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Abstract—Data from the West Coast Bottom Trawl Survey and from surveys conducted with a manned submersible in nearby untrawlable areas were used to compare length distributions for greenspotted rockfish (*Sebastes chlorostictus*), greenstriped rockfish (*S. elongatus*), canary rockfish (*S. pinniger*), and vermilion rockfish (*S. miniatus*) off central California. For all 4 species, broader size ranges and greater proportions of small fish were present in the data from the submersible surveys, and length distributions were significantly different (P<0.01) in comparisons of all lengths from the submersible surveys with all lengths from the trawl surveys, as well as in comparisons of lengths from the submersible surveys and trawl surveys over trawlable habitat. For 3 species, length distributions were significantly different in comparisons of lengths obtained from submersible surveys on trawlable and on untrawlable habitats. Trawl selectivity curves from recent stock assessments were evaluated in relation to the length data for greenspotted, greenstriped, and canary rockfish. Although derived from a larger spatiotemporal extent than our study, greenspotted and greenstriped rockfish selectivity curves appear to account for the reduced frequency of small fish in the trawl survey, whereas the canary rockfish selectivity curve does not. Similar comparisons between submersible and trawl-survey rockfish lengths from other regions of the west coast could help address spatial variability in trawl survey selectivity and further inform selectivity functions for stock assessments.

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A comparison of length distributions of rockfishes (*Sebastes* spp.) from submersible and trawl surveys off central California

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Rockfishes (genus *Sebastes*) have been historically significant for California commercial and recreational fisheries. Approximately 40 of the more than 60 species that occur off California have been harvested over the last 150 years (Love et al., 2002; Love, 2006). Most of these species occur at depths of 30–500 m on the continental shelf and upper continental slope off California, and associate with complex rocky seafloor habitats, such as pinnacles, rock ridges, boulders, canyon walls, and cobbles, mixed with varying amounts of low relief soft sediments (Love and Yoklavich, 2006). The diversity of deepwater rockfishes and the complex habitats that they occupy make them difficult to study and manage.

Most Pacific rockfishes are managed by the Pacific Fisheries Management Council in accordance with its Pacific Coast Groundfish Fishery Management Plan and stock assessment process (website), as first required by the Magnuson–Stevens Fishery Conservation and Management Act of 1976. Since 1999, several rockfish species have recovered from an overfished to a rebuilt status; currently, 2 species remain classified as overfished and in rebuilding status (cowcod [*S. levis*]; and yelloweye rockfish [*S. ruberrimus*]). However, regulatory measures implemented to reduce fishing mortality for rebuilding rockfish stocks have also reduced the amount of fishery-dependent data available for stock assessments (Field et al., 2006; Starr et al., 2016). A principal source of fishery-independent data for rockfish stock assessments is the Northwest Fisheries Science Center (NWFSC) West Coast Bottom Trawl Survey (hereafter referred to as the trawl survey; Keller et al., 2017), which cannot be conducted in complex rocky habitats where the highest densities of most deep-water rockfishes occur. Recognizing that trawl survey data may not represent many rockfish populations adequately, the Pacific Fisheries Management Council has encouraged the development of survey methods in untrawlable areas and research on the relative density, age, and length composition of rockfishes in trawlable and untrawlable areas (PFMC[1]). In particular, comparisons of length composition data between trawlable and untrawlable

[1] PFMC (Pacific Fishery Management Council). 2013. Groundfish fishery management plan. *In* Research and data needs 2013, p. 21–31. Pacific Fishery Management Council, Portland, OR.. [Available at website.]

areas could increase understanding of trawl-survey selectivity, thereby improving model estimates of stock abundance.

Length composition data are among the fundamental sources of information used to assess fish populations (Ono et al., 2015), and sampled lengths ideally would represent the true distribution of lengths in a population. Length distributions are used to estimate critical population parameters (e.g., growth, mortality, recruitment), and the selectivity of fishing gear or scientific sampling methods. Length-dependent selectivity values are estimated from the fit of a stock assessment model to trawl survey data; selectivity can be thought of as a function of the availability of all lengths in the population to the trawl gear and the efficiency with which the gear samples those available lengths (Sampson, 2014; Weinberg et al., 2016). Selectivity also can be considered as the probability of a fish being sampled in relation to its length (Maunder et al., 2014). The selectivity function relates the index of abundance from the trawl survey to the estimate of total population abundance from the stock assessment model, and can interact with related model parameters, such as growth and natural mortality. Therefore, appropriate specification of selectivity is critical for reliable model outputs, evaluation of stock status, and resulting management recommendations (Maunder et al., 2014; Sampson, 2014; Weinberg et al., 2016).

Submersible surveys of demersal rockfishes that are most abundant in deepwater, untrawlable habitats can provide non-extractive, fishery-independent estimates of abundance, size composition, and biomass for stock assessments, e.g., cowcod (Yoklavich et al., 2007; Dick and MacCall, 2014); and yelloweye rockfish (O'Connell et al.[2]). Such surveys provide spatially explicit data that reveal patterns in abundance, size, and biomass, as well as habitat associations and community structure that are not possible with other survey methods (Yoklavich et al., 2000; Yoklavich and O'Connell, 2008; Wedding and Yoklavich, 2015). Length composition data from submersible surveys of rockfishes in areas of untrawlable habitat can be used to assess the extent to which length data from trawl surveys represent these populations on a regional basis, and to provide information to aid stock assessors with choosing a function that best represents trawl survey selectivity for a given species.

In this study, we examined length data collected off central California in trawl surveys and from surveys conducted with a manned submersible in nearby untrawlable areas. Our objectives were to compare length distributions of demersal rockfishes sampled in these two surveys, to evaluate the extent to which they might differ, and thereby to inform trawl survey selectivity functions used in stock assessments for selected species.

[2] O'Connell, V., C. Brylinsky, and D. Carlile. 2003. Demersal shelf rockfish stock assessment and fishery evaluation report for 2004. Alaska Dep. Fish Game., Reg. Inf. Rep. 1J03-39, 36 p. [Available from website]

Materials and methods

Our study area was located off central California within the region bounded by latitudes 36°N (just south of Big Creek) and 37°N (Davenport), which was the geographic extent of the most recent submersible surveys conducted during a 7-yr period 2003–2009 (Fig. 1). We chose the period 2003–2009 for our study because our initial examination of length data for several species sampled during the trawl survey indicated that we would need to combine data from multiple years to ensure adequate data for comparison.

Submersible surveys of fishes and habitats were conducted with the 2-person *Delta* (Delta Oceanographics,[3] Torrance, CA) during daytime hours (typically 0700–1700) between late August and early November in years 2003, 2004, 2007, 2008, and 2009. Surveys of a total of 919 strip transects 2 m in width and averaging 248 m in length (standard deviation [SD] 54.4) were conducted at depths ranging from 24 to 326 m in submarine canyon and continental shelf locations. Strip-transect surveys of 10-min duration were directed by a scientific navigator aboard the support FV *Velero IV* and were located in areas of rocky substrata determined from maps of bathymetry and interpreted seafloor habitat (Monterey Bay Aquarium Research Institute, website; California State University Monterey Bay Seafloor Mapping Lab, website; Yoklavich et al., 1997; Eittreim et al., 2002). The position of the submersible was displayed in ArcGIS, vers. 9.0–9.3 (Esri, Redlands, CA) and tracked at 1- to 3-s intervals with an ORE Trackpoint II ultra-short baseline (USBL) acoustic system (EdgeTech, West Wareham, MA) and WinFrog software (Fugro, Leidschendam, Netherlands). The length of each transect was estimated either from the edited and smoothed USBL navigation data, or from a MiniRLG2 ring laser gyrocompass (Teledyne TSS, Watford, UK) and NavQuest 600 Micro Doppler Velocity Log (LinkQuest, Inc., San Diego, CA) mounted on the outside of the submersible. Details about the *Delta* survey vehicle, its associated equipment, and visual survey methods are described by Laidig and Yoklavich (2016) and Yoklavich and O'Connell (2008).

From inside *Delta*, a pilot and a scientist conducted the transect surveys. The pilot operated the submersible within 1 m of the seafloor at a speed of 0.3–0.5 m/s (0.5–1.0 kn), while the scientist identified and counted all fishes within the transect, and estimated their total lengths (TL) to the nearest 5 cm by direct observation in situ. A video camera and lights (Laidig and Yoklavich, 2016), mounted externally on the starboard side of

[3] Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

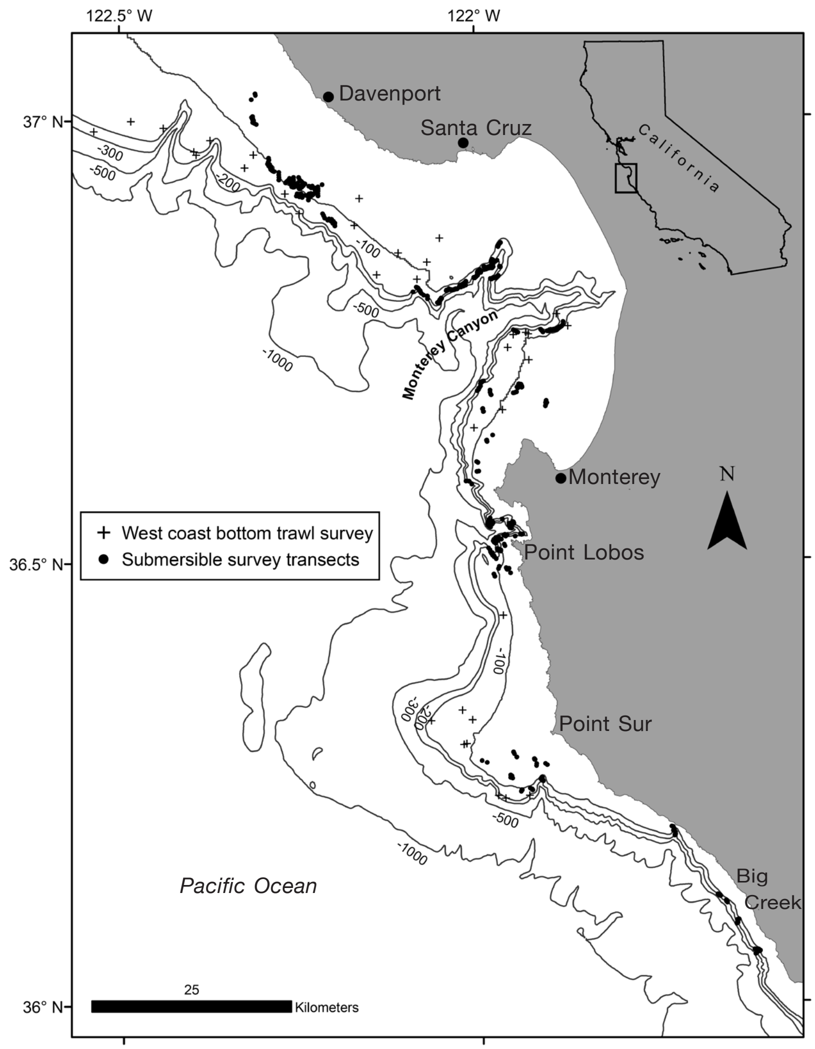

Figure 1

The study area off central California with locations where transects of submersible surveys (black dots) and hauls of the Northwest Fisheries Science Center West Coast Bottom Trawl Survey (black crosses) were conducted from 2003 through 2009. Only transects and hauls with positive occurrence of one or more of the following 4 rockfish species at depths 55–326 m are shown: greenspotted rockfish (*Sebastes chlorostictus*), greenstriped rockfish (*S. elongatus*), vermilion rockfish (*S. miniatus*), and canary rockfish (*S. pinniger*). Depth contours are in meters.

the submersible above the scientist's viewport, recorded the view of the transect area and the scientist's narration. Two parallel lasers, spaced 20 cm apart on either side of the camera, aided estimates of fish lengths. A handheld sonar gun was used by the scientist to estimate and maintain the 2-m transect width. The time of each fish observation, along with counts and length estimates, was entered into a relational database during subsequent video analysis.

The amount and type of seafloor habitat within each subsmersible transect were defined from a video review. Contiguous patches comprised primary (>50% of the area) and secondary (>20% of the area) habitat types delineated by time (at least a 3-s duration) along each transect. Habitat types were 1) high-relief rock outcrop (>1 m and <3 m in-place rock), pinnacle (>3 m, isolated rock outcrop) and boulder (>25 cm); and 2) low-relief cobble (>6 cm and <25 cm), flat rock, brachiopod bed, pebble (>2 cm and <6 cm), gravel (>4 mm and <2 cm), sand, and mud. The area of each habitat patch was estimated by multiplying the 2-m transect width by the patch length. We categorized these habitat patches as untrawlable or trawlable after consulting with scientists familiar with the trawl survey and our habitat classification method (Whitmire,[4] Wakefield[5]). Untrawlable habitats were considered to be primary and secondary combinations of at least 1 high-relief type, e.g., boulder-boulder, rock-mud, or sand-pinnacle. Trawlable habitats were primary and secondary combinations of low-relief types, e.g., cobble-cobble, cobble-mud, mud-mud, flat rock-sand. Trawlable habitats within a transect were considered to be proxies for the type of area surveyed by a trawl, although these patches were too small to be trawled. We noted the occurrence of each fish on untrawlable or trawlable habitat patches.

The current trawl survey has been conducted annually off the U.S. west coast since 2003, from Cape Flattery, Washington (48.3°N latitude), to the border with Mexico (32.6°N latitude). Detailed descriptions of the survey design, sampling allocation, protocols, and equipment are provided by Keller et al. (2017). A stratified, random grid design and chartered commercial bottom trawlers were used to sample depths 55–1280 m during daylight (after sunrise and before sunset). Cells within the grid were 3.7 km (2.0 nautical mile [nmi]) latitude by 2.8 km (1.5 nmi) longitude in size and were selected randomly from depth and latitudinal strata. Within a selected cell, the captain of the vessel surveyed the seafloor with sonar to find suitable areas that were large enough to accommodate a 15-min trawl haul conducted at a speed of 1.1 m/s (2.2 kn). Trawlable habitat types were low to moderate in relief and included little substrata larger than cobble (Wakefield[5]).

The trawl net was an Aberdeen-type bottom trawl (NET Systems, Inc., Bainbridge Island, WA) with a 14.0-cm (5.5-in) stretch mesh and 3.8-cm (1.5-in) mesh liner that extended from the middle of the intermediate section to the codend. The spread of the net when deployed was approximately 5 m high and 14 m at the wing tips. The footrope had a continuous series of 25.4-cm (10-in) rubber disks that allowed the net to pass over cobbles (Wakefield[5]). Predetermined species of management concern or interest were subsampled randomly for individual length measurements. Depending on the species, up to 100 individuals were measured (fork length [FL]) to the nearest cm from each haul (Keller et al., 2017).

Trawl survey data were obtained from the NWFSC Data Warehouse: (website). We selected trawl hauls with the project name “Groundfish Slope and Shelf Combination Survey,” with a “satisfactory” performance (determined from sensors attached to the trawl net to monitor bottom contact and the net opening [Keller et al., 2017]), and from latitudes 36° to 37°N and years 2003–2009, resulting in a total of 139 hauls conducted at depths 60–1208 m from June through October.

We examined the length data from the trawl and submersible surveys for harvested deepwater rockfishes that commonly occur off central California within the overlapping depth range of the two surveys (55–326 m) (Love et al., 2002). Species with at least 50 length records from each survey were considered for comparison. We also considered species that have different orientations to the seafloor (i.e., on-the-bottom dwellers, near-the-bottom dwellers) and habitat associations, as described in Yoklavich et al. (2000), Love et al. (2002), and Laidig et al. (2009). On the basis of these considerations, we selected 4 rockfishes for analysis: greenspotted rockfish (*S. chlorostictus*), a bottom-dwelling species that occurs on a wide range of habitats; greenstriped rockfish (*S. elongatus*), a bottom-dwelling species that occurs primarily on low-relief cobble and mud; canary rockfish (*S. pinniger*), a near-bottom species that occurs over high-relief rock; and vermilion rockfish (*S. miniatus)*, a near-bottom species that occurs over high-relief rock.

From submersible transects and trawl hauls (i.e., samples) with positive occurrences and length data for each of these 4 species, we examined the number of samples, total area sampled, and numbers and depths of fish measured from each survey. Fish length data from depths <55 m in the submersible survey were eliminated to match the shallow depth limit of the trawl survey. Fish length data from the trawl survey fell within the 326-m maximum depth of the submersible survey; therefore none was eliminated. Fish lengths measured from the trawl survey were converted from FL to TL by using conversions from Echeverria and Lenarz (1984). Within the 2 surveys, length data for each species were weighted by sampling effort.

For each species, we compared 1) all lengths from trawl and submersible surveys; 2) lengths from the submersible survey associated with untrawlable and trawlable habitats; and 3) lengths from trawl and submersible surveys associated with trawlable habitats. For these comparisons, we plotted lengths as the percentage of total frequency, using trawl data binned to 5-cm increments (bin as the midpoint) to match the format of the submersible data, and we added the trawl survey selectivity curve (not available for vermilion rockfish) from the most recent stock assessment to the plots with trawl data. To test whether 2 length-frequency distributions came from the same distribution, we used Pearson’s chi-square two-sample test in R statistical software, vers. 3.3.2 (R Core Team, 2016) and trawl data binned to 5-cm increments. The means of the length data and the 10%, 50%, and 90% quantiles were calculated (trawl data, however, not binned) with R statistical software (R Core Team, 2016).

Results

The spatial distribution of submersible transects and trawl hauls with 1 or more of the 4 species present in our study from depths ≥55 m was fundamentally

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[4] Whitmire, C. 2017. Personal commun. Northwest Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 99 Pacific St., Bldg. 255-A, Monterey, CA 93940.

[5] Wakefield, W. 2017. Personal commun. Northwest Fish. Sci. Cent., Natl. Mar. Fish. Serv., 2032 SE OSU Dr., Newport, OR 97365-5275.

Table 1

Characteristics of samples from submersible and bottom-trawl surveys used to compare length distributions of 4 species of rockfish (*Sebastes* spp.) off central California (36–37°N latitude) during 2003–2009. Habitats categorized as trawlable within the submersible surveys were considered rough proxies for the trawl survey because they were too small to be trawled. Common depth ranges for species are from Love et al. (2002).

Species	Survey	No. of transects or hauls	Total area sampled (m^2)	Area of trawlable habitat surveyed (%)	No. of fish measured	Avg. depth and depth range (m) of measured fish	Common depth range (m) of species
Greenspotted rockfish	Submersible	503	250,970	40	3282	132 (55–307)	30–363
	Trawl	20	318,699	100	292	109 (85–239)	
Greenstriped rockfish	Submersible	369	189,596	47	2157	125 (80–299)	100–250
	Trawl	28	461,814	100	601	126 (94–264)	
Vermilion rockfish	Submersible	139	65,846	22	695	111 (55–203)	50–150
	Trawl	6	90,812	100	80	111 (81–121)	
Canary rockfish	Submersible	120	53,313	27	667	108 (55–233)	80–200
	Trawl	9	144,062	100	90	98 (84–161)	

different (Fig. 1). A total of 609 submersible transects were clustered in canyons and areas of relief, whereas 35 trawl hauls were dispersed outside of these areas. Length data from the trawl and submersible surveys were collected from overlapping depths throughout the common depth range of all 4 species (Table 1). Range of depth was broader for the submersible data. Trawlable habitat represented less than 50% of the total habitat sampled along submersible transects and varied by species. Transects with vermilion and canary rockfishes present contained the least amount of trawlable habitat, while those with greenspotted and greenstriped rockfishes contained greater amounts of habitat categorized as trawlable. In general, the amount of seafloor area sampled in relation to the number of fish measured was considerably greater for trawl hauls than for submersible transects.

The first comparison, that of length distributions of all individuals of each of the 4 species, revealed significantly different distributions for the 2 surveys (Pearson's chi-square two-sample test, $P<0.001$), and there was a broader range of lengths and greater proportion of small fish in the submersible data (Fig. 2, Table 2). Greater proportions of greenspotted and greenstriped rockfishes <30 cm TL and <20 cm TL respectively, and canary and vermilion rockfishes <40 cm TL and <45 cm TL respectively, were present in the submersible data than in the trawl data. Binned maximum lengths from the 2 surveys were the same for greenstriped (40 cm TL) and vermilion (60 cm TL) rockfishes, 5 cm TL larger in the submersible survey for greenspotted rockfish (50 cm TL), and 15 cm TL larger in the submersible survey for canary rockfish (70 cm TL). Greenspotted rockfish length distributions were most similar between the surveys, although two peaks were present in the trawl survey data; all but the smallest (5 cm TL) and largest (50 cm TL) length bins were represented in trawl survey data for this species. Length distributions of vermilion and canary rockfishes were most dissimilar between the surveys; several length bins with data from the submersible survey were missing data from the trawl survey, and the 10% length quartiles differed by ca. 10-cm-TL.

Trawl survey selectivity curves for greenspotted and greenstriped rockfishes are consistent with a reduced proportion of small fish compared with the proportion from the submersible survey (Fig. 2). The disproportionate number of small canary rockfish in the submersible survey, compared with that in the trawl survey, is not consistent with the estimated trawl selectivity curve for that species. If canary rockfish larger than 15 cm TL are 100% vulnerable to the trawl survey, as implied by the selectivity curve, the expected proportions of small sizes would be at least as large as those in the submersible survey.

The second comparison, that of length distributions of fish from the submersible survey on untrawlable and trawlable habitats (Fig. 3), revealed significantly different distributions for greenspotted, greenstriped, and canary rockfishes (Pearson's chi-square two-sample test, $P<0.001$), whereas those of vermilion rockfish were not (Table 3). Mean lengths for all, except vermilion rockfish, were smaller on trawlable than on untrawlable habitat. All sizes of greenspotted rockfish were present on both habitat types; however, small (<20 cm TL) fish occurred in greater proportion on trawlable than on untrawlable habitat. Greenstriped rockfish, with almost equal numbers of lengths from the 2 habitats, had a greater proportion of small (<20 cm TL) fish on trawlable habitat. The small number of canary rockfish that were surveyed on trawlable habitat (35 individuals) also had a greater proportion of small (<20 cm TL) fish than the proportion of small fish present on untrawlable habitat. Although length distributions

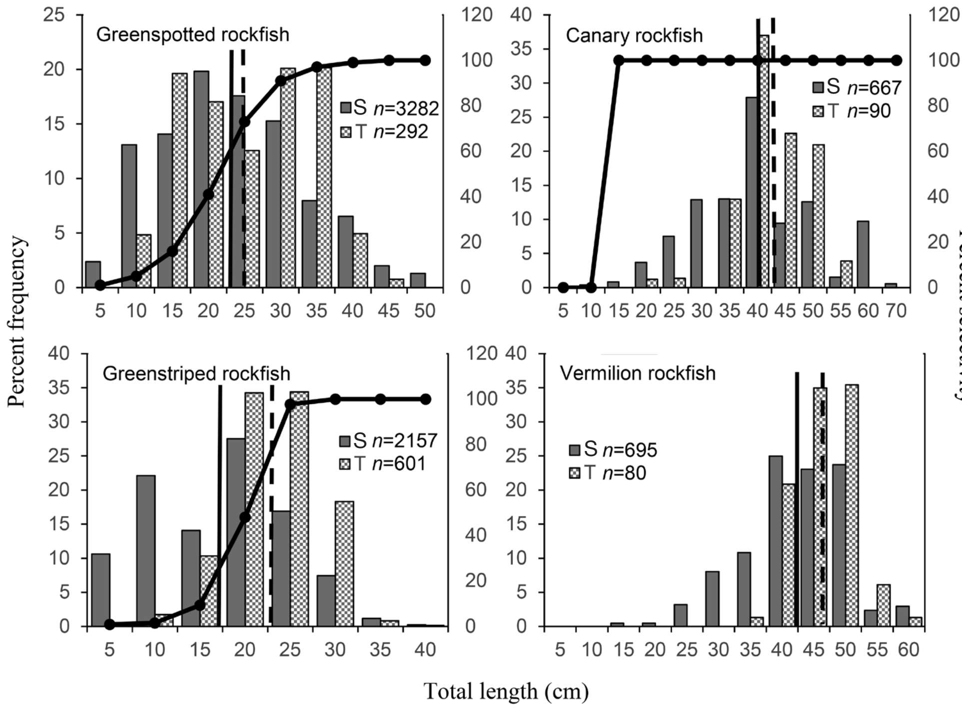

Figure 2

Length-frequency distributions of 4 species of rockfish (*Sebastes* spp.) sampled in submersible surveys (S, dark gray bars) and the Northwest Fisheries Science Center West Coast Bottom Trawl Survey (T, checkered bars) conducted off central California (36–37°N latitude) during 2003–2009. The curved line represents the bottom-trawl selectivity function from the most recent stock assessment for each species (not available for vermilion rockfish, *Sebastes miniatus*). The solid and dashed vertical lines indicate the mean lengths from submersible and bottom-trawl surveys, respectively.

Table 2

Values for 10%, 50%, and 90% total length quantiles (cm) and results of a chi-square two-sample test in comparing length distributions of all individuals of 4 species of rockfish (*Sebastes* spp.) from submersible surveys in untrawlable areas and trawl surveys conducted off central California (36–37°N latitude) during 2003–2009. Length data were estimated to the nearest 5 cm during submersible surveys and to the nearest 1 cm during trawl surveys. For the chi-square test, length data from trawl surveys were binned to 5-cm increments (bin as midpoint) to match the format of data from submersible surveys.

Species	Submersible 10%, 50%, 90% length quantiles	Trawl 10%, 50%, 90% length quantiles	Chi-square two-sample test
Greenspotted rockfish	10, 25, 35	14, 26, 36	88.311, df=9, $P<0.001$
Greenstriped rockfish	5, 20, 25	17, 23, 29	314.36, df=7, $P<0.001$
Vermilion rockfish	30, 45, 50	42, 47, 52	29.5, df=9, $P<0.001$
Canary rockfish	25, 40, 60	37, 42, 50	50.354, df=11, $P<0.001$

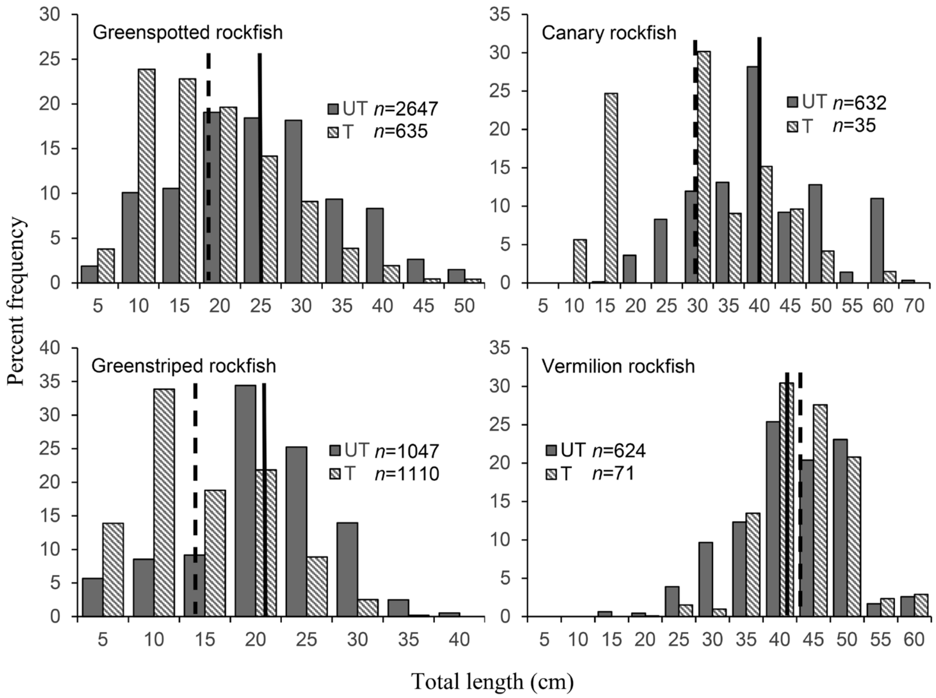

Figure 3

Length-frequency distributions of 4 species of rockfish (*Sebastes* spp.) on untrawlable high-relief habitat (UT, dark gray bars) and trawlable low relief habitat (T, hatched bars) from submersible surveys conducted off central California (36–37°N latitude) during 2003–2009. The solid and dashed vertical lines indicate the mean lengths of fish on untrawlable and trawlable habitats, respectively.

Table 3

Values of 10%, 50%, and 90% total length quantiles (cm) and results of a chi-square two-sample test in comparing length distributions of 4 species of rockfish (*Sebastes* spp.) from submersible surveys conducted in untrawlable and trawlable habitat off central California (36–37°N latitude) during 2003–2009. Length data were estimated to the nearest 5 cm.

Species	10%, 50%, 90% length quantiles, untrawlable habitat	10%, 50%, 90% length quantiles, trawlable habitat	Chi-square two-sample test
Greenspotted rockfish	10, 25, 40	10, 15, 30	235.33, df=9, P<0.001
Greenstriped rockfish	10, 20, 30	5, 15, 25	466.99, df=7, P<0.001
Vermilion rockfish	30, 40, 50	35, 45, 50	9.2217, df=9, P=0.4171
Canary rockfish	25, 40, 60	15, 30, 45	202.52, df=11, P<0.001

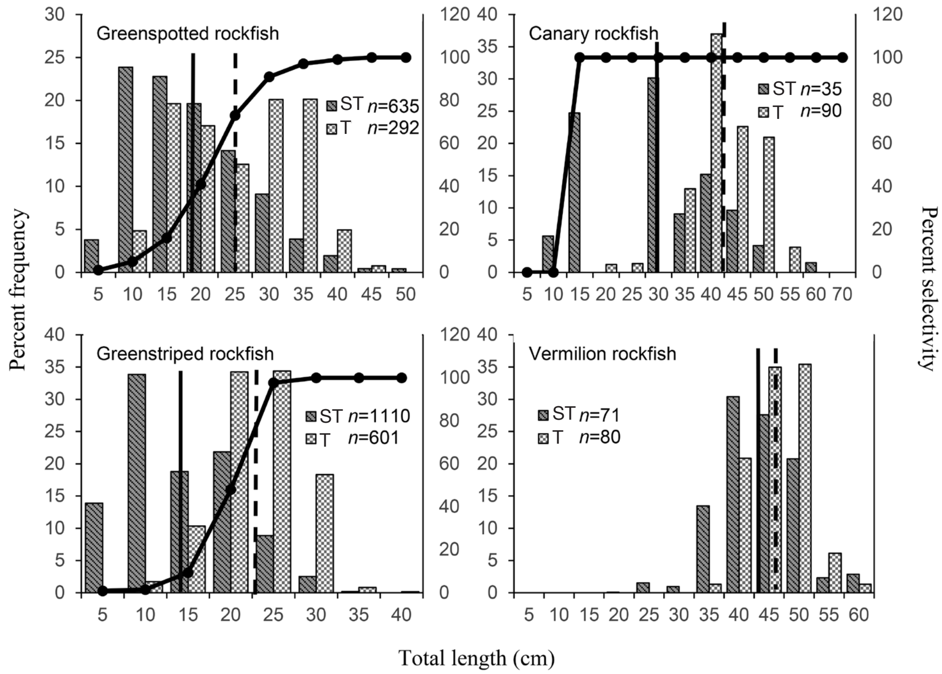

Figure 4

Length-frequency distributions of 4 species of rockfish (*Sebastes* spp.) on trawlable low-relief habitat from submersible surveys (ST, dark gray bars with diagonal hatches) and the Northwest Fisheries Science Center West Coast Bottom Trawl Survey (T, checkered bars) conducted off central California (36–37°N latitude) during 2003–2009. The curved line represents the bottom-trawl selectivity function from the most recent stock assessment for each species (not available for vermilion rockfish, *Sebastes miniatus*). The solid and dashed vertical lines indicate the mean lengths from submersible and bottom-trawl surveys, respectively.

of vermilion rockfish on the 2 habitats were not significantly different, fish <35 cm TL occurred in greater proportion on untrawlable habitat.

The third comparison, that of length distributions of fish from submersible surveys on low-relief trawlable habitat with those from the trawl survey (Fig. 4) was significantly different for all 4 species (Pearson's chi-square two-sample test, $P<0.001$; Table 4). In these comparisons, the dissimilarity in length distributions between the two surveys was even more apparent for greenspotted, greenstriped, and canary rockfishes than when all submersible survey data for these species, regardless of habitat, were compared with trawl survey data (Fig. 2, Table 2). The difference in the proportion of small fish present in the two surveys was particularly pronounced for greenstriped and canary rockfishes, with 10% length quartiles of 5 and 17 cm TL (greenstriped) and 15 and 37 cm TL (canary) in submersible and trawl survey data, respectively. In contrast, length distributions for vermilion rockfish were more similar between surveys than length distributions for the other species, owing to a greater proportion of large vermilion rockfish (>45 cm TL) on trawlable habitat in the submersible survey data.

Discussion

Our study provides a useful comparison of length data collected by the West Coast Bottom Trawl Survey and nearby submersible surveys in untrawlable areas, for some deepwater rockfishes off central California. Although the trawl survey samples areas of soft and low-relief habitats where relatively low densities of many rockfishes occur, there were enough length data for comparisons of some species that associate mostly with mixed and high-relief rocky habitats. The broader length and depth distributions present in the submersible survey data allowed informative comparisons with the trawl survey data. We could not directly address whether the low proportion of small sizes in the trawl data was due to habitat (i.e., small fish not available on trawlable habitat) or gear selectivity. However, the greater proportion of small sizes present on trawlable habitats in the submersible survey data (in particular for greenstriped rockfish), and the similar maximum lengths present in both surveys (Fig. 4) suggest that gear selectivity was the cause. Similarly, commercial trawl gear selects for larger sizes and would not be expected

Table 4

Values for 10%, 50%, and 90% total length quantiles (cm) and results of a chi-square two-sample test in comparing length distributions of 4 species of rockfish (*Sebastes* spp.) from submersible surveys in low-relief (<25 cm), trawlable habitat and from trawl surveys conducted off central California (36–37°N latitude) during 2003–2009. Length data were estimated to the nearest 5 cm during submersible surveys and to the nearest 1 cm during trawl surveys. For the chi-square test, length data from trawl surveys were binned to 5-cm increments (bin as midpoint) to match the format of data from submersible surveys.

Species	10%, 50%, 90% length quantiles, untrawlable habitat	10%, 50%, 90% length quantiles, trawlable habitat	Chi-square two-sample test
Greenspotted rockfish	10, 15, 30	14, 26, 36	138.9, df=9, P<0.001
Greenstriped rockfish	5, 15, 25	17, 23, 29	574.01, df=7, P<0.001
Vermilion rockfish	35, 45, 50	42, 47, 52	16.58, df=7, P<0.02032
Canary rockfish	15, 30, 45	37, 42, 50	73.905, df=10, P<0.001

to cause the reduced numbers of small sizes we observed in the trawl survey data.

An important consideration for our study was the accuracy of visually estimated fish lengths from the submersible survey. Trawl length data are in-hand measurements to the nearest cm, whereas submersible length data are visually estimated underwater to the nearest 5 cm with the aid of paired lasers. Yoklavich et al. (2007) conducted a study to address the error associated with visual estimates of fish length from the *Delta* submersible and found lengths were underestimated by 1.1 cm on average. Given that the trawl survey data were binned to 5-cm increments for plotting and the chi-square test, and maximum lengths from the submersible survey were similar or greater than those from the trawl survey, we did not consider the relatively small amount of error associated with visually estimated length data to have contributed greatly to the differences found in our study.

Before our comparisons of lengths, we surmised that lengths from the submersible survey would be more similar to lengths from the trawl survey for greenspotted and greenstriped rockfishes than for canary and vermilion rockfishes, on the basis of known habitat associations of these species that would make them more or less available to the trawl survey. To some extent, this assumption held true. Greenspotted rockfish, which associate with a wide variety of high- and low-relief habitats (Yoklavich et al., 2000; Love et al., 2002; Laidig et al., 2009), had similar length distributions and mean lengths between the surveys when all fish, regardless of habitat, were compared; the distributions were significantly different, however, because of the large amount of length data from the submersible survey. Canary and vermilion rockfishes associate strongly with high-relief rock habitats (Yoklavich et al., 2000; Love et al., 2002; Laidig et al., 2009), had the most dissimilar length distributions between the surveys for all fish regardless of habitat, and had the least amount of length data from the trawl survey. Our result for greenstriped rockfish was somewhat surprising because, given that this species associates most commonly with low-relief trawlable habitats (Yoklavich et al., 2000; Love et al., 2002; Jagielo et al., 2003; Laidig et al., 2009) and had the greatest amount of length data (601 measurements) from the trawl survey, we did not expect to find such strong dissimilarity in the length distributions between the surveys. However, the trawl survey selectivity curve from the stock assessment for greenstriped rockfish (Hicks et al., 2009) correctly assumes that smaller fish were not sampled by the trawl survey.

Given that adults of many rockfish species are known to associate with high-relief rocky habitats, for assessments based on trawl survey data, it is often assumed that selectivity for the survey is "dome-shaped," i.e., availability of larger fish to the survey may decline beyond a given size (Dick et al., 2011; Taylor and Wetzel, 2011; Hamel et al., 2013; He et al., 2015). One mechanism for this pattern could be ontogenetic movement into untrawlable habitat (Love and Yoklavich, 2008). Although limited in spatial and temporal extent compared with stock assessments based on trawl survey data from the entire U.S. west coast and multiple years, our results for these 4 species suggest that the major difference between size compositions from the submersible and trawl surveys may be a reduced frequency of smaller individuals in the trawl survey. The estimated selectivity curves in the assessments of greenspotted and greenstriped rockfishes appear to account for this difference, but for the selectivity curve for the canary rockfish assessment, all fishes larger than ~15 cm TL are assumed to be 100% available to the gear. It is important to note that the assessments are based on data from years and areas not represented in this analysis, which may be the reason for the differences in length composition observed in our study. These differences would imply that selectivity varies over time or space (or both). Time-varying selectivity is commonly assumed in rockfish assessments, although spatial variability in survey selectivity is considered less often, despite known latitudinal clines in size for many rockfishes (Fraidenburg, 1980; Gertseva et al., 2010; Keller et al., 2012). The differences we observed between surveys also could be due to a reduction in availability of large fish to the submersible survey, but that seems unlikely given that we found greater proportions of large sizes for 3 species on untrawlable habitat patches (Fig. 3, Table 3). With regard to survey efficiency, the probability of detection of fish in submersible surveys increases with fish size, and the reaction of large rockfishes to the *Delta* has been found to be minimal (Yoklavich et al., 2007; Laidig and Yoklavich, 2016).

A number of studies have compared other aspects of data collected during underwater visual surveys and trawl surveys of rockfishes, including fish density on trawlable habitat (Adams et al., 1995), trawl catch efficiency (Krieger, 1993), fish frequency of occurrence and weights on trawlable and untrawlable habitat (Starr et al., 2016), and species composition and densities on trawled and untrawlable habitat (Jagielo et al., 2003). Lauth et al. (2004) estimated size-specific selectivity for a trawl survey of thornyheads (*Sebastolobus* spp.) off Oregon, using independent estimates of density and lengths obtained with a video camera sled on trawlable habitat. Lauth et al. (2004) calculated much lower selectivity values for fish >30 cm TL than the most recent stock assessment (which was based on data from California, Oregon, and Washington), raising the question of spatial variability in trawl survey selectivity for thornyheads.

As far as we know, ours is the first study to compare length distributions of rockfishes from trawl surveys with those from submersible surveys conducted in nearby areas inaccessible to trawls. Additional comparisons can be made for other species from these central California data sets, and from existing submersible and trawl data sets from southern California. Similar comparisons of rockfish lengths estimated from submersible and trawl surveys from other regions of the west coast could help address spatial variability in trawl survey selectivity (Sampson, 2014) and assumptions about the trawl selectivity functions used in stock assessments for rockfishes.

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