 6). The particularly high CPUE of handlines also reflects the artifact of lumping catch from nearby fishing samples together (see Methods: Fishing Estimates of Species Composition and CPUE).

A key result of our work was that CPUE did not vary consistently among gear types across different habitats and depths. The significant gear-by-site and gear-by-depth interactions detected for many of the sampled species (Table 6) indicate that the relative efficacy (CPUE) differs between sampling gears in different sites and habitats and at different depths. The frequent occurrences of these significant interactions for most of the abundant sampled species indicate that this is a common phenomenon across all species (Fig. 7, Table 6). Given that we saw these interactions in 7 of the 9 species we evaluated, it is likely that the interactions between gear type and site or depth will greatly affect the estimate of CPUE for almost all species.

Size Frequency Analysis

Within a location, SCUBA and fishing gear methods yielded similar estimates of mean lengths of most species (for fishes over 20 cm long) (Fig. 8). We compared length frequency distributions for fishes with total lengths ≥ 20 cm to account for the fact that fishing gear did not catch the smaller individuals of each species. The length frequency distributions of fish sampled varied among gear types and sites. Interestingly, SCUBA divers saw both larger and smaller individuals for each species. Two sample K-S tests for individual species (comparison of fish greater than or equal to 20 cm TL) indicated significant differences in length distributions between sites for some species for all gear types (Table 7). We also tested for differences in size frequencies among gear types within each location (Table 8) using two-sample K-S tests. Significant differences in length frequency distributions were not consistent among the sampling methods or between sites. Length frequency distributions of few species differed between stick, trap, and handline methods, whereas length distributions of many species differed between SCUBA and fishing methods. All four sampling methods detected significant differences in length distributions of gopher rockfish and black and yellow rockfish between the two sites. None of the sampling methods detected differences in size distributions of cabezon or lingcod between sites.

Comparison of Population Estimates Among Gear Types for Individual Species

We first compared population estimates derived from the Petersen mark-recapture method with the multiple sample (Schnabel) method. Because the Schnabel method enabled us to treat information from multiple days, it allowed us to increase the sample size of population estimates. The increased sample size yielded smaller estimates of precision of population estimates; thus we chose to use the Schnabel method as our primary method for comparison of population sizes.

Recapture information by gear type and site was compiled for all combined species (Table 9) and individually for abundant species (Table 10). The number of fish observed, tagged, and recaptured was similar between the two sites. For all combined species, sticks recaptured the highest percentage of tagged fishes, SCUBA divers saw the most tagged fish, and traps were least effective at recapturing tagged fishes. Few (< 2.2 %) tagged kelp greenling, kelp rockfish, cabezon, and olive/yellowtail rockfish were recaptured or re-sighted by any sampling gear type.

We next compared population estimates derived from the expansion of diver density estimates with population estimates from the mark-recapture experiments for each of the abundant species caught with fishing gear (Fig. 9). We calculated population sizes using just recaptures from the fishing gear and also using both fishing recaptures and diver re-sightings. Population estimates based on fishing gear alone produced the highest estimates of black rockfish, gopher rockfish, and black and yellow rockfish at the north site. The combined fishing and diver mark-recapture analysis resulted in the highest population estimates for the semi-pelagic species such as blue rockfish, kelp rockfish, and olive-yellowtail rockfish in the north (low-relief) site and for 6 of 9 species at the south site. No cabezon or kelp greenling were recaptured or re-sighted, thus, expansions of diver densities was the only method of obtaining an estimate of population size for these two species. Except for blue rockfish at the south site, population estimates from expansion of diver densities were smaller for all species at both sites. We used linear regression analysis to examine the relationships between CPUE and population estimates for the 9 most abundantly caught species. None of the analyses were significant at the $P < 0.05$ level.

Comparison of Precision of CPUE and Population Estimates Among Sampling Methods

For each of the nine most abundantly sampled species, we compared the relative estimates of CPUE with the relative abundance estimates generated by the tag-recapture sampling to assess the relative accuracy of CPUE estimates generated by the different sampling gear (Fig. 7). The relative CPUE of lingcod, gopher rockfish, and yellowtail rockfish between the two sample sites estimated by scuba and handline (south > north) reflected similar differences in their estimates of relative abundance (tag-recapture; Fig. 7a, 7b, and 7i). Sticks also generated relative CPUE estimates for gopher rockfish similar to that of the relative abundance between sites, however sticks and traps did not generate relative differences in CPUE between sites similar to the estimates of abundance for these species (south ≤ north). These patterns suggest that estimates of relative CPUE generated by scuba and handline more accurately reflect relative abundance of these species between the two study sites. In contrast, scuba and sticks generated relative differences in CPUE similar to differences in abundance between sites for black and yellow rockfish, whereas handline and sticks did not (Fig. 7c). Relative CPUE of black rockfish between sites generated by scuba corresponded with relative abundance estimates, but not for the other three sampling methods (Fig. 7e). None of the sampling methods generated similar patterns of relative CPUE to that of the estimated relative abundance of kelp rockfish (north > south), likely reflecting the relatively similar abundance of this species between sites and the lack of differences in estimates of CPUE as well. Most perplexing was the opposite pattern of relative CPUE generated by all sampling gears (south > north) compared to the estimate or relative abundance (south < north) for S. mystinus (Fig. 7d).

Estimates of the relative precision of CPUE, as indicated by the Coefficient of Variation (standard deviation/mean), were low (100 – 1700%) for all species and sampling methods (Fig. 10). Precision of CPUE estimates were similar between sites and gear for the abundant gopher and black and yellow rockfishes, but differed markedly among sampling methods for other species. For all species, estimates of CPUE from SCUBA surveys had the greatest precision, followed by handlines, sticks, and traps. Precision was greater in the high-relief (south) site than in the low-relief (north) site for almost all species, a pattern which is similar to the one described by the abundance estimates generated by diver density expansions.

For each of the nine most abundantly sampled species, we compared the precision of the population estimates generated from the different sampling gear by the tag-recapture technique. We plotted the 95% confidence intervals, expressed as a percentage of the mean to compare the relative accuracy of population estimates (Fig. 11). The number of recaptures of several species were too low to provide estimates of the 95% CI of population size using the Schnabel tag-recapture technique. For species we could evaluate, at the low-relief (north) site, estimates of the relative precision (95% CI/mean ratios) ranged from 74 – 465% of the mean. Handline and stick gear yielded the lowest ratios. SCUBA sampling methods provided comparable estimates of precision for all species except black and yellow rockfish and lingcod, presumably because of the cryptic nature of those fishes. At the high-relief (south) site, estimates of the relative precision (95% CI/mean ratios) ranged from 70 – 220% of the mean, except for lingcod estimates from stick gear, which was 1860% of the mean, caused by very low numbers of lingcod recaptured by sticks. At the high-relief site, SCUBA, handline, and sticks generally provided more precise estimates of population size.

Lastly, we evaluated the relative precision of the population estimates derived from expansion of estimates of fish density from SCUBA transects, again by plotting the 95% confidence intervals, expressed as a percentage of the mean (Fig. 12). The precision of abundance estimates generated by the expansion of SCUBA transects was consistently higher than any tag-recapture method. The 95% CI/mean ratios ranged from 28–98% at the low-relief site, and from 29–73% at the high-relief site. This is probably due to the large sample unit provided by the 30 m long by 2 m wide by 4 m high SCUBA transect.

Acoustic Tagging

We tagged 1697 fish with external dart tags that were colored to correspond with the fishing gear and location where the fish were caught (Table 9). None of the recaptured fish demonstrated movement between boxes. Also, SCUBA divers did not observe any fish at a site with colored tags from the other location.

In addition to external tagging, 23 cabezon, 7 lingcod, and 6 grass rockfish were surgically implanted with acoustic transmitters between 8/8/2005 and 9/8/2005. These fish were caught and released within an array of 20 Vemco VR 2 receivers. The receivers were located to monitor movements of fishes at and between the two tagging locations, as well as some adjacent areas (Fig 4). The array was deployed in Fall 2005 and acoustic data were collected in June 2006.

Of the 23 cabezon tagged, 6 were translocated to other locations ranging from 500 to 1030 m from their sites of capture (Table 11). Five of the six translocated cabezon returned to their original location within a time period of 2 to 26 days. One cabezon (# 4059) did not home, remaining at the site of translocation. Additionally, two of the six grass rockfish tagged were translocated, and both of these fish returned to their original sites of capture. Grass rockfish # 4047 homed back to its original location after 41 days, where it remained for 125 days before moving approximately 500 m to a nearby reception zone. Grass rockfish # 4045 remained at its displaced site for 39 days, left the area, and then was detected at its original location four days later.

Most of the tagged fish in our study did not move far from one area. For 70% of the tagged cabezon and lingcod, more than 90% of the signals detected from the tags were recorded within two reception zones, an approximate area of 0.14 km^2. Compared to cabezon and lingcod, grass rockfish demonstrated relatively greater movements with only half of the tagged fish remaining within two reception zones for 90% of the detected signals. Of the 36 fish we tagged acoustically, one cabezon and one grass rockfish demonstrated substantial movements throughout the array. The cabezon moved from an area of low relief to high, covering an approximate distance of 2 km. The grass rockfish moved less, approximately 1.1 km, but these movements encompassed a depth change between 12 m and 30 m.

Table 1. Total number of fish caught by each sampling gear in each sampling site. Totals are presented for (A) all fish, and (B) only those greater than 20 cm Total Length (TL).

A) All Fish

Gear type	North	South	Both Sites
Sticks	517	525	1042
Traps	142	175	317
Handline	580	746	1326
Scuba	1229	3526	4755

B) All Fish > 20 cm TL

Gear type	North	South	Both Sites
Sticks	514	523	1037
Traps	141	172	313
Handline	580	735	1315
Scuba	486	854	1340

Table 2. Percentage of species observed or caught for both study sites combined. Diversity (H) and Evenness indices (J) were calculated from Shannon-Weaver indices of diversity (J = H/Hmax). Blank spaces denote that a particular species was not observed.

	SCUBA % Observed	**Sticks % Caught**	**Traps % Caught**	**Handline % Caught**
Sebastes mystinus	72.2	21.6	1.6	55.1
Sebastes atrovirens	5.3	3.1	2.9	2.5
Sebastes melanops	3.5	5.4		13.6
Sebastes carnatus	3.5	43.7	51.9	15.3
Embiotoca lateralis	3.3			
Sebastes serranoides/flavidus	2.7	0.7		1.7
Hexagrammos decagrammus	2.2	0.4	1.3	0.2
Oxylebius pictus	2.0			
Sebastes chrysomelas	1.7	14.3	35.3	8.6
Ophiodon elongatus	0.7	3.4	0.3	1.8
Damalichthys vacca	0.5			
Oxyjulis californica	0.5			
Sebastes miniatus	0.4	2.6		0.1
Coryphopterus nicholsii	0.2			
Embiotoca jacksoni	0.2			
Scorpaenichthys marmoratus	0.2	1.2	3.2	
Hypsurus caryi	0.1			
Sebastes caurinus	0.1	1.6	0.6	0.9
Acanthogobius flavimanus	0.1			
Rhacochilus toxotes	0.1			
Brachyistius frenatus	0.1			
Sebastes nebulosus	0.1	0.6	0.6	0.2
Semicossyphus pulcher	<0.1			
Sebastes pinniger	<0.1			
Sebastes serriceps	<0.1	0.6		
Anarrhichthys ocellatus	<0.1	0.1		
Citharichthys stigmaeus	<0.1			
Kasatkia seigeli	<0.1			
Platyrhinoidis triseriata	<0.1			
Sebastes rastrelliger	<0.1		0.3	
Hexagrammos lagocephalus			1.9	
Squalus acanthias		0.6		
Total Number of Fish	11,662	950	312	1,264
Total # of Species	31	16	11	12
H (Diversity)	1.28	1.72	1.22	1.40
J (Evenness)	0.37	0.64	0.51	0.58

Table 3. Results of the multivariate analysis of variance (MANOVA) on the effects of sampling sites (north, south), gear (sticks, traps, handlines, divers), depth, and their interactive effects on the species composition (relative CPUE) of the 9 most abundantly sampled fishes (> 20 cm TL).

	Pillai's Trace	**F Value**	**DF**	**Den DF**	**Pr > F**
Site	0.0587	14.26	9	2060	<.0001
Gear	0.0730	5.71	27	6186	<.0001
Site*Gear	0.0986	7.79	27	6186	<.0001
Depth	0.0744	18.40	9	2060	<.0001
Site*Depth	0.0420	10.04	9	2060	<.0001
Gear *Depth	0.0719	5.63	27	6186	<.0001
Site*Gear*Depth	0.0681	5.32	27	6186	<.0001

Table 4. Comparison of species accumulation curves among the different sampling methods.

	SCUBA (all spp. seen)	**SCUBA (spp. seen fishing)**	**Sticks**	**Traps**	**Handlines**
Total number of species seen	28	15	14	12	11
Number of samples required to see 9 species	4	11	69	182	48
Mean number of species seen in 50 samples	20.2	12.2	8.1	5.1	9
Number of samples required to find 95% of total species seen	185	158	351	411	131

Table 5. Estimates of mean density (fish/60m^2) of the nine species most abundantly sampled (all methods combined) by SCUBA divers on visual transects at the north and south study sites. Values in parentheses are 1 standard error.

	North	**South**
S. mystinus	3.39 (0.88)	7.46 (1.09)
S. atrovirens	0.86 (0.12)	0.99 (0.14)
S. melanops	0.76 (0.13)	1.07 (0.15)
H. decagrammus	0.48 (0.07)	0.44 (0.07)
S. carnatus	0.45 (0.08)	1.02 (0.15)
S. chrysomelas	0.23 (0.07)	0.49 (0.12)
S. serranoides/flavidus	0.16 (0.05)	0.83 (0.18)
O. elongatus	0.15 (0.04)	0.17 (0.04)
S. marmoratus	0.04 (0.02)	0.07 (0.03)

Table 6. Results of ANOVA tests (P values) of the effects gear type, site, depth and their interactive effects on the CPUE of nine kelp forest fishes. P values highlighted in bold were considered significant (> 0.05).

	Site	**Gear**	**Site* Gear**	**Depth**	**Depth* Site**	**Depth *Gear**	**Depth* Site*Gear**
S. marmoratus	**0.0135**	0.7649	0.0979	0.3154	**0.0408**	0.8141	0.1554
H. decagrammus	0.1263	0.796	0.3387	0.7553	0.0934	0.7795	0.2376
O. elongatus	0.079	**0.0007**	0.0591	0.2785	0.4685	**0.0015**	0.6867
S. chrysomelas	**0.0503**	<.0001	**0.0017**	**<.0001**	**0.0298**	**<.0001**	**0.0069**
S. melanops	0.0694	0.9792	0.2714	0.7133	0.0596	0.9663	0.3678
S. mystinus	**<.0001**	**0.0426**	**<.0001**	0.858	**<.0001**	0.1309	**<.0001**
S. carnatus	**0.0323**	**<.0001**	0.0525	**<.0001**	**0.0142**	**<.0001**	**0.0081**
S. atrovirens	**<.0001**	0.7897	**<.0001**	0.1088	**<.0001**	0.7625	**<.0001**
S. serranoides	**<.0001**	0.9814	**<.0001**	0.8767	0.8403	**0.0002**	**0.0428**

Table 7. Differences in length distributions between locations of each sampling technique, as determined by two-sample K-S tests for fishes ≥ 20 cm. Single asterisks (*) denote a significant difference in length frequency distributions ($p \leq 0.05$), double asterisks (**) are highly significant ($p \leq 0.001$), “ns” equals no significant difference, and blanks indicate insufficient data for the tests.

	Sticks	**Traps**	**Handline**	**SCUBA**
H. decagrammus				ns
O. elongatus	ns		ns	ns
S. atrovirens	*	ns	ns	**
S. carnatus	**	**	**	**
S. caurinus			*	
S. chrysomelas	**	**	**	*
S. marmoratus	ns	ns		ns
S. melanops	*		**	*
S. miniatus	ns			ns
S. mystinus	*		**	**
S. serranoides/flavidus				ns
S. serriceps	ns		ns	

Table 8. Differences in length frequency distributions of species among gear types, by location, as determined by two-sample K-S tests for fishes ≥ 20 cm. Single asterisks (*) indicate a significant difference in length frequency distributions ($p \leq 0.05$), double asterisks (**) are highly significant ($p \leq 0.001$) "n.s." denotes no significant difference, and blanks indicate insufficient data for the tests.

North	**Stick vs. Traps**	**Stick vs. Handline**	**Stick vs. SCUBA**	**Trap vs. Handline**	**Trap vs. SCUBA**	**Handline vs. SCUBA**
H. decagrammus			ns			
O. elongatus		ns	ns			ns
S. atrovirens	*	ns	**	ns	**	**
S. carnatus	ns	*	**	ns	**	**
S. caurinus		ns	ns			ns
S. chrysomelas	ns	ns	**	ns	**	**
S. marmoratus			ns			
S. melanops	ns	ns	**	ns	ns	**
S. miniatus			**			
S. mystinus		*	**			**
South	**Stick vs. Traps**	**Stick vs. Handline**	**Stick vs. SCUBA**	**Trap vs. Handline**	**Trap vs. SCUBA**	**Handline vs. SCUBA**
H. decagrammus					ns	
O. elongatus		ns	ns			ns
S. atrovirens	ns	ns	**	ns	*	**
S. carnatus	ns	ns	**	ns	**	*
S. caurinus						
S. chrysomelas	ns	ns	**	*	**	*
S. marmoratus	ns		ns		ns	
S. melanops		ns	**			**
S. miniatus			ns			
S. mystinus	*	**	**	*	**	**

Table 9. Summary of tag and recapture results by sampling site. No. Caught or Observed includes recaptures and % Recaptured denotes the percentage of recaptured fish from the total number of fish caught. These data do not include fishes recaptured by anglers who reported catching a tagged fish.

North Site	No. Caught or Observed	No. Tagged	No. Recaptured	% Recaptured
Sticks	514	358	49	9.5
Traps	141	106	2	1.4
Handline	580	348	30	5.2
SCUBA	3603	0	88	2.4

South Site	No. Caught	No. Tagged	No. Recaptured	% Recaptured
Sticks	523	329	43	8.2
Traps	172	112	3	1.7
Handline	735	444	32	4.4
SCUBA	5351	0	95	1.8

Table 10. Summary of tag and recapture results by species and sampling type.

	Sticks			Traps		
	No. Tagged	**No. Recaptured**	**% Recaptured**	**No. Tagged**	**No. Recaptured**	**% Recaptured**
O. elongatus	30	4	13.3	1	0	0
S. carnatus	316	54	17.1	134	2	1.5
S. caurinus	11	3	27.3	2	2	100.0
S. chrysomelas	106	12	11.3	55	0	0
S. melanops	47	1	2.1	0	0	0
S. miniatus	19		0.0	0	0	0
S. mystinus	99	18	18.2	2	1	50.0

	Handline			SCUBA		
	No. Tagged	**No. Recaptured**	**% Recaptured**	**No. Observed**	**No. Recaptured**	**% Recaptured**
O. elongatus	19	1	5.3	94	7	7.4
S. carnatus	154	23	14.9	412	33	8.0
S. caurinus	9	1	11.1	17	1	5.9
S. chrysomelas	90	7	7.8	183	12	6.6
S. melanops	147	5	3.4	415	26	6.3
S. miniatus	1	1	100.0	52	8	15.4
S. mystinus	327	24	7.3	5814	79	1.4

*this table is only for fish > 20 cm in length
SCUBA includes fish seen on random swims and transects

Table 11a. Percentage of acoustic signals for each tagged fish detected at recevier locations. Lined boxes represent the closest receiver to site of capture. Yellow boxes denote locations where fish were released. Tag IDs with asterisks are translocated fish.

A) Lingcod — Location

Tag ID	1	2	4	5	6	7	7.1	7.2	8	9	10	11	12	13	15	16	17	18	19	20	22
36					2.1				12.5	20.8		64.6									
37									40.0	60.0											
172																<0.1	0.8	96.6	2.5	<0.1	
173																	0.6	89.4	10.0		
225									0.1	0.7		99.1	<0.1								<0.1
226										<0.1		99.7	0.2								<0.1
4049																		100			

B) Grass Rockfish — Location

Tag ID	1	2	4	5	6	7	7.1	7.2	8	9	10	11	12	13	15	16	17	18	19	20	22
3361							93.6	6.4													
3365				<0.1	33.7	<0.1	66.1	<0.1													
4045*	58.9			41.1																	
4046								100													
4047*			46.7	8.4	44.9																
4050						<0.1			3.0	0.1	96.5	0.2	<0.1		<0.1					<0.1	<0.1

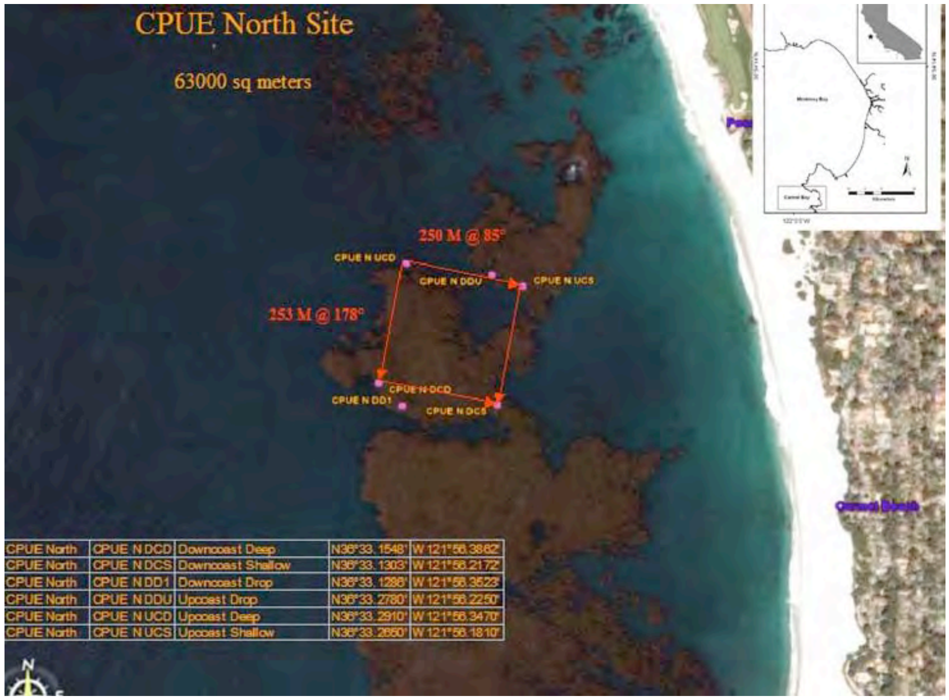
Table 11b. Percentage of acoustic signals for each tagged fish detected at recevier locations. Lined boxes represent the closest receiver to site of capture. Yellow boxes denote locations where fish were released. Tag IDs with asterisks are translocated fish.

C) Cabezon

Location

Tag ID	1	2	4	5	6	7	7.1	7.2	8	9	10	11	12	13	15	16	17	18	19	20	22
175					0.6	0.0	99.3	0.1													
176					0.5		28.6	70.9													
177	1.7			97.2	1.1																
231				97.7	2.2		0.1														
3360			<0.1	99.8	0.1		<0.1														
3362			0.5	99.3	0.2																
3363*	98.8	<0.1		1.2																	
3364					3.3		96.7														
3366			0.4	99.6																	
4048																1.5	16.9	66.0	15.6		
4051				1.1			1.7	12.8	5.1	4.0	70.8	4.5									
4052																0.5	16.4	82.3	0.8		
4059*			<0.1	99.8	0.1																
4065				4.6			4.8	90.5			<0.1										
4066*	76.9			23.1																	
4067				96.6			2.5										0.2	0.7			
4068*				37.0		1.8	3.9	57.3													
4069*				96.9	0.3		2.8														
4070						<0.1		78.9			0.8	0.3	0.5	0.7	<0.1	0.7	2.1	9.5	6.6		
4071	100																				
4072*	94.8	<0.1		5.2																	
4073					76.0		24.0														
4074				1.5		16.5		82.0													

A.



B.

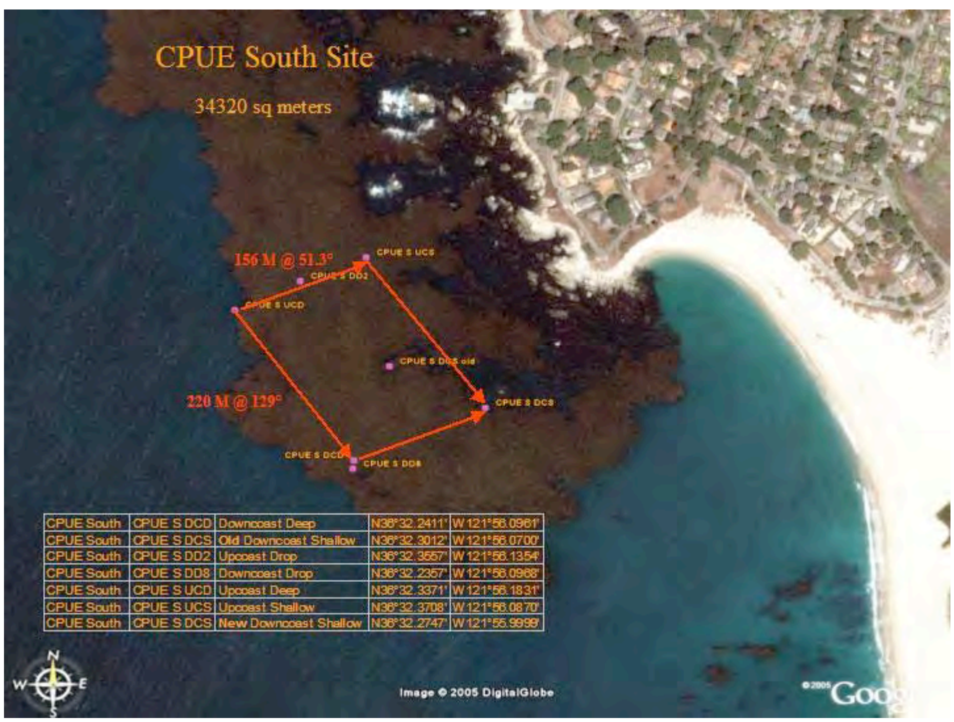


Figure. 1. Location of the northern, low relief (A) and southern, high relief (B) study site at the back (east end) of Carmel Bay, central California.

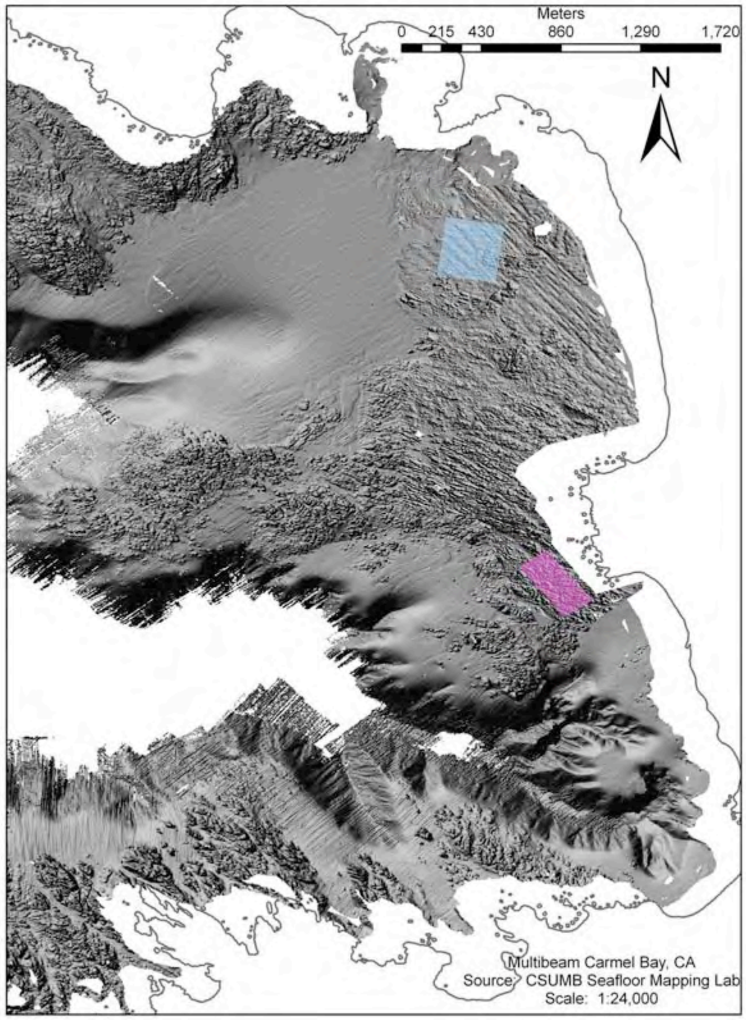


Figure 2. Multibeam images depicting the depth contours and topographic relief of the northern (light blue) and southern (purple) study site at the back (east end) of Carmel Bay, central California.

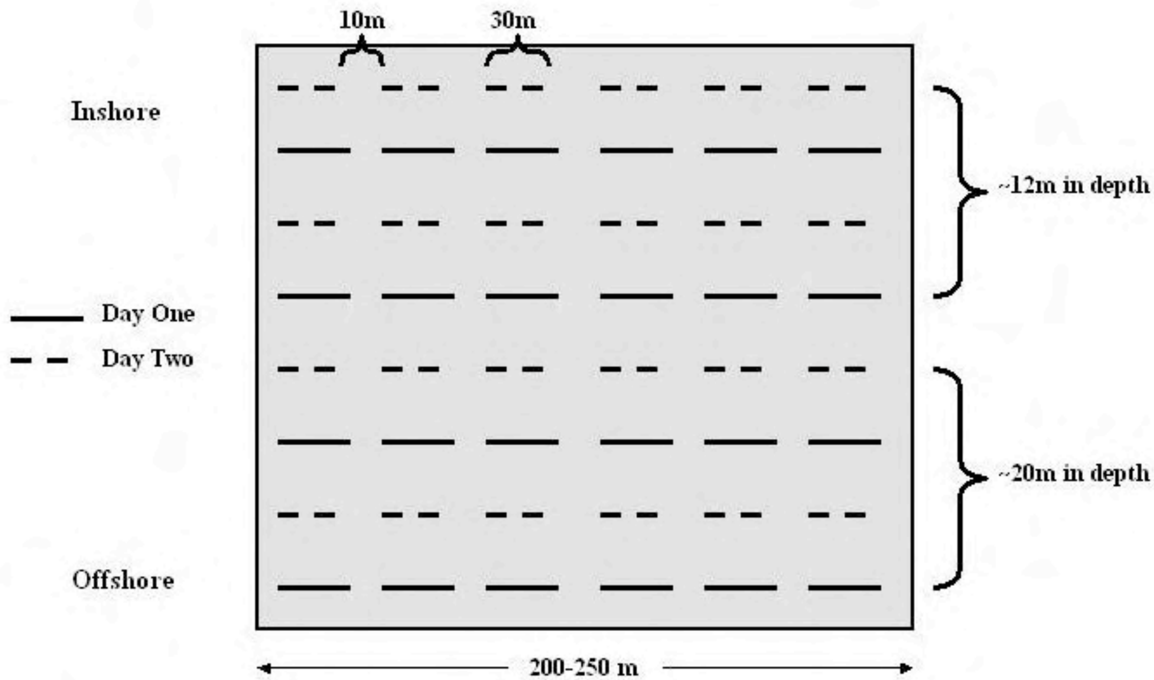


Figure 3. Spatial sampling design of diver surveys to estimate fish density, size, and species composition. Six 30 m transects were sampled at each of eight strata from offshore to onshore of the study site. The 12 transects indicated by solid lines were sampled on one day and the remaining transects indicated by dashed lines were sampling on the second sampling day. Adjacent transects were separated by approximately 10 m distance.

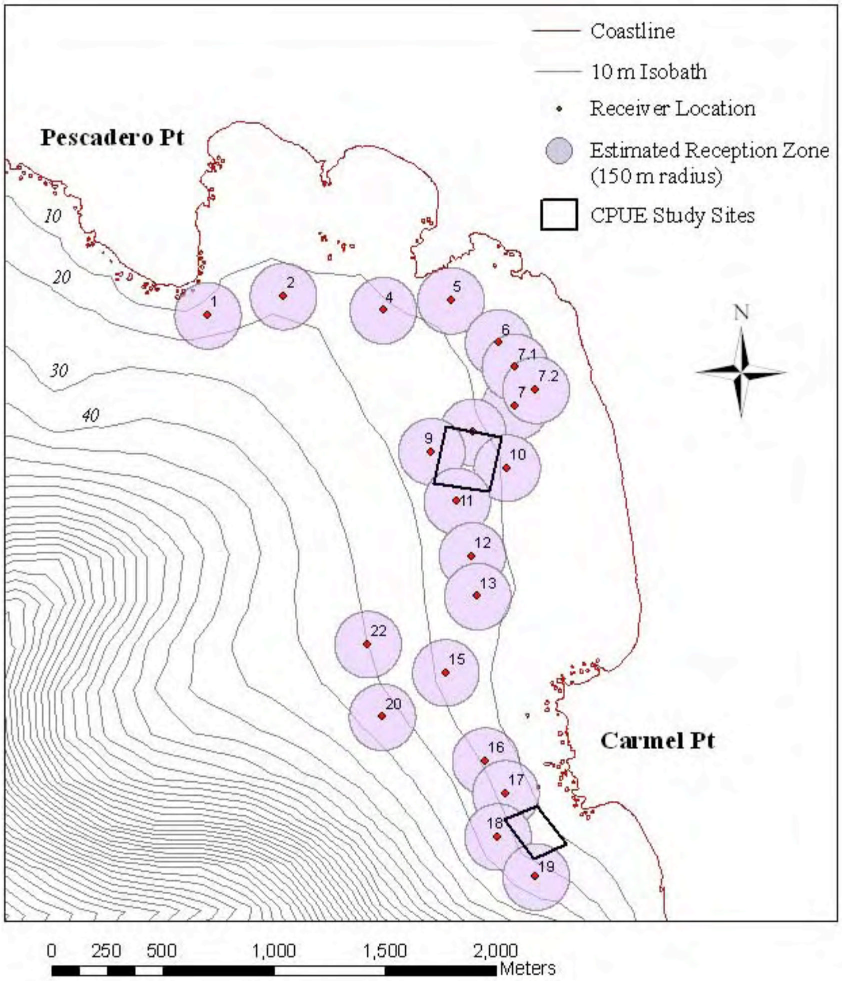
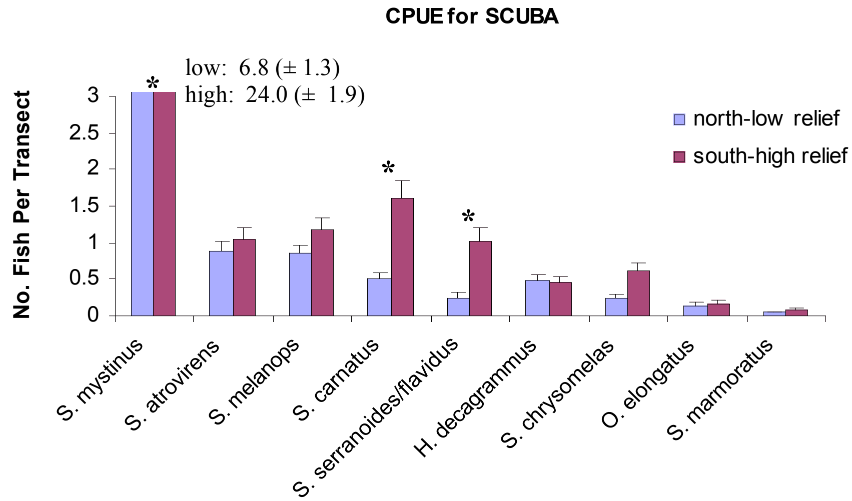


Figure 4. Distribution of the telemetry receivers used to monitor the distribution and movement of fishes tagged with acoustic transmitters.

A.



B.

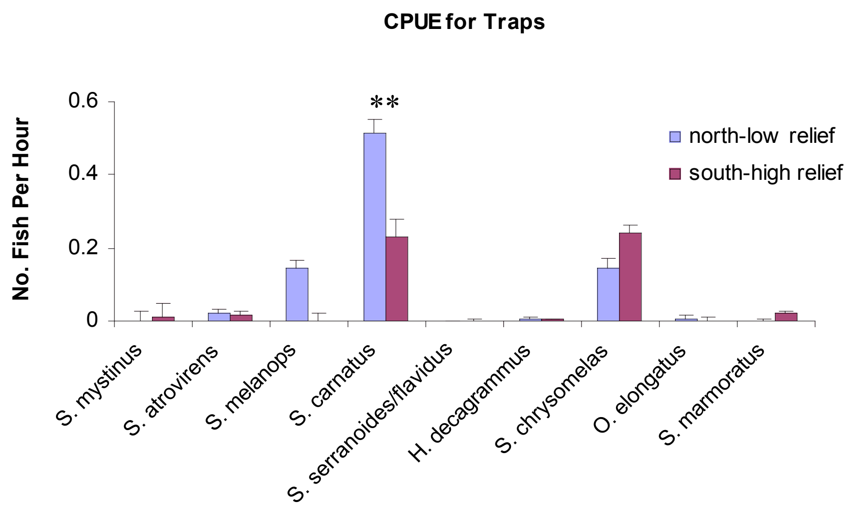
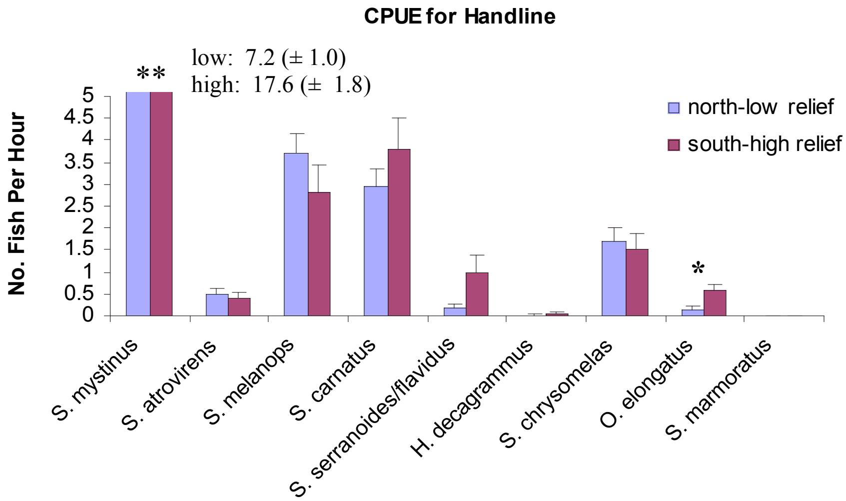


Figure 5. Estimated species composition (i.e. relative CPUE) of the nine most abundant species sampled in the northern, low relief (blue) and southern, high relief (red) sites by (A) SCUBA, (B) trap, (C) handline, and (D) stick sampling methods. Significance of differences in CPUE between sites was determined using two-sample t-tests where * denotes a p-value of less than 0.05 and ** denotes a p-value of less than 0.001.

C.



D.

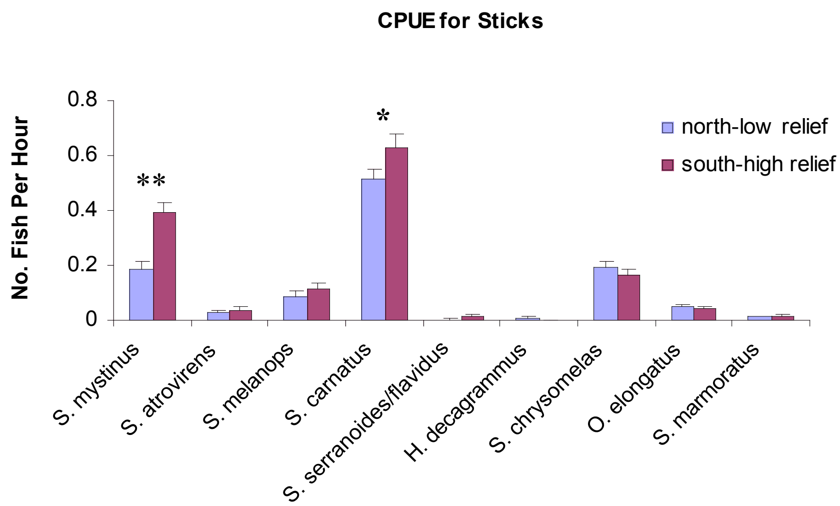


Figure 5 continued. Estimated species composition (i.e. relative CPUE) of the nine most abundant species sampled in the northern, low relief (blue) and southern, high relief (red) sites by (A) SCUBA, (B) trap, (C) handline, and (D) stick sampling methods. Significance of differences in CPUE between sites was determined using two-sample t-tests where * denotes a p-value of less than 0.05 and ** denotes a p-value of less than 0.001.

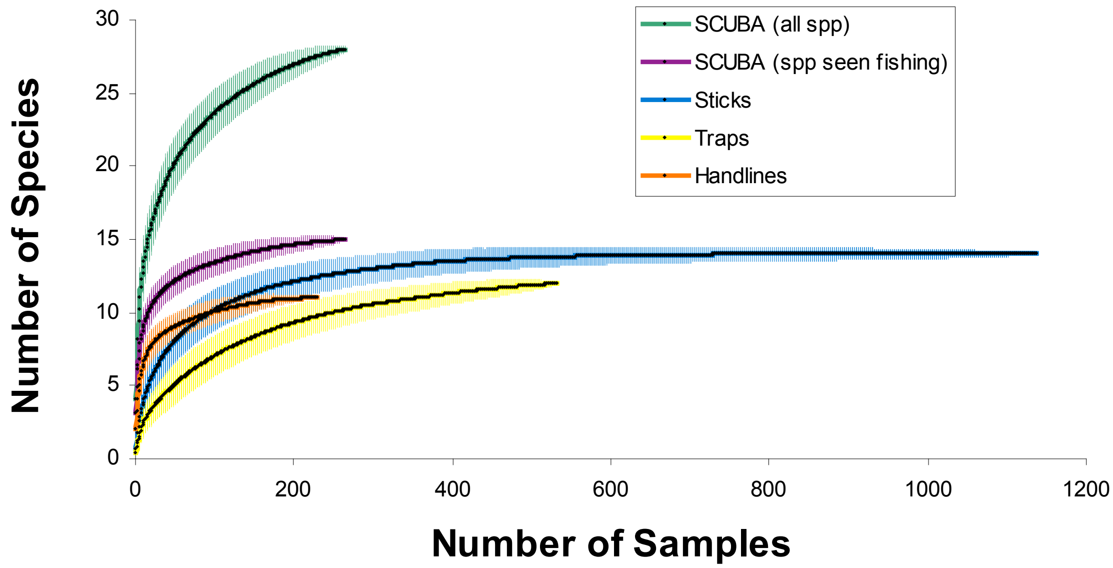


Figure 6. Species accumulation curves for SCUBA (green, using dataset containing all species seen by divers), SCUBA (purple, using dataset limited to species observed by all fishing methods), Sticks (blue), Traps (yellow), and handlines (orange). Plot values are mean number of species seen in simulated groupings of increasing numbers samples. Colored areas indicate standard deviations above and below mean values.

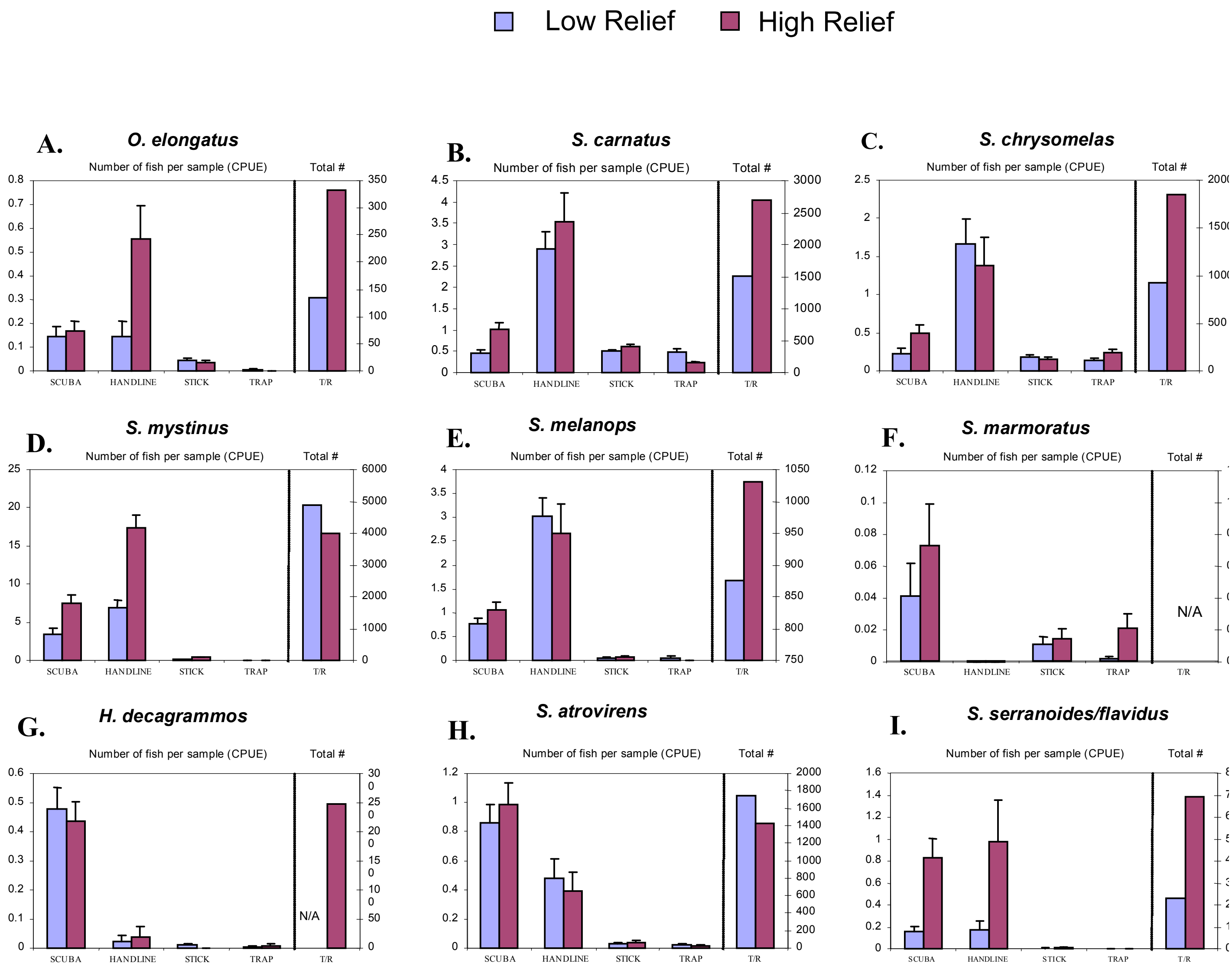
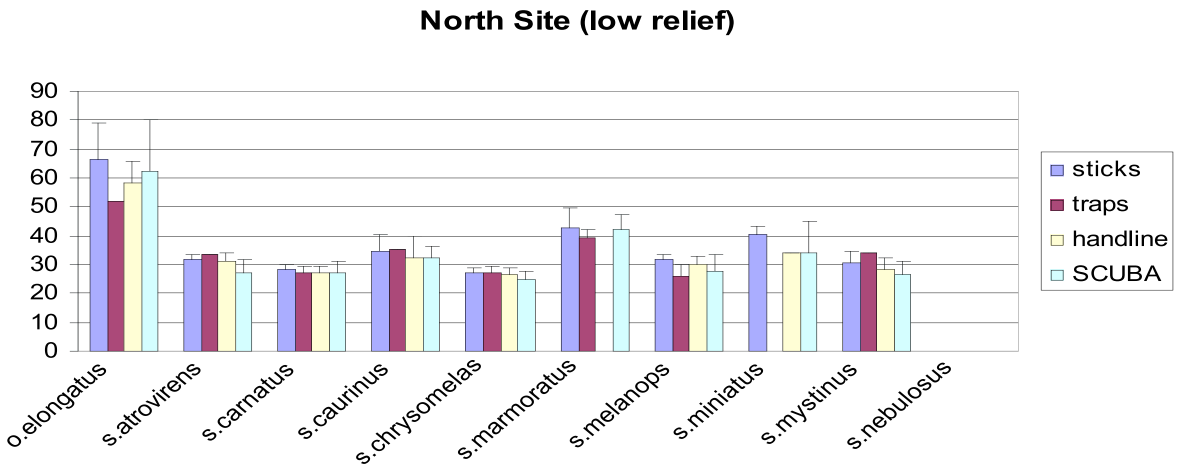


Figure 7. Estimated species composition (i.e. relative CPUE) of the 9 most abundant species sampled in the northern, low (blue) and southern, high (red) relief sites by SCUBA, Handlines, Sticks and Traps. Species include:. *O. elongatus* (A), *S. Carnatus* (B), *S. chrysomelas* (C), *S. mystinus* (D), *S. melanops* (E), *S. marmoratus* (F), *H. decagrammos* (G), *S. atrovirens* (H) and *S. serranoides/flavidus* (I). Tag Recapture abundance estimates obtained from using all observations of tagged and untagged fish (from SCUBA, Sticks, Traps and Handlines) are available for 6 of these species and are provided for reference on a separate axis.

North Site (low relief)



South Site (high relief)

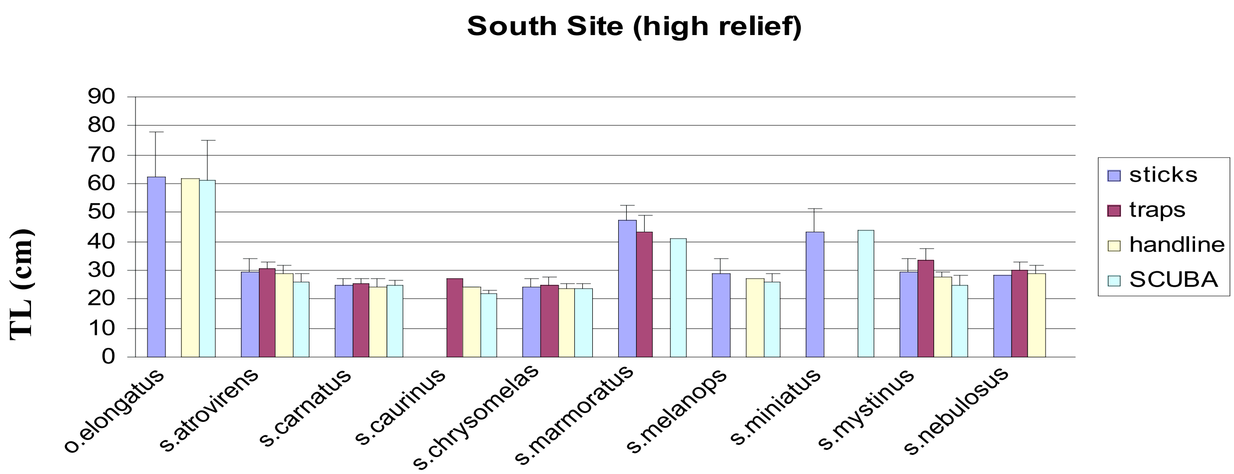
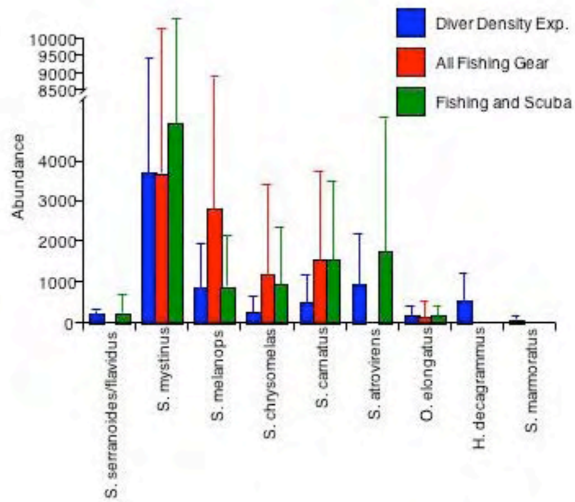


Fig. 8. Mean total length (cm) and standard deviations for abundant species. Size frequency data were truncated to only include fishes with total lengths ≥ 20 cm.

A. North Site



B. South Site

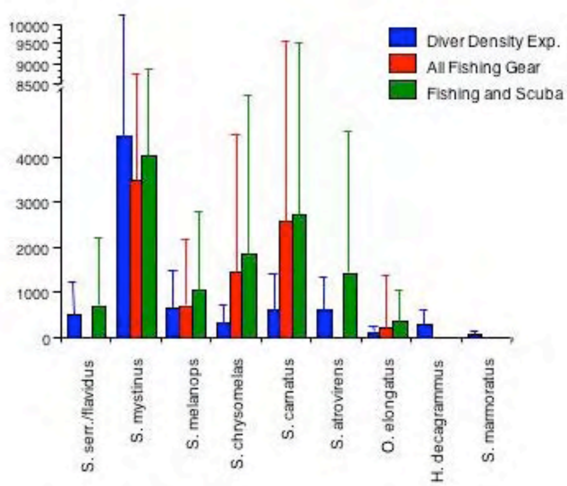


Figure 9. Schnabel tag-recapture estimates of population abundance at north (A) and south (B) study site.

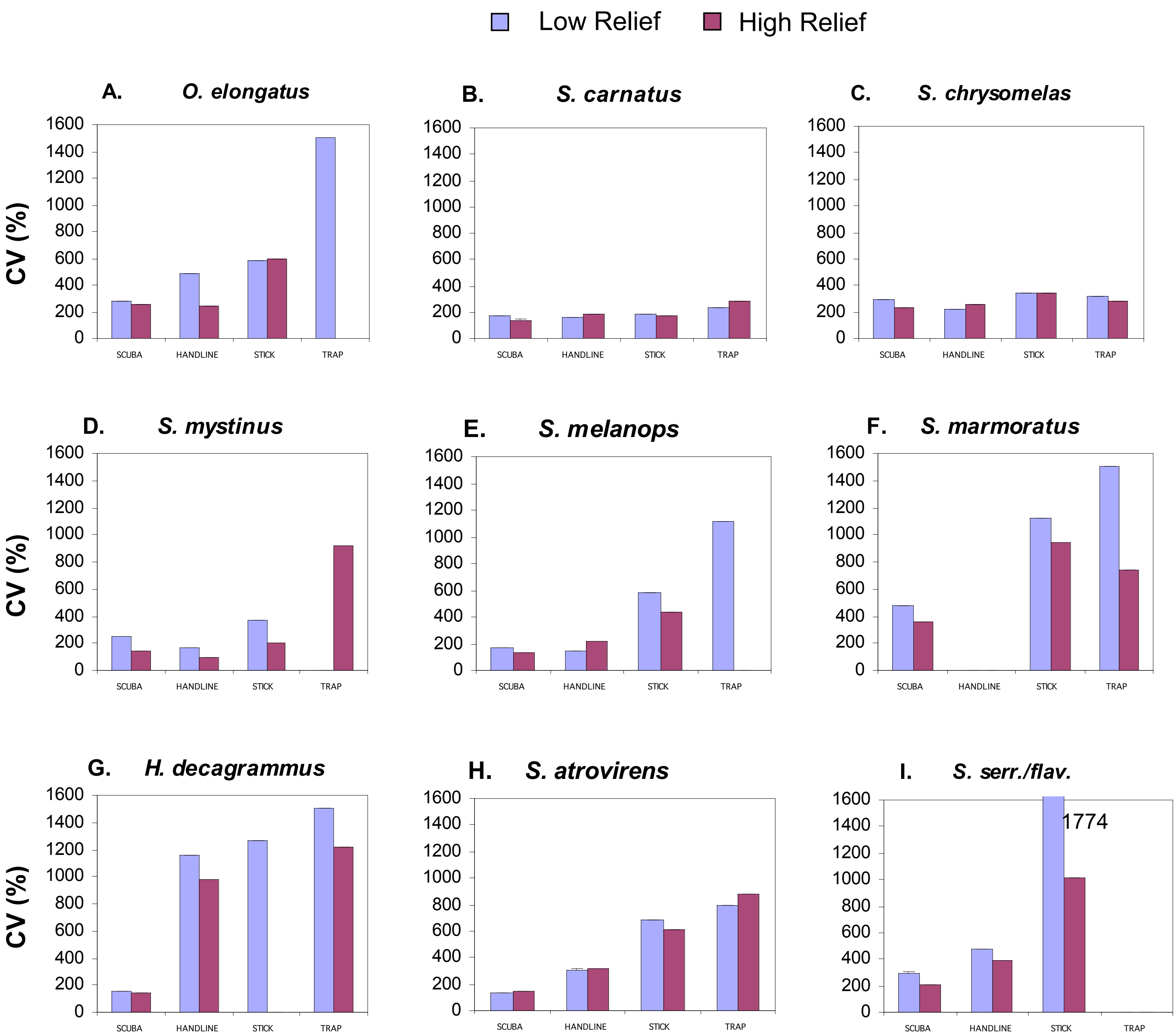
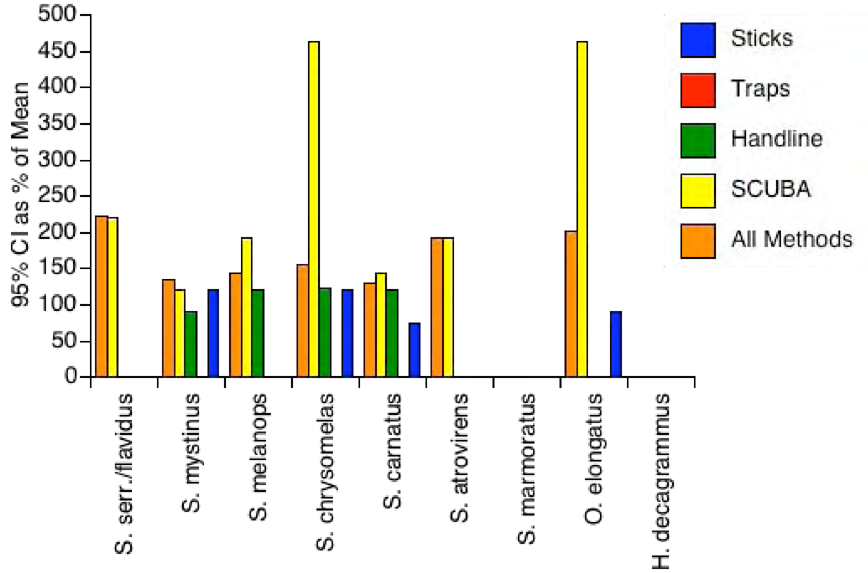


Figure 10. Relative precision of the CPUE estimates generated by the different sampling methods. Plotted are the coefficients of variation (expressed as percentages) of the 9 most abundant species sampled in the northern, low (blue) and southern, high (red) relief sites by SCUBA, Handlines, Sticks and Traps. Species include: *O. elongatus* (A), *S. carnatus* (B), *S. chrysomelas* (C), *S. mystinus* (D), *S. melanops* (E), *S. marmoratus* (F), *H. decagrammos* (G), *S. atrovirens* (H) and *S. serranoides/flavidus* (I).

A) North Site



B) South Site

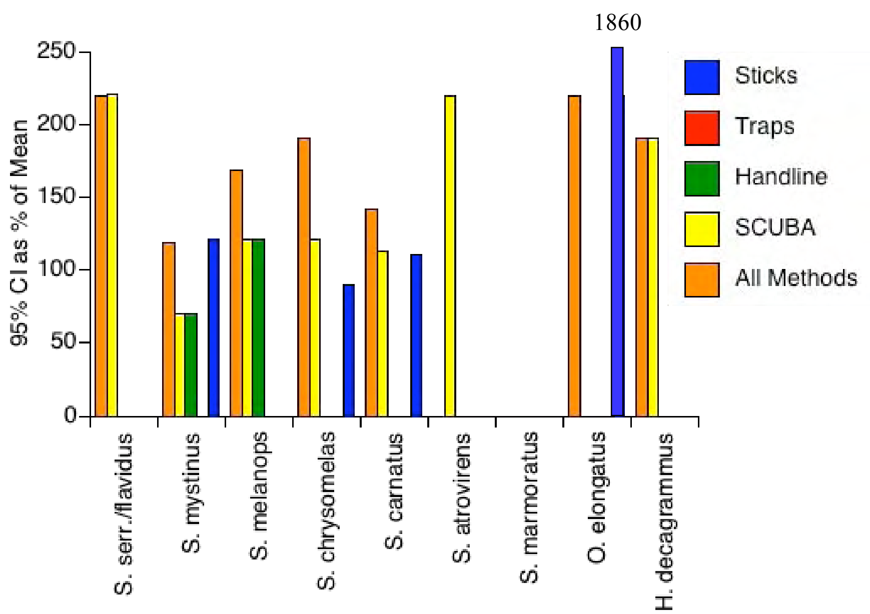


Figure 11. Relative precision of the population estimates generated by the mark-recapture methods. Plotted are the 95% confidence interval expressed as a percentage of the mean for the nine most commonly caught species.

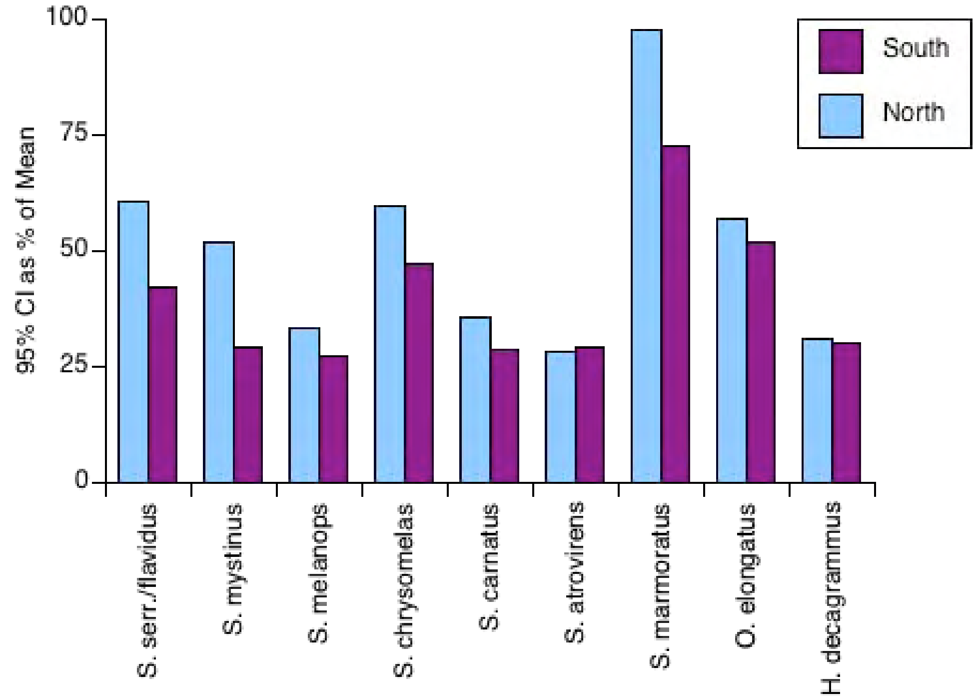


Figure 12. Relative precision of the population estimates generated by the expansion of density estimates by diver sampling. Plotted are the 95% confidence interval expressed as a percentage of the mean for the northern and southern study sites.