Population estimates of Pacific coast groundfishes from video transects and swept-area trawls

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Abstract.—Demersal fish surveys are used for two purposes: to detect trends in multispecies communities for environmental assessment and to provide fishery independent stock assessments for management. We compared remotely operated vehicle (ROV) and swept-area trawl surveys to evaluate their strengths and weaknesses for these two purposes. ROV abundance estimates tended to be higher and have lower coefficients of variation than did trawl abundance estimates. This trend is greatest for benthic species and particularly so for small, cylindrically shaped fishes. For patchily distributed, off-bottom fishes such as rockfish, *Sebastes* spp., sablefish, *Anoplopoma fimbria*, and Pacific whiting, *Merluccius productus*, the results vary between ROV and trawl estimates. For environmental assessment, the ROV estimates are superior because, for most species, abundances are higher and smaller changes can be detected. For fisheries management of commercially important species, the results are divided. Dover sole, *Microstomus pacificus*, and thornyheads, *Sebastolobus* spp., have higher ROV abundance estimates and lower coefficients of variation than the trawl. Sablefish, which exhibit more off-bottom behavior, have higher trawl estimates at two of three depths. The ROV and trawl provide different types of information not available from other gear. Much of the difference between the two types of surveys stems from the nature of the sampling gear and from the behavior, body shape, and size of the fishes.

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Estimates of population abundance are essential to research for understanding the impact of human activities on marine demersal fish populations. Traditionally, swept-area trawl surveys have been used to obtain abundance estimates aimed at fisheries management. Recently, environmental surveys, used to monitor the impacts of pollution and coastal development, have become more widespread and important. These two types of surveys have different goals. Data from fisheries surveys are used as input for predictive models to forecast the results of alternative fisheries management strategies and are usually directed toward either a single species or a small species group. Environmental surveys are used to detect trends in populations over time, to distinguish those trends from natural variation, and are usually directed at an entire multispecies fish community.

Both types of survey population estimates are subject to the problems of bias and precision. Bias is a particular problem for fisheries surveys. Fishery stock assessment is based on models that integrate fishery catch-at-age data with fishery-independent survey estimates of abundance (Deriso et al., 1985). The catch-at-age data, sampled from the commercial fishery, document the trend of population change resulting from recruitment of young fish into the population and from removal of individuals out of the population due to fishing and natural mortality. The fishery-independent survey data are used as a measure of either relative or absolute abundance (Doubleday and Rivard, 1981). These survey data are used to calibrate or "tune" the trend obtained from the catch-at-age data to determine how close the population is to a threshold value of overfishing (Kimura, 1989). Survey data also yield valuable information on migration routes, or biological parameters such as age-at-maturity, fecundity, and feeding. Biased survey estimates can result in very precise estimates of population abundance which are either lower or higher than the true population abundance.

For environmental surveys, the problem of precision is the major concern. Here, the goal is to detect a trend in population size, often of all the fish in the habitat, and to distinguish that trend from natural variation in fish populations. Abundance estimates from trawl surveys tend to have very large variances; often means and variances are correlated (see Lenarz and Adams, 1980). Resulting confidence intervals around means range from 50 to 100% for flatfish species and are greater than 100% for rockfish, *Sebastes* spp. (Raymore and Weinberg, 1990). As a result, all but the most extreme changes in population size are masked by these large confidence intervals. Methods commonly used to deal with this variability are transformations using the negative binomial (Lenarz and Adams, 1980) or the Delta distribution (Pennington, 1986). Data transformed by using these distributions often result in the variance being independent of the mean; however, the large confidence intervals and low statistical power remain.

In this study we examined video transects conducted from a remotely operated vehicle (ROV) as an alternative method for making population estimates of demersal fishes and compared these estimates to those from a conventional swept-area trawl survey.

Methods

Study site

The study site off central California lies along a cone-shaped ridge which runs southwest from Santa Cruz, California, and separates Monterey Canyon to the south from Ascension Canyon to the north (Fig. 1). Surface topography of the ridge is smooth and relatively unbroken (Greene[1]). The ridge is composed of sandstone, is covered with mud of pelagic origin, and is characterized by occasional areas of exposed bedrock. The stations where ROV and trawl operations were conducted were located along the ridge at depths of 200, 400, and 600 m (see Fig. 1).

[1] Greene, G. U.S. Geological Service, Pacific Marine Geology, 345 Middlefield Rd., Menlo Park, CA 94025. Personal commun., 1992.

ROV operations

ROV operations were conducted by using the Monterey Bay Aquarium Research Institute's ROV *Ventana* aboard the RV *Point Lobos*. The ROV was equipped with a Sony DXC-3000 video camera with a 5.5–44 mm zoom lens, illuminated by four 400-W sodium scandium lights. The zoom lens was used only for identification off the transect. Fiber-optic cable was used for viewing and recording images. The ROV was also equipped with a combined dual signal, a global positioning system and sonar system, which recorded the ROV position every 10 seconds. Depth, altitude off bottom, and various camera settings were also recorded.

At least three replicate transects were made at each depth. Transects at the 200-m, 400-m, and 600-m depths were sampled (for dates, see Table 1). Because a video transect covering the same total area as a trawl was not practical, a transect length of similar distance covered by a trawl was chosen (approximately 1.8 km or 1 nmi). Strip transects were used rather than line transects because the orientation of the lights produced a very sharp boundary between illuminated width of the transect and the darkness (Burnham et al., 1980; Butler et al., 1991). Transects were made at a speed of approximately 1.8 km/hr (1 knot) parallel to the isobath, interrupted occasionally by stops for fish identification or vehicle maintenance. Transects were made with a camera angle of 30° off the parallel horizon to the bottom and with a camera height averaging 0.7 m off the bottom. Fish were identified from videotapes by two independent viewers, and the response of each fish to the ROV was recorded as follows: 1) strongly attracted (rapidly moving into the frame); 2) weakly attracted

Table 1

Dates of remotely operated vehicle (ROV) and trawl sampling cruises at 200-m, 400-m, and 600-m depth strata off central California. The number in parentheses is the number of transects or trawls occurring during that month.

Depth stratum (m)	ROV	Trawl
200	Oct 1991 (3)	Apr 1991 (2)
		Sep 1991 (3)
		Jan 1992 (3)
400	Mar 1991 (1)	Apr 1991 (1)
	Oct 1991 (1)	Sep 1991 (3)
	Oct 1992 (2)	Jan 1992 (4)
600	Jul 1991 (1)	Apr 1991 (2)
	Sep 1991 (2)	Sep 1991 (4)
		Jan 1992 (3)

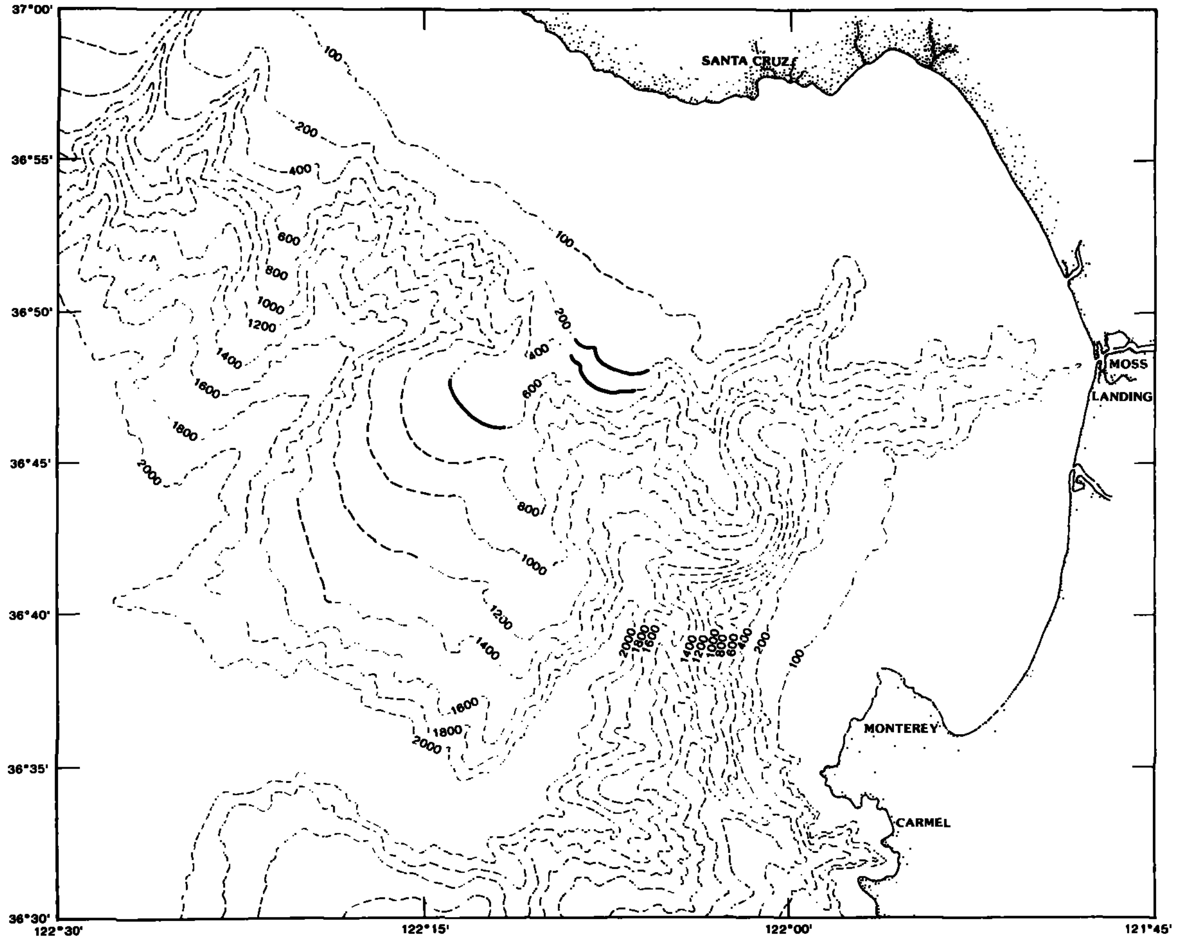

Figure 1

Study site off central California marked for 200-m, 400-m, and 600-m depth comparisons of population estimates from video transects conducted from an ROV survey and from swept-area trawl surveys.

(slowly moving into the frame); 3) no response (no movement); 4) weakly avoided (slowly moving out of the frame); and 5) strongly avoided (rapidly moving out of the frame). A time line, at which the fish were counted, was chosen in the center of the viewing area. To determine transect width at the time line, the ROV was transected over a 5-m square grid, and known lengths from the grid were measured on the monitor. From these lengths and standard photometric equations (Wakefield and Genin, 1987), the transect width was calculated to be 1.8 m (see Fig. 2). The vertical perspective of the video ranged from a height of 0.7 m at the camera to a visual horizon of 2.4 m in front of the ROV. The number of fish per transect was converted to fish per hectare by dividing the number of fish observed by the area covered (transect distance multiplied by transect width).

Trawl operations

Trawling was conducted on separate cruises on the RV *David Starr Jordan*. Three trawl surveys were conducted and a sample size of at least three trawls per station was taken per cruise (for dates, see Table 1). During the April 1991 cruise, all three replicates were not completed owing to inclement weather. Parallel tows were made along the same isobath as the ROV transect at a speed of approximately 3.7 km/hr (2 knots) for 30 minutes, although control of the trawl was not as exact as that of the ROV. The net, an Aberdeen high-rise trawl net with a 29-m (96-ft) headrope, was equipped with 1.5 × 2.1 m steel doors. Trawl openings were not measured; this type of trawl has an average horizontal opening of 13.5 m (see Fig. 2) and an average vertical opening of 5.5 m

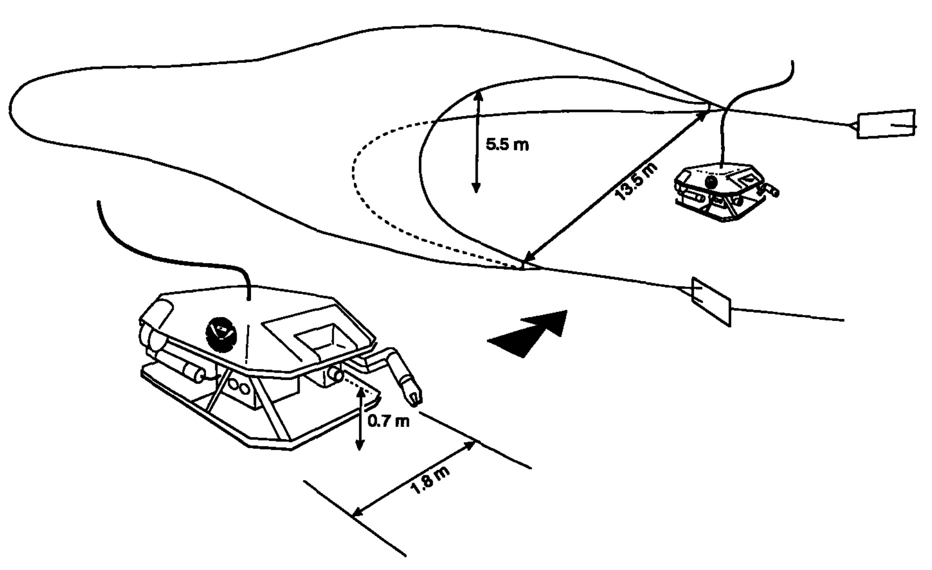

Figure 2

Sampling dimensions of a remotely operated vehicle (ROV) video transect and a trawl. Drawings of gear and sampling volumes are made to scale.

(Rose[2]). On deck, catches were handled with standard protocol (Smith and Bakkala, 1982) and were sorted to species, weighed, and measured. Lengths were measured for either a subsample of 100 fish or the entire catch, if it comprised less than 100 fish. When the catch was greater than 100 fish for a species, total species number was extrapolated from total species weight by using the average weight per fish from the subsample weight and numbers. Numbers of species per hectare were expanded by dividing the total species number by the area covered (distance traveled by a tow multiplied by the average width of the trawl).

Differences in ROV and trawl abundance estimates for individual species at each depth were tested by using t-tests for differences of unpaired log-transformed means. A sign test was used to determine whether the number of times that an ROV abundance estimate (or coefficient of variation) was higher than the trawl was greater than would have been expected randomly (i.e. a 50/50 ratio).

Statistical power is defined as $1-\beta$, where β is the probability of failing to reject a hypothesis when it is false, and therefore power is the probability of correctly rejecting a false hypothesis (Peterman, 1990). The power of the ROV and trawl abundance estimates was evaluated by calculating the required sample size to detect a 50% reduction from the log-transformed mean abundance at a fixed level of α (0.05) and at a high level of power ($1-\beta$, 0.80). Comparisons were made for the commercially important species (Dover sole, *Microstomus pacificus*; thornyheads, *Sebastolobus* spp.; and sablefish, *Anoplopoma fimbria*) and for a group of other abundant taxa (catsharks, Scyliorhinidae; skates, Rajidae; and eelpouts, Zoarcidae) at the 400-m depth (the only depth where all of these taxa occurred in both the ROV and the trawl surveys).

Results

More fish per hectare were observed from the ROV than were captured in the trawl at the 400-m and 600-m depths, whereas more fish were captured in the trawl at the 200-m depth (Fig. 3). However, the differences in the log-transformed total ROV and trawl estimates were only significant at the 400-m and 600-m depths (400 m: t=5.50, P<0.001; 600 m: t=3.28, P=0.011) and not at the 200-m depth (200 m: t=0.32, P=0.713). Numbers captured in the trawl at the 200-m depth were higher owing to a single large catch of two species of rockfish in one trawl. The ROV estimates of fish numbers were higher for most individual species or taxonomic groups that occurred in

[2] Rose, C. National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way N.E., BIN C15700, Seattle, WA, 98115–0700. Personal commun., 1992.

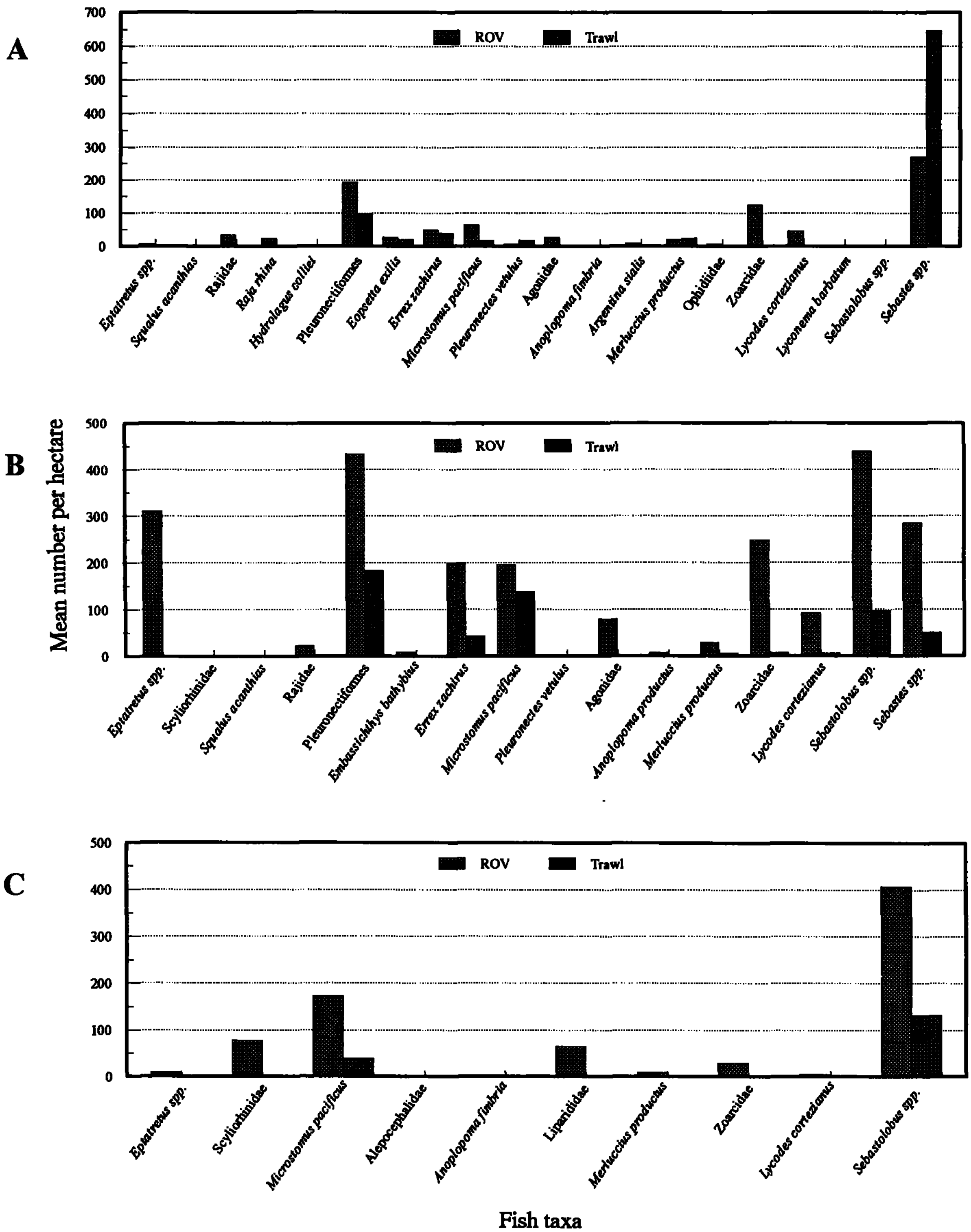

Figure 3

Mean numbers of fish per hectare estimated from an ROV video strip-transect survey and a swept-area trawl survey from (**A**) the 200-m depth station (ROV, n=3 and trawl, n=8); (**B**) the 400-m depth station (ROV, n=4 and trawl, n=8); and (**C**) the 600-m depth station (ROV, n=3 and trawl, n=9).

any abundance (greater than 1 fish/hectare in either estimate). For the 200-m, 400-m, and 600-m depths (Fig. 3), the mean ROV estimates were higher than the trawl estimates for 13 of 20, 15 of 16, and 9 of 10 comparisons, respectively (sign test 200 m: P=0.180; 400 m: P=0.001; and 600 m: P=0.011).

Especially large differences between the ROV and trawl estimates existed for strongly bottom-associated groups: skates, flatfish (Pleuronectiformes), and thornyheads, and particularly for small, cylindrically shaped fish that remained on the bottom: hagfish (*Eptatretus* spp.) poachers (Agonidae), and eelpouts. No significant differences were found between ROV and trawl estimates for fishes with more off-bottom behavior ("roundfish"), such as Pacific whiting, *Merluccius productus*, sablefish, and rockfish. Spiny dogfish, *Squalus acanthias,* were captured at every depth in low numbers in the trawls and were the only species to occur consistently in the trawls that were not seen with the ROV.

Coefficients of variation were generally smaller for the ROV estimates than for the trawl estimates. For species that occurred in both the ROV and the trawls, the coefficients were smaller for the ROV estimate in 10 of 15 comparisons at the 200-m depth, in 10 of 13 comparisons at the 400-m depth, and in 8 of 10 comparisons at the 600-m depth ([Fig. 4] sign test; 200 m: P=0.170; 400 m: P=0.050; and 600 m: P=0.050). ROV coefficients of variation were always larger for catsharks only and were mixed for Pacific whiting and some species of flatfish. At all depths, ROV coefficients of variation were smaller for rockfish and thornyheads, species typically with very large variances. Coefficients of variation for total fish number were much larger for the trawl estimates than for the ROV estimates at all depths (200-m, 2.4 times; 400-m, 4.6 times; and 600-m depths, 3.0 times).

The required sample sizes to detect a 50% reduction in the log-transformed means for a fixed level of power ($1-\beta$, 0.80) were smaller for the ROV than for the trawl, except for catsharks (Table 2). When the ROV sample sizes were smaller, the difference in sample sizes ranged from 1.3 to 19 times. For catsharks, a taxon with high variability, the ROV sample size was nearly six times larger than that for the trawls.

Most fishes showed no response to the ROV (Table 3). Considering all fish taxa observed, 80% showed no response to the ROV, 6% were attracted, and 14%

Table 2

The required sample size to detect a 50% reduction from the log-transform mean abundance of commercially important and abundant fish taxa at the 400-m depth from ROV and trawl surveys. The calculations were made at a fixed level of α (0.05) and power ($1-\beta$, 0.80).

	ROV	Trawl
Commercially important taxa		
Microstomus pacificus	5	95
Anoplopoma fimbria	25	55
Sebastolobus spp.	29	38
Abundant taxa		
Scyliorhinidae	251	43
Rajidae	9	104
Zoarcidae	14	90

Table 3

Response of commonly occurring fish taxa to the remotely operated vehicle (ROV). Fish from all depths (n=10) were recorded. Unid. = unidentified.

	Strongly attracted	Weakly attracted	No response	Weakly avoided	Strongly avoided
Eptatretus spp.	0	8	182	5	9
Scyliorhinidae	0	2	22	19	0
Rajidae unid.	0	2	42	4	8
Errex zachirus	0	1	89	3	26
Microstomus pacificus	0	3	326	10	21
Anoplopoma fimbria	0	4	5	2	2
Merluccius productus	0	45	28	11	7
Lycodes cortezianus	0	1	69	12	8
Sebastolobus spp.	0	2	173	8	10
Sebastes spp.	0	0	14	2	0
All taxa	0	68	950	76	91

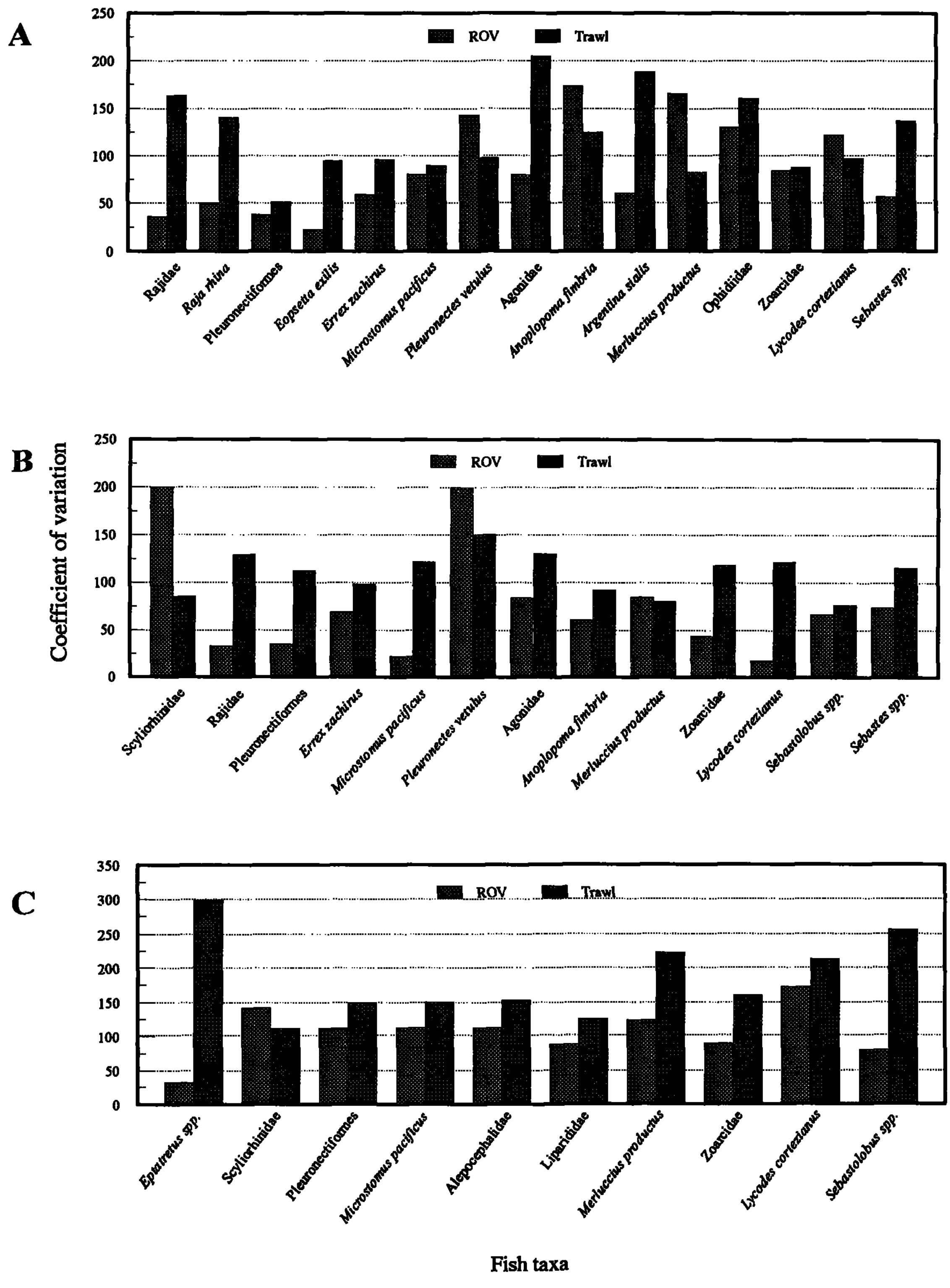

Figure 4

Coefficients of variation of the mean number of fish per hectare estimated from an ROV video strip-transect survey and a swept-area trawl survey from (A) the 200-m depth station (ROV, n=3 and trawl, n=8); (B) the 400-m depth station (ROV, n=4 and trawl, n=8); and (C) the 600-m depth station (ROV, n=3 and trawl, n=9).

avoided it. Pacific whiting had the strongest response (69%), appearing to be attracted to the ROV. Sablefish had the next strongest response (62%), but their numbers were low, averaging 3.75 individuals over all depths. Their behavior was variable: some animals swam away, some swam toward the ROV, and some ignored the ROV. Catsharks showed approximately equal numbers responding and not responding, and those that did respond consistently avoided the ROV.

Finally, the red octopus, *Octopus rubescens*, was the most abundant animal counted from the ROV. It was observed from the ROV only at the 200-m depth at numbers of 1,610 per hectare (SE=516.4) and was not captured in the trawls. The ROV red octopus abundance estimates were higher than any fish estimate from the trawls.

Discussion

Much of the difference between the ROV and trawl estimates was due to the different mechanical nature of the sampling gear and to the body shape and behavior of the fishes. The ROV intensively sampled a narrow area directly in front and extending up a short height off the bottom. The trawl sampled a much wider area, including a larger area off the bottom, but with what must have been a great deal of escapement. The result was that ROV abundance estimates were higher and had lower coefficients of variation for fishes either strongly associated with the bottom or with a body shape and size, or both, that would pass through the mesh (such as the red octopus). Conversely, animals with highly patchy distributions and off-bottom behavior (catsharks, rockfish at the 200-m depth) had higher abundance estimates from the larger volume trawl. Although both the ROV and trawl estimates were adjusted to the same surface area, there was no adjustment made to reflect the 7.7 times greater off-bottom height sampled by the trawl (Fig. 2). Probably neither method does a particularly good job of estimating off-bottom fishes that are patchily distributed. Visual estimates of fish abundance either from submersibles (Uzmann et al., 1977) or from divers (Kulbicki and Wantiez, 1990) are reported to be higher than those from otter trawl estimates for multispecies assessments, but the reverse was true in this study for rockfishes (see also Krieger, 1993).

The smaller sample sizes required to detect a 50% reduction of the ROV abundance estimates would improve the ability to detect trends in abundance such that a smaller increment of change would be detectable. The degree on improvement would vary with species. Reductions of the order of 1.3 to 19 times in required sample size are sufficient to increase the ability to detect true changes in population size. Much of the decrease in required sample size (and increase in statistical power) comes from the much higher ROV abundance estimates. If samples are drawn from two populations with similar levels of variation, a 50% decrease in abundance of the larger estimate is much larger and therefore easier to detect. Unfortunately, a great deal of variation due to patchiness in fish distribution remains.

For an environmental assessment, the ROV estimates provide a better overall picture of the community than do the trawl estimates. While the similarity in the presence and absence of species in the two methods was surprisingly high, the ROV abundance estimates generally tended to be higher and had lower coefficients of variation. Species that were usually in direct contact with the bottom had much higher ROV abundance estimates than did those captured in the trawl. Small, cylindrically shaped fishes (hagfish, poachers, and eelpouts) had particularly large differences between ROV and trawl abundance estimates, probably owing to escapement under the footrope or through the trawl webbing. The most obvious example of escapement or avoidance was that provided by the red octopus, which was more abundant in the ROV sampling than any fish, but which was not captured by the trawl.

For the commercially important species at these depths (Dover sole, thornyheads, and sablefish), the results were mixed. For Dover sole and thornyheads, ROV abundance estimates were higher and coefficients of variation were lower. For sablefish, abudance estimates were higher for the trawl sampling at 200-m and 600-m depths. Although rockfish at the 200-m depth are not commercially important, the trawl estimates for this taxon were higher, and this is likely to be true of commercially important rockfishes.

Stock assessment integrates patterns of removals and information on year-to-year variation in recruitment from catch-at-age data with mean levels of abundance and longer term trends from survey data (Deriso et al., 1985; Methot, 1990). Using simulations, Kimura (1989) showed that, if survey data are biased, the results can be a precise, but biased, inference regarding the population. The higher ROV abundance estimates mean that trawl estimates are biased too low and that there is actually a larger difference between years of low population size and threshold levels of overfishing set by these assessments. The risk of overfishing is actually lower than that which was assumed. A more dangerous situation arises when bottom trawl estimates are larger than the ROV estimates, as with rockfish (also see Krieger, 1993). Here the difference between years of low population and threshold levels of overfishing is actually less than that which was realized, a difference that increases the risk of overfishing.

ROV's have the ability to identify the degree of species' attraction to or avoidance of the sampling gear. Three species showed a strong response to the ROV: Pacific whiting, sablefish, and catsharks. Pacific whiting was the only species that was attracted to the ROV (Table 3). These three species are usually observed off-bottom and in motion, rather than resting in contact with the bottom. Fishes that are commonly in motion should be in a better position to respond quickly to stimuli (motion, light, etc.) around them. Understanding and accounting for fish behavior could improve the accuracy of an estimate. For trawl gear, the level of attraction or avoidance is unknown. Anecdotal evidence for attraction (crowding of fish between doors suggested by Krieger [1993]) and for avoidance (net sounder readings of rockfish rising up out of the path of the net [Adams[3]]), have been reported, but there is no simple way of evaluating these phenomena for trawl gear.

While the presence of large seasonal or interannual variation in fish numbers could have introduced bias into the estimates, there is no reason to believe this occurred. None of the 20 most common species captured by the three trawl surveys, which covered almost the entire study period, exhibited a consistent seasonal or overall trend in fish abundance. Also, the consistency of trends in abundance derived from ROV's and trawls from all depths, even though they were sampled at different times, suggests that large varations in abundance were not an important source of bias. However, if this bias had occurred, it would have been a larger problem for the ROV estimates than for the trawl estimates. The ROV samples at depth were taken during one time period, with the exception of the 400-m depth, whereas the trawl samples were taken at all depths during three cruises over nearly the entire time period.

Both ROV and trawl surveys contain additional information that may be critical to the goals of an abundance study. ROV surveys provide much biological information, particularly on habitat and species association. In two instances, we observed feeding behavior. Trawl surveys deliver the fish on deck; for common types of biological studies, such as ageing or food habits, these specimens are critical. In addition, these specimens enable accurate species identification. Identifcation, however, is expected to become less of a problem as video technology improves.

Finally, there is the chronic problem of the low statistical power of tests of these abundance estimates owing to large, associated variances. Since increasing the sample size is often not practical, the only alternative is to stratify the sampling more effectively rather than simply on the basis of depth. Better stratification can come only from a greater understanding of the biological factors responsible for fish distributions. An adequate understanding would include the association of fish with microhabitat and the biological behavior of fishes that leads to patchiness. Surveys could then be stratified on the basis of areas where fish are occurring at background levels and in large patches. Trawl surveys have been unsuccessful in achieving such separation. Information gained from the ROV could lead to the biological understanding necessary to achieve more efficient stratification designs.

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