A fishery-independent assessment of an overfished rockfish stock, cowcod (*Sebastes levis*), using direct observations from an occupied submersible

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Abstract: A meaningful assessment of cowcod (*Sebastes levis*) has been conducted using visual, nonextractive, habitat-specific methods. Following the precipitous decline of rockfish (*Sebastes* spp.) stocks along the Pacific coast, it was evident that more effective methods were needed to assess several species in untrawlable habitats. Cowcod were surveyed within large Cowcod Conservation Areas (CCAs) off southern California using direct observations from the research submersible *Delta* over eight major offshore rocky banks in depths of 74 to 322 m. Maps of seafloor substratum and bathymetry were used to identify and quantify these areas. A line-transect analysis of fish counts, perpendicular distances of fish from the track line, lengths of survey tracks, and area of each rocky bank was used to estimate abundance. Biomass, calculated from abundance, fish length, and a weight–length relationship, varied with mean size of cowcod on these banks. These fishery-independent results have contributed to the recent assessment of cowcod by the Pacific Fishery Management Council. A time series of results from visual surveys is now necessary to evaluate a trend in cowcod biomass with respect to increased time of protection within the CCAs.

Résumé : Nous avons fait une évaluation significative du sébaste *Sebastes levis* (« cowcod ») en utilisant des méthodes visuelles qui ne nécessitent pas de retraits et qui sont spécifiques à l'habitat. Après le déclin rapide des stocks de sébastes (*Sebastes* spp.) le long de la côte du Pacifique, il est devenu évident qu'il fallait des méthodes plus efficaces pour évaluer plusieurs des espèces dans les habitats dans lesquels on ne peut utiliser de chalut. Nous avons inventorié les *S. levis* dans de grandes aires de conservation de *S. levis* (« Cowcod Conservation Areas », CCA) au large du sud de la Californie au moyen d'observations directes faites du submersible de recherche *Delta* sur huit bancs rocheux du large à des profondeurs de 74–322 m. Des cartes du substrat du fond de la mer et la bathymétrie ont servi à identifier et à quantifier ces zones. Nous avons estimé l'abondance à partir de l'analyse des dénombrements de poissons sur des transects linéaires, des distances perpendiculaires des poissons à partir d'un tracé linéaire, des longueurs des tracés d'échantillonnage et de la surface de chaque banc rocheux. La biomasse, calculée à partir de l'abondance, de la longueur des poissons et d'une relation masse–longueur, varie en fonction de la taille moyenne des *S. levis* sur ces bancs. Ces résultats obtenus indépendamment de la pêche ont contribué à l'évaluation faite récemment de *S. levis* par le Pacific Fishery Management Council. Il faudra maintenant établir une série chronologique de résultats provenant des inventaires visuels afin d'évaluer la tendance de la biomasse des *S. levis* en fonction de la durée croissante de la protection dans les CCA.

[Traduit par la Rédaction]

Introduction

Survey data of adult groundfishes off the US west coast recently have been called into question because of ineffective methods used to assess several species in heterogeneous high-relief habitats (e.g., US General Accounting Office (GAO) 2004). In these habitats, sedentary rockfishes (*Sebastes* spp.) in particular are difficult or impossible to appraise accurately with such conventional survey methods as bottom-trawl gear. This is because this gear is virtually excluded from irregular rock habitats (Zimmermann 2003) where many rockfish species are most abundant (Stein et al. 1992; Love and Yoklavich 2006). Consequently, alternative survey techniques using visual observations are being developed to accurately assess the abundance and, in some cases, the recovery of such species (O'Connell and Carlile 1993; Jagielo et al. 2003).

Received 26 December 2006. Accepted 9 October 2007. Published on the NRC Research Press Web site at cjfas.nrc.ca on 27 November 2007. J19731

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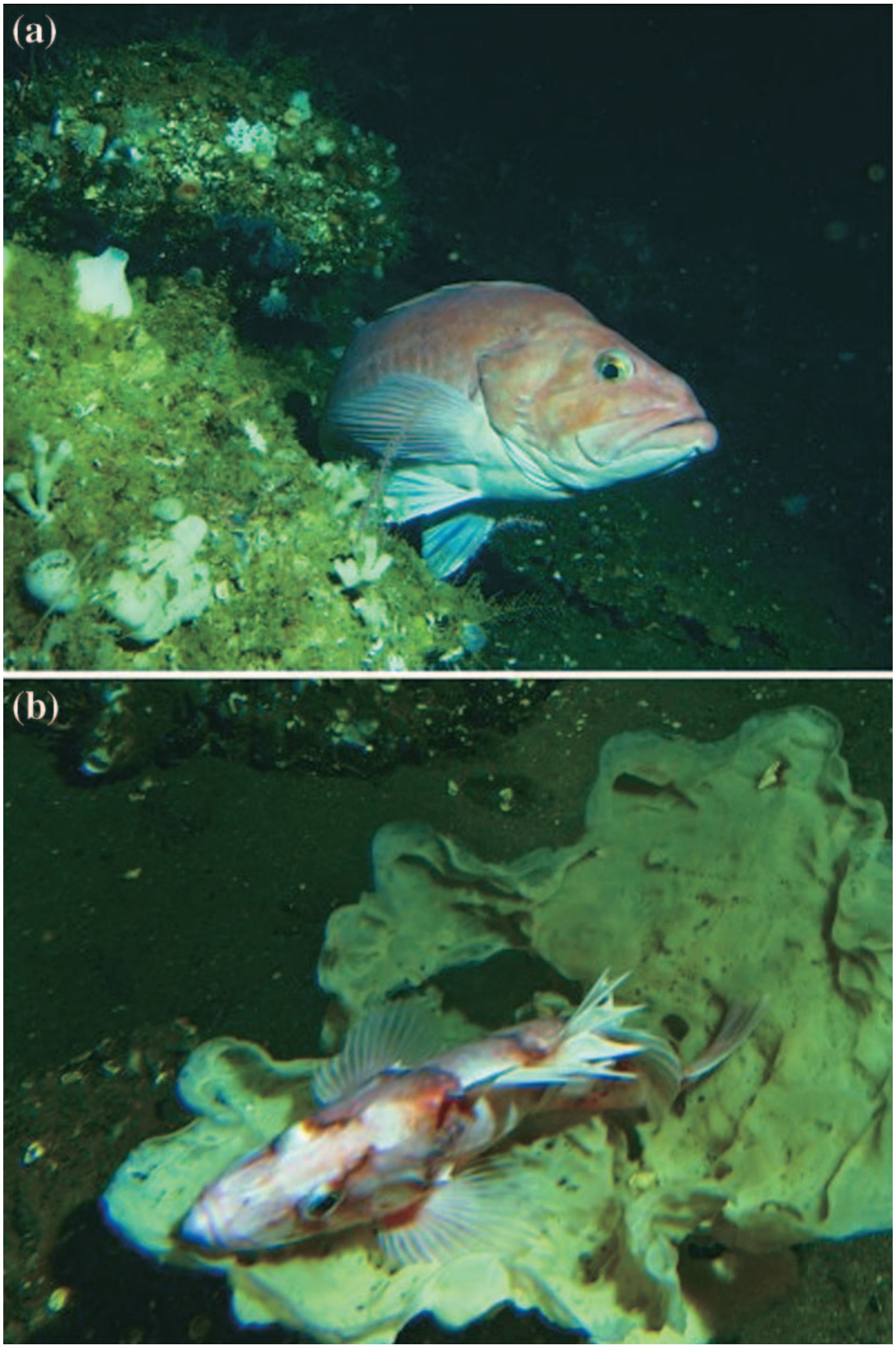
 doi:10.1139/F07-145

Fig. 1. (*a*) Adult cowcod (*Sebastes levis*) in rocky habitat (photograph by J. Bright), and (*b*) subadult cowcod inside a sponge (photograph by M. McCrea) in 190–200 m water depth off southern California.



Along with six other species of rockfishes on the west coast, cowcod (*Sebastes levis*; Fig. 1) has been declared overfished by NOAA's National Marine Fisheries Service (NMFS). Harvested both commercially and recreationally for decades off central and southern California, this sedentary species presently is estimated to be at about 7% of its unfished biomass, and it will likely take close to 90 years to rebuild the population to 40% of historic levels (Butler et al. 2003). Based on fishing records and larval fish surveys, cowcod historically have been most abundant in high-relief rock habitats around some of the islands and on offshore banks of the Southern California Bight (Moser et al. 2000; Butler et al. 2003). In an unprecedented effort to protect cowcod from incidental harvest in some of these key areas, two Cowcod Conservation Areas (CCAs) were established by the Pacific Fishery Management Council (PFMC) in 2001.

The CCAs encompass 14 750 km^2 (4300 nm^2) where fishing for all groundfishes is prohibited year-round in water depths greater than about 36 m. It is notable that these closed areas also protect at least 50 other species of rockfishes, in addition to cowcod.

Survey data for juvenile and adult cowcod, and indeed for most groundfish species, historically have been sparse off southern California, and there have been no comprehensive fishery-independent surveys of demersal stages of cowcod in this area. The goal of our study was to effectively survey cowcod by making direct visual counts along quantifiable track lines inside the CCAs. Our objectives were to collect bank-specific data on abundance, size, and biomass of cowcod living in mixed sediment and rock substrata and to evaluate our submersible line-transect method for the assessment of cowcod.

Materials and methods

We surveyed demersal juvenile and adult cowcod from 8 October to 4 November 2002 using a one-sided line-transect method (Buckland et al. 2001) and direct visual observations made during dives in an occupied research submersible (*Delta*). The *Delta* (length = 4.8 m long) accommodates one scientific observer and one pilot and has a maximum operating depth of 365 m and a cruising speed of 1.5 knots. Our surveys were conducted over eight major offshore rocky banks inside the two newly established CCAs off southern California (Fig. 2). All of these banks are long-time recreational and commercial fishing sites (Butler et al. 2003).

An individual dive was considered the sample unit for this survey. During a dive, we tried to maintain a constant distance within 1 m of the seafloor and a constant speed between 0.5 and 1.0 knots, depending on substratum type (i.e., generally slower speed in complex habitats). Target duration of each dive was 60 min, although the last dive of a day was occasionally cut short if the submersible depleted its power source. Dives were made during daytime and documented with three video cameras. An externally mounted high-8 color video camera was positioned above the middle porthole on the starboard side of the submersible. The scientific observer conducted the survey through this same porthole, verbally recording onto the videotape the incidence of cowcod along the track line of each dive. The observer also estimated the size (total length in centimetres) of each cowcod and its perpendicular distance (in feet, later converted to metres (1 foot = 0.3048 m)) from the track line. Horizontal visibility was very good (9–18 m) throughout the survey. Two parallel lasers were installed at 20 cm apart on either side of the external video camera; this system was used to estimate the total length of fish to the nearest 5 cm for juveniles (<40 cm) and 10 cm for fish ≥40 cm. Perpendicular distances to cowcod from the track line were estimated by observers, who trained their eyes using a handheld sonar gun aimed at objects (e.g., either large fish or nearby boulders) when they were perpendicular to the submersible.

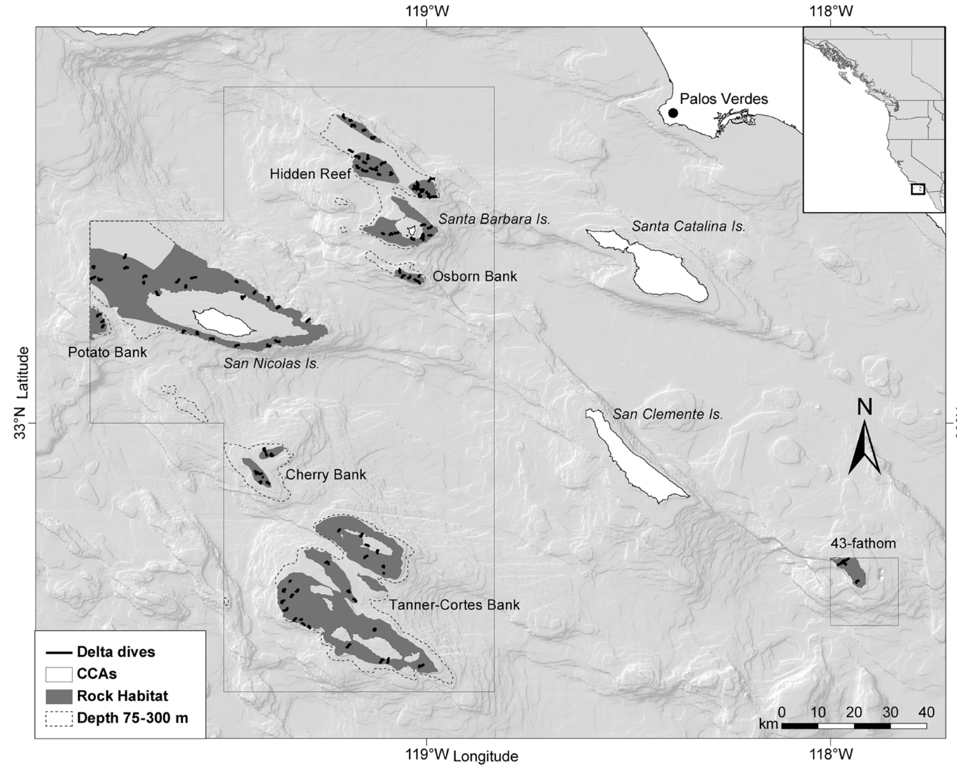
A second color video camera was positioned inside the submersible in front of the lower port on the starboard side during most dives to record fishes in the area closest to the submersible (i.e., monitoring the line at zero perpendicular distance). Additionally, a monochrome, low-light video camera was externally mounted facing forward of the survey to document potential movement (avoidance or attraction) of cowcod prior to detection by observer in the submersible.

We restricted our survey to mixed sediment and rock substrata (i.e., rock outcrops, boulders, and cobbles interspersed with sand or mud sediments) within a nominal depth range of 75–300 m. These criteria represented likely cowcod habitats (Yoklavich et al. 2000; Johnson et al. 2001). Digital, georeferenced maps of seafloor substratum types (on a spatial scale of 10s of metres to kilometres), interpreted from side-scan sonar, multibeam bathymetry, seismic reflection, and other geophysical surveys (Greene et al. 2003), and bathymetric data in 5-m intervals (P. Serpa, California Department of Fish and Game, 20 Lower Ragsdale Drive, Suite 100, Monterey, CA 93940, USA, personal communication) were used to identify and quantify the sites meeting these criteria. Additionally, catch and effort records of cowcod from onboard creel censuses of commercial passenger fishing vessels conducted by CDFG in 1975–1978 and 1986–1989 were used to assist in locating appropriate survey sites (M.S. Love and M.M. Yoklavich, unpublished data). We were able to focus our survey on the eight banks (i.e., 9% (1330 km^2) of the total area inside the CCAs) that represented essentially all available cowcod habitat (Fig. 2).

Each of these eight banks was gridded into 1.5 km × 1.5 km cells, based on likely distance to be covered during a dive. Cells were then randomly selected to locate dives. The direction of each dive was selected haphazardly, keeping terrain on the starboard side and gradually trending upslope (if there was a slope) during the duration of the dive. During each dive, the *Delta* submersible was tracked using an ORE Trackpoint II plus (ORE Offshore, West Wareham, Massachusetts) ultra-short baseline (USBL) acoustic system, differential GPS, and WINFROG software (vers. 3.1; FUGRO, San Diego, California); the position of the submersible was collected every 30 s throughout each dive. The positioning system was linked to an ArcView® GIS (vers. 3.2; ESRI Corp., Redlands, California), and a scientific navigator aboard the support vessel tracked the submersible in real time relative to depth and gridded seafloor habitat maps. The navigator directed the submersible's course via two-way radio communication with the pilot, keeping the submersible within the designated grid cell and habitat. The pilot and scientific observer inside the submersible did not influence the direction of travel. The length of each dive track line was calculated from the navigation data, after removing obvious outliers and smoothing both the easting and northing values with a five-point boxcar moving average.

We used the multiple covariates distance sampling analysis engine in Distance 4.1 (Release 2) software (Buckland et al. 2004; Thomas et al. 2004) to calculate density and total abundance for cowcod at each of the eight banks. Fish size was included as a covariate in the detection function because cowcod vary greatly in size (5–100 cm) and larger fish can be seen more easily at a distance. Key assumptions of the line-transect method include the following: (*i*) all individuals on the track line are detected (i.e., the track-line detection probability ($g(0)$) = 1); (*ii*) a closed population during the survey (i.e., no immigration, emigration, births, and deaths);

Fig. 2. Rocky areas within a depth range from 75 to 300 m (shaded areas) that were surveyed for cowcod (*Sebastes levis*) using the *Delta* submersible (scattered black lines indicate dive tracks) within the Cowcod Conservation Areas (boxes) in 2002 off southern California.



(*iii*) cowcod are randomly distributed relative to the track line; (*iv*) cowcod behavior is independent of the observer and submersible (i.e., no avoidance or attraction); and (*v*) measurements are exact.

Density of cowcod was estimated by bank as

$$D_j = \frac{n_j f(0, c_j)}{L_j}$$

where n_j is the total number of cowcod detected from all samples (dives) on the *j*th bank; c_j is the mean size of cowcod on the *j*th bank; $f(0,c_j)$ is the probability density function evaluated at zero perpendicular distance for fish of size c_j (note that the function *f* is the probability density of the modeled detection function, *g*); and L_j is the sum of individual transect lengths on the *j*th bank. Bank-specific effective strip widths (ESWs) were calculated as $f(0,c_j)^{-1}$ (Buckland et al. 2001). The frequency distribution of perpendicular sighting distances of cowcod from the track line was modeled using either a half-normal or a Hazard rate estimator with or without cosine adjustment terms. The best model was selected based on minimizing Akaike's information criterion (AIC) for data from each of the eight banks. Truncation of the most distant observations was investigated to improve model fit and robustness, as recommended by Buckland et al. (2001). Variance of the encounter rate ($n_j \cdot L_j^{-1}$) was estimated empirically (Distance bootstrap with 500 replicates); variance of $f(0,c_j)$ was estimated by maximum likelihood. Total abundance of cowcod on each bank was estimated as

$$N_j = D_j A_j$$

where A_j is the estimated area of the *j*th bank, which was assumed to be known without error. Total abundance was estimated as the sum of cowcod across all banks, and pooled estimates of density over all banks in the CCAs were made from the area-weighted bank densities. Variance in total abundance was calculated using Goodman's (1960) formula for the variance of products, based on the estimated variances of the encounter rate ($n \cdot L^{-1}$) and the pooled detection function. Bank-specific cowcod biomass (B_j) was calculated as

$$B_j = N_j X_j$$

where X_j is the mean weight of cowcod on the *j*th bank. Mean weight was calculated from the estimated lengths of fish and the relationship between total length (TL; cm) and weight (*W*; g) for cowcod, $W = 0.01009\text{TL}^{3.09332}$ (adapted from Love et al. 1990). Larger cowcod were detected at greater distances from the transect line during our surveys. Therefore, to avoid size bias, only cowcod sighted within 2.7 m of the transect line (i.e., the distance where the probability of detection was > 0.6 (Buckland et al. 2001)) were included in the estimation of mean weight. Within this distance, a regression of fish size vs. distance was flat (p = 0.76, r^2 = 0.0006). Total cowcod biomass was subsequently estimated as the sum of the biomass of cowcods across all banks. The coefficient of variation (CV) of the biomass estimate was obtained using the delta method (Seber 2002).

Results

During 28 days of mostly ideal sea conditions, we made 94 submersible dives (about 130 h underwater) to survey

Table 1. Depth range, total area, number of submersible dives, length of dive track lines (*L*), and number (total, after truncation, and within 2.7 m of transect), encounter rate, estimated strip width (ESW), and average weight (of fish observed within 2.7 m of transect line) of cowcod (*Sebastes levis*) on eight offshore rocky banks inside the Cowcod Conservation Areas in the Southern California Bight.

Study site	Depth (m)	Area (km^2)	No. of dives	*L* (m)	Total no. of fish	No. of fish after truncation	Encounter rate ($no.\cdot m^{-1}$)	CV of encounter rate ($no.\cdot m^{-1}$)	ESW (m)	CV of ESW (m)	No. of fish within 2.7 m	Mean weight (kg)	CV of mean weight (kg)
43-Fathom	79–251	10	4	7 295	39	38	0.005209	0.282	4.26	0.116	27	4.01	0.14
Cherry	98–254	32	8	10 736	21	16	0.001490	0.308	3.55	0.193	10	1.76	0.32
Hidden	102–287	98	25	38 046	72	68	0.001787	0.168	3.37	0.099	52	1.77	0.16
Osborn	75–296	11	5	4 052	11	11	0.002715	0.544	3.58	0.232	6	1.66	0.59
Potato	99–250	22	3	3 651	8	8	0.002191	0.155	3.96	0.254	5	1.67	0.27
San Nicolas	74–322	499	21	31 731	28	28	0.000882	0.262	2.98	0.154	21	0.32	0.48
Santa Barbara	75–271	81	6	7 983	3	3	0.000376	0.705	2.63	0.475	1	0.04	
Tanner–Cortes	76–299	573	22	28 869	37	35	0.001212	0.231	3.90	0.130	20	1.55	0.24
Total	74–322	1326	94	132 363	219	207	0.001564	0.191	3.55	0.055	142	1.93	0.14

Note: Associated coefficient of variation (CV) is reported.

juvenile and adult cowcod on eight offshore rocky banks inside the CCAs (Table 1). Number of samples (dives) on each bank was 3–8 on the smallest banks (43-Fathom (10 km^2 total area), Osborn (11 km^2), Potato (22 km^2), Cherry (32 km^2), and Santa Barbara Island (81 km^2)), and 21–25 dives on the larger banks (Hidden (98 km^2 total area), Tanner–Cortes (573 km^2), and San Nicolas Island (499 km^2)). A total of 132 363 linear metres was surveyed. Actual depth of dives ranged from 74 to 322 m.

To test the key assumption that cowcod behavior is independent of the observer and submersible (i.e., no avoidance or attraction), we compared positions of cowcod on paired, time-synchronized video cameras; one camera was positioned forward along the track line and the other was positioned perpendicular to it. Video from 24 dives was reviewed, and 28 of the 30 cowcod seen by both cameras exhibited no movement. No cowcod was observed crossing from side to side across the path of the submersible. Only two cowcod moved from their original position; this movement occurred at about 8 m ahead of the submersible and was judged not to be a response to the approaching submersible based on distance and swimming behavior. Additionally, out of 74 cowcod evaluated from the survey camera positioned perpendicular to the track line, only one fish moved from 0.3 m to 1.5 m away from the submersible and 73 cowcod did not move at all.

A related assumption that there was no deviation along the track line due to maneuvering of the submersible around boulders also could potentially lead to a bias in encounter rate or error in recorded perpendicular distance of cowcod. From 30 dives comprising 31 453 m of high-relief habitats that we reviewed from videotape of the forward-looking camera, 87 individual course changes were made that could have been necessary to avoid contact with rock; this comprised <1% of the seafloor that was examined. Ninety-three percent of the 87 course changes had similar habitat on both sides. From this we estimated that a possible bias due to course changes could have occurred in <0.2% of rock habitat, and only one cowcod was seen during the 87 possible course changes. We concluded that neither fish movement nor submersible maneuvering introduced a bias in our estimates of encounter rate or perpendicular distance.

There were 241 cowcod observed during the survey; 22 of these occurred on the portside of the submersible (i.e., not within the line-transect area) and therefore were not used in the density analyses. Thirty-two percent of the sightings were of juveniles (<40 cm TL). Cowcod size distribution ranged from 5 to 100 cm and was bimodal, with modes at 20 and 50 cm TL (Fig. 3). Juveniles in the well-represented 15–20 cm size bins likely represented 1- to 3-year-old fishes, as estimated from a von Bertalanffy growth model (Butler et al. 2003).

Estimation of the detection function was improved by truncating about 6% of the most distant observations, so 12 cowcod, occurring at distances greater than 8 m from the submersible track line, were removed for model fitting. A half-normal model was selected based on minimum AIC (i.e., AIC = 727.1 and 738.5 for half-normal and hazard rate models, respectively). The basic shape of the function was the same for the combined model (all fishes from all banks; Fig. 4*a*) and for size-specific models (see, for example,

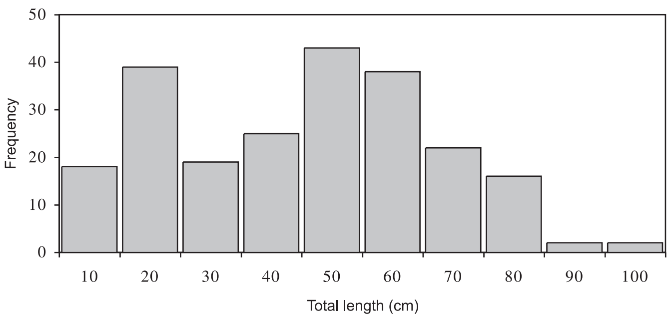


Fig. 3. Size distribution of cowcod (*Sebastes levis*; n = 219) observed from the *Delta* submersible during surveys on rocky banks within the Cowcod Conservation Areas in 2002 off southern California.

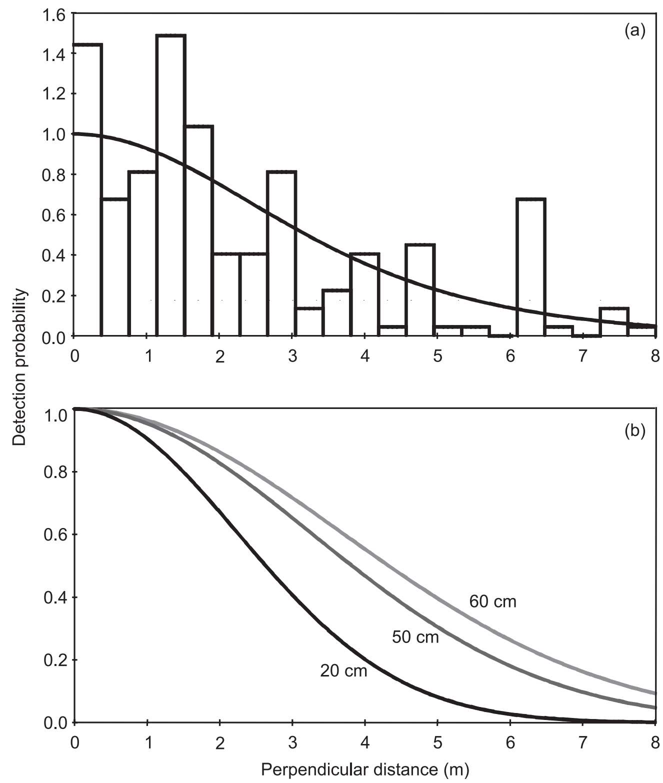


Fig. 4. (*a*) Distribution of perpendicular sighting distances (histogram) and half-normal fit (curve) for cowcod (*Sebastes levis*; n = 207) surveyed from *Delta* submersible on offshore rocky banks in Southern California Bight in 2002. Distances were truncated at 8 m prior to fitting the detection function. (*b*) Examples of estimated detection functions for three values of the covariate fish size (20, 50, and 60 cm total length).

Fig. 4*b*), but ESW was wider with increasing fish size. ESW was relatively narrow at Santa Barbara (2.63 m) and San Nicolas Island (2.98 m), associated with small cowcod at these sites (mean weights of 0.04 and 0.71 kg, respectively; Table 1). Estimated ESW was greatest at 43-Fathom and Tanner–Cortes Banks (4.26 and 3.90 m, respectively), corresponding to larger cowcod at these sites (mean weights of 3.54 and 3.47 kg, respectively).

The highest density of cowcod was found on 43-Fathom Bank (1223 fish·km^{-2}, n = 38, standard error (SE) = 372; Fig. 5*a*), the smallest (10 km^2) of our study sites. Lowest densities occurred on the rock outcrops around the two island study sites (San Nicolas and Santa Barbara) and Tanner–Cortes Bank. The other four banks had moderate densities of cowcod (420–759 fish·km^{-2}, n = 8–68, SE = 104–449). In terms of total abundance, Tanner–Cortes Bank was the hot spot followed by San Nicolas Island and Hidden Bank (Fig. 5*b*); these are the three largest study sites. The rest of the banks all contributed low numbers of cowcod. Biomass estimates ranged from 507 kg (coefficient of variation (CV) = 67%) at Santa Barbara Island to 277 097 kg (CV = 37%) at Tanner–Cortes Bank (Fig. 5*c*); this reflected mean size of fishes on these banks (i.e., 0.04 and 1.55 kg, respectively; Table 1).

The average density for the population of cowcod on the eight major rocky banks surveyed within the CCAs was estimated to be 328 fish·km^{-2} (CV = 20%), and overall abundance was 435 366 fish (Table 2). Overall biomass of cowcod across the eight banks was estimated as 524 278 kg (CV = 26%, 95% confidence interval (CI) = 318 571 – 862 814; Table 2).

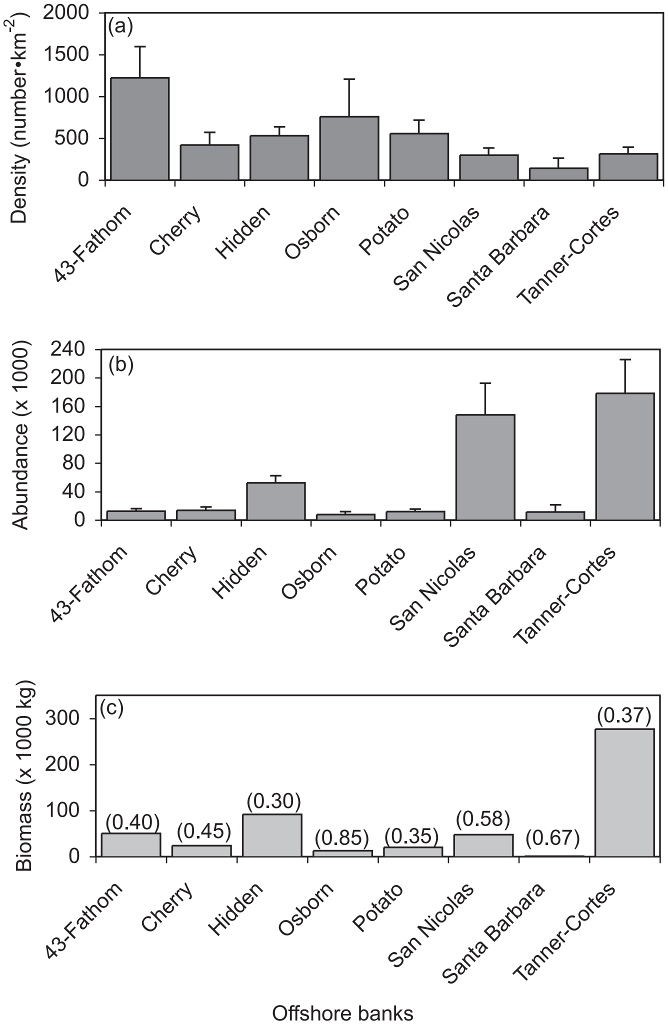
Discussion

Arguably the most important immediate finding of our study is that we have successfully demonstrated the feasibility of conducting a meaningful assessment of cowcod using visual, nonextractive, habitat-specific survey methodologies. This is the only fishery-independent assessment of the cowcod population and includes estimates of density, total abundance, and biomass with reasonably good measures of precision on each of eight major banks inside the CCAs. The PFMC currently is using this information to improve their cowcod stock assessment and evaluate the rebuilding program for the depleted cowcod population. Our bank-specific estimates should also inform decisions made by the PFMC and NMFS regarding proposals for modifications to the boundaries of the CCAs presented by the fishing communities.

This is not the first demonstration of direct-observation survey methods to estimate abundance of a demersal rockfish population for management purposes. O'Connell and Carlile (1993) introduced the use of line-transect methods in conjunction with habitat-specific survey design to estimate density and abundance of yelloweye rockfish (*Sebastes ruberrimus*) over a large area of the eastern Gulf of Alaska (GOA), and they have been using this approach since 1990 to survey quillback (*Sebastes maliger*), tiger (*Sebastes nigrocinctus*), and rosethorn (*Sebastes helvomaculatus*) rockfishes, in addition to yelloweye rockfishes. Recommendations of allowable biological catch for the entire demersal shelf rockfish assemblage in the eastern GOA are based on abundance of adult yelloweye rockfishes as estimated from such visual surveys (see, for example, O'Connell et al. 2001).

Our survey methods build upon those of O'Connell and Carlile (1993) and provide critical evaluation of several fundamental assumptions that underlie line-transect surveys. In addition, the similarities in behavior (sedentary, solitary), morphology (large, easily recognizable), and habitat associations (irregular rock and boulders) of the targeted species

Fig. 5. (*a*) Density, (*b*) total abundance, and (*c*) biomass of cowcod (*Sebastes levis*) as estimated from line-transect surveys conducted from the *Delta* submersible on eight rocky banks inside the Cowcod Conservation Areas. In (*a*) and (*b*), vertical lines indicate standard error. In (*c*), coefficient of variation for biomass is reported in parentheses.



(yelloweye rockfish and cowcod) in these two unique surveys might provide some insight into the interpretation of our cowcod density and variance estimates. Although both surveys were conducted in prime habitats and depths, overall estimated mean density of cowcod (328 fish·km^{-2}) off southern California was at least six times lower than that of yelloweye rockfish in eastern GOA (1954–2217 fish·km^{-2}; O'Connell and Carlile 1993). Coefficients of variation for fish were similar for both studies (20% for cowcod; 15%–25% for yelloweye), indicating a similar level of precision in the estimated population density. From the stock assessment model for cowcod in southern California (Butler et al. 2003), cowcod population size was estimated to be about 7% that of the unfished level 80 years ago. Considering this estimated level of depletion and our current estimated density, we might expect that original densities of cowcods approached those of the healthy, yet fished population of yelloweye rockfish in eastern GOA (O'Connell and Carlile 1993). This would be consistent with relatively unfished densities of cowcod that were estimated in Monterey Bay (Yoklavich et al. 2000). Although rebuilding the overfished cowcod population to 40% of historic levels has been estimated to take 87 years (Butler et al. 2003), the relatively high number of small cowcod in our survey hopefully represents the nascent rebuilding of this population. Monitoring this recovery will be critical as the results of protection are manifested within the CCAs.

Table 2. Overall density, abundance, biomass, and related statistics for all cowcod (*Sebastes levis*) surveyed on eight offshore rocky banks within the Cowcod Conservation Areas in Southern California Bight, October–November 2002.

Statistic	Estimate
Number of observed fish	207
Total length of trackline (m)	132 363
Density (number·km^{-2})	328
Total area (km^2)	1 326
Abundance	435 366
CV (density, abundance)	0.20
Mean weight (kg)	1.93
CV (mean weight)	0.14
Biomass (kg)	524 278
CV (biomass)	0.26
Lower 95% CI (biomass) (kg)	318 571
Upper 95% CI (biomass) (kg)	862 814

Note: Coefficient of variation, CV (abundance) is based on Distance bootstrap; CV (biomass) is based on delta method. CI, confidence interval.

Why use direct-observation surveys?

Like all survey methods, visually counting cowcod along the track of a submersible has several advantages and some disadvantages. First and foremost among the advantages is that there is no other way to accurately estimate the abundance of this species (as well as several others), particularly now that most of the continental shelf and upper slope have been closed to groundfishing off southern California, leaving few sources of fish information from catches. More importantly, conventional, extractive trawl surveys have proven to be ineffective in assessing the abundance of rockfish species that live in complex high-relief habitats (Jagielo et al. 2003; Zimmermann 2003; Wallace 2007). Cowcod, particularly adults that occur exclusively in mixed boulder habitats, are grossly underestimated in trawl surveys. In addition, the complex geological setting and resultant extreme topography of the Southern California Bight, including a series of islands surrounded by marine terraces, exposed rock ridges and banks, and deep sediment-filled basins and canyons, preclude effective trawl surveys and trawl fisheries in many areas of the Bight.

Surface-based sampling gear, such as the fixed commercial longlines widely used on rock outcrops throughout the Bight, also can be biased as an index of abundance for demersal fishes. Catch per unit effort (CPUE) can overestimate population size especially for species of low actual abundance because of attraction to bait (Grimes et al. 1982). Conversely, CPUE can underestimate the population size in areas of relatively high abundance because of hook saturation. It also is difficult to produce density estimates from CPUEs because area swept is largely unknown in longline surveys. Additionally, CPUE may be especially misleading as an index of population abundance for sedentary species, as catches can remain relatively high as fishermen move away from depleted areas seeking new, less exploited ones.

Hydroacoustics is a nonextractive survey method commonly used to estimate numbers of aggregating fishes in midwater, away from the seafloor. This method, however, has proven ineffective in identifying and accurately enumerating solitary rockfishes that occur on, under, or in complex rock habitats (Starr et al. 1996). Densities in strip transects surveyed by direct observation from an occupied submersible were more than six times greater than those estimated during hydroacoustic surveys of fishes near the bottom (Starr et al. 1996).

Surveys of larval abundance also have been considered in the estimation of biomass of some species of rockfish (Ralston et al. 2003). However, this type of fishery-independent survey is not useful in an assessment of the cowcod population because of the extremely rare occurrence of their larvae in ichthyoplankton tows made within the CCAs off southern California (Moser et al. 2000).

Nonextractive, direct-observation techniques such as those described here are especially ideal when surveying fishes of low abundance occurring in high-relief rock inside a marine protected area such as the CCAs. Although extractive collections can be advantageous in discerning size, age, and sex of the target species, they also can adversely affect the population parameters that are being estimated when species abundance is extremely low (e.g., cowcod). Nonextractive methods also are required when trying to protect sensitive components of habitats (e.g., structure-forming sessile invertebrates, such as the black coral (*Antipathes dendrochristos*) that is often co-located with cowcod (Tissot et al. 2006)), which can be disturbed when using some types of extractive gear to survey fish populations. Direct-observation surveys allow for habitat-specific assessments, which can result in more accurate and precise estimates of associated fishes. These methods can be used in habitat-specific assessments of a number of economically and ecologically valuable sedentary benthic fish species (e.g., lingcod (*Ophiodon elongatus*), greenspotted (*Sebastes chlorostictus*) and greenblotched (*Sebastes rosenblatti*) rockfishes, and adult bocaccio (*Sebastes paucispinis*)).

Why use line-transect surveys?

Strip transects typically have been used when quantifying marine benthic fishes from an occupied submersible (Love et al. 2000; Yoklavich et al. 2002; Jagielo et al. 2003). This sampling method assumes 100% detectability of the target species within the strip. To ensure that this assumption is met, it has been necessary to use a relatively narrow strip width (usually 2 m) during these surveys. The result is that many individuals outside the strip are sighted but not included in the survey. This can be especially problematic for those species of very low densities and can require considerably more samples (dives) to assess density with reasonable variance over large areas.

Cowcod are large, sedentary, easily recognizable targets that also are rare and sparsely distributed in their environment. Line-transect methods meet our need to maximize the efficient use of submersible time by increasing the probability of detecting the cowcod along the dive track line. During a line transect, the observer notes the perpendicular distance from the track line of each cowcod that is sighted. Rather than the proviso of 100% detectability within a strip of fixed width, the line-transect method requires 100% detectability on the track line (that is, at zero distance from the submersible), with decreasing probability of detection as distance to the track line increases. Using the line-transect method, the effective strip width in our survey of cowcod almost doubled (i.e., increasing from 2 m to an average of 3.5 m for strip- and line-transect methods, respectively) for the same amount of effort (number of dives).

The assumption of 100% detectability on the track line is easily met for adult cowcod, considering their relatively large size and sedentary behavior, the lack of avoidance or attraction behavior relative to the submersible, and our use of a second video camera directed toward the area adjacent to the track line. In contrast, it is unlikely that 100% of the larger juvenile cowcod (>20 cm TL) are seen on the track line, because some individuals are likely out of view among small boulders or in crevices (Love and Yoklavich 2007). The assumption of $g(0) = 1$ (that is, all individuals on the track line are detected) in this analysis is, therefore, expected to result in an underestimation of the density of juvenile cowcod by an unknown amount. Additional studies will be required to estimate the true detection probability for juvenile cowcod along the track line in high-relief habitats.

Several additional assumptions are required for unbiased estimates of density and abundance during line-transect surveys. The short duration of both the dives and the survey provides little opportunity for immigration, emigration, births, and deaths of this sedentary species, satisfying the closed-population requirement. The assumption that cowcod are distributed randomly relative to the track line was met by randomizing the sample sites and traversing haphazardly across substratum types and across the depth gradient during each dive.

A third important assumption is that cowcod behavior is independent of the observer and submersible (i.e., no avoidance or attraction). Based on over 30 years of collective experience using the *Delta* submersible to survey fishes in various rock habitats along the Pacific coast, there is broad consensus that a submersible traveling at a constant and slow speed, as in the present study, creates little or no response (either avoidance or attraction) from solitary, demersal rockfishes (M.S. Love and M.M. Yoklavich, personal observations; V. O'Connell, Alaska Department of Fish and Game, 304 Lake Street, Room 103, Sitka, AK 99835, USA, personal communication). In our study, a third, forward-looking external video camera was positioned on the front of the submersible primarily to document various species of rockfishes occurring in midwater above the submersible. There was no indication of movement of cowcod as the submersible approached on any of the three video cameras, which led to our conclusion that there was no bias introduced by the survey method.

A final assumption for unbiased estimates of density and abundance is that measurements are exact. We attempted to minimize these sources of error and evaluate their influence on abundance estimates. In a recent, separate study, we have estimated the error associated with underwater measurements of fish size, distance to fish, and length of transect. Using paired lasers and the *Delta* submersible, five observers measured fish replicas (n = 189–230) of known total length placed at various distances from lines set on the seafloor. We generally underestimated fish size (mean deviation = –1.1 cm, SD = 1.2) and distance to fish (mean deviation = –0.10 m, SD = 0.10) but did not consider these small amounts in our estimates of abundance. Underestimating fish size would result in an underestimate of biomass, and underestimating distance to fish would result in an overestimate of density. In future studies, we intend to develop observer-specific correction factors for estimates of distance and size.

Additional sources of potential measurement error include the estimation of the total length of transect surveyed and the total area of each bank. We assumed that these variables were known without error, although some amount of error was likely to have existed in their estimation. From a recent comparison between two 100 m lines set on the seafloor and the estimated track length from *Delta* navigation data, track length was overestimated by an average of 7% (n = 23), which would result in an underestimate of fish density (M.M. Yoklavich, unpublished data).

The combination of all potential sources of error in measurements could result in either an upwards or downwards bias in densities and total abundance, depending on the direction of estimation error, and variances could be underestimated. The inclusion of these potential sources of error, however, would not be expected to change the precision of the overall abundance and biomass estimates substantially, because the variances in encounter rate (19.1%) and in $f(0)$ (5.5%) contributed the most towards overall precision.

Our estimated abundance and survey efficiency can be further improved by incorporating more accurate estimates of the size of the rocky banks into future monitoring of the cowcod population inside the CCAs. We recently completed a survey of seafloor habitats in several of our study sites using high-resolution multibeam bathymetry (Goldfinger et al. 2005). The results of this survey provide more accurate interpretations and spatial estimates of the types of seafloor substrata available as fish habitats. Preliminary Distance models run with and without habitat stratification (rock and nonrock substrata) for five of our eight study sites (banks) resulted in similar estimates of cowcod abundance. AIC was the same for stratified (484.0) and unstratified (484.4) analyses with 8 m truncation. From these results, we determined that our survey design adequately sampled the habitats (rock and sand) and depths (shallow (75–150 m), medium (151–225 m), and deep (226–300 m)) in proportion to occurrence in the study areas. Therefore the unstratified analysis was appropriate for our study sites. This information will be useful in the design of an efficient monitoring plan for the CCAs.

Our survey protocols and resulting estimates of density, abundance, and biomass of the cowcod population on the major banks inside the CCAs will serve as the foundation for long-term monitoring of these closed areas and have already been incorporated into the most recent stock assessment of this species (Dick et al. 2007). From these initial estimates, we can now evaluate appropriate time intervals and the distribution and magnitude of sampling effort needed to assess trends in the cowcod population within and, if desired, beyond the CCAs.

Acknowledgements

Field surveys were successfully conducted with assistance from D. Schroeder, M. Nishimoto, L. Snook, T. Laidig, T. Anderson, R. Starr, B. Lea, C. Wahle, and the dedicated crews of the R/V *Velero* and R/V *Delta*. M. Amend, J. Harvey, and D. Watters assisted with analyses. This research and manuscript were improved by thoughtful comments from E. Dick, T. Laidig, A. MacCall, T. O'Connell, S. Ralston, S. Sogard, D. Watters, members of the CIE review (T. Gerrodette, M. Kingsley, D. Sampson) and PFMC Cowcod STAR panels, and three anonymous reviewers. Underwater photographs were provided by J. Bright and M. McCrea. Partial funding was provided by NOAA's NMFS Offices of Habitat Conservation and Protected Resources, National Undersea Research Program, Marine Protected Area Science Center, and the David and Lucile Packard Foundation.

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