Understanding the Capabilities of New Technologies and Methods to Survey West Coast Groundfishes

Results from a visual survey conducted in 2011 using the *Dual Deepworker* manned submersible at *Footprint* and *Piggy* banks off Southern California

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Introduction

Surveys of west coast groundfishes are needed in high-relief rocky areas that are inaccessible to traditional net-based mobile fishing gear (e.g., bottom trawls). Several species, such as cowcod (*Sebastes levis*) and yelloweye (*S. ruberrimus*) rockfish, are strongly associated with these rocky habitats, have populations at various levels of depletion, and occupy habitats that have incurred substantial impacts (Love and Yoklavich 2006; Yoklavich et al. 2007). Now that much of the continental shelf and upper slope are closed to groundfishing off southern California in particular, it is important to develop effective monitoring strategies for these species.

Non-lethal survey methods, whether optical, acoustical, or some combination of both, are needed to adequately assess these vulnerable species while minimizing impact on the fishes and their habitat. To that end, a field study was conducted to evaluate the capabilities of three tools/technologies (i.e., a Seabed autonomous underwater vehicle [AUV]; a manned submersible [SUB]; and the collaborative optically assisted acoustical survey technique [COAST]) to survey groundfishes in complex rocky areas, and to appraise the information collected during the three surveys.

The specific objectives of our project using visual survey techniques from a SUB were to (1) collect data on counts and sizes for several rockfish (*Sebastes*) species (both common and rare, large- and small-bodied, and semi-aggregating and highly demersal/solitary) and other taxa of interest (lingcod [*Ophiodon elongatus*], thornyheads [*Sebastolobus*], and Pacific hake [*Merluccius productus*]); (2) estimate densities (and associated precision) for these taxa; (3) estimate size composition for these species; (4) estimate abundance and biomass (and precision) for these taxa; and (5) estimate biodiversity of fish species within the study site.

The results of our SUB survey subsequently will be compared with those from the two other studies that assessed these fish assemblages using an AUV and a remotely operated vehicle (ROV) coupled with hydroacoustics (i.e., the COAST approach).

Methods

Underwater surveys of demersal fishes and habitats were conducted on two rocky seamounts off southern California, 21-30 September 2011, using non-extractive transect methodologies and direct observations from the Nuytco *Dual Deepworker* SUB onboard the F/V *Velero IV*. The study site is located inside the State and Federal Footprint Marine Reserves, offshore of Santa Cruz Island, and includes two seamounts: the Piggy Bank and the Footprint Bank (in the general vicinity of 33.9° N and 119°5 W; **Figure 1**). The Piggy Bank is about 30 km^2 in area, ranging in depth from 275 to 900 meters; the Footprint Bank is about 10 km^2 in area, ranging in depth from 80 to 500 meters. The underwater visual surveys were planned to span from 400 m to the top of each seamount.

A pilot operated the untethered SUB while an experienced scientist identified all fish species and estimated their total length (TL). Each transect was documented with two external high-definition (HD) color video cameras mounted at 45° on the starboard side of the SUB, one positioned in the same direction and field of view as the observer and the other camera located below the observer's field of view to record fishes in the area closest to the SUB (that may not have been seen by the observer). The videotape was time-stamped and annotated in real-time by the scientist inside the SUB.

Seventeen dives were conducted during daytime (generally 0900-1700 h) over 10 days. Duration of dives ranged from 1.4 to 3.2 h (mean= 2.3 h, SE = 0.1). We tracked the SUB from the support vessel using a Linkquest *Tracklink 1500* ultra-short baseline (USBL) navigation system integrated with differential GPS and Fugro Pelagos *WinFrog* software; navigational data were time-stamped and recorded every 3 sec throughout each dive. The positioning system was linked to an ESRI *ArcMap* geographical information system (GIS), and a scientific navigator aboard the support vessel tracked the SUB in real time relative to bathymetry. The pilot and observer inside the SUB did not influence the direction of travel.

Each dive included multiple 15-minute-long strip transects, which were located randomly (prior to the cruise) within 100-m depth strata on each of the two seamounts (**Figure 1**). Maps of high-resolution bathymetry and backscatter data from multibeam acoustic surveys of this area were available prior to our study (Dartnell et al. 2005). From those data we derived depth contours at 100-meter intervals at Footprint (0-100, 100-200, 200-300, and 300-400 meters) and at Piggy Bank (200-300 and 300-400 meters), and calculated the area of each stratum using *ArcMap* 9.3 (**Table 1**). Large areas of soft sediment in the northeast section of the study site were excluded from our sampling frame. Number of transects per stratum was based on optimal sample variances from past visual surveys in the study area, the area of each depth stratum (**Table 1**), and the amount of time available for the entire survey. We performed a bootstrap analysis of coefficients of variation in density of various fish species and species richness estimated from similar SUB transects conducted in 2005 on Footprint seamount at depths < 200 m. We concluded that 15 transects produced optimal sample variances for the area within the 100-200 meter depth stratum at Footprint, and applied that ratio (15 transects/1.23 km^2) to determine the number of transects to be conducted within the other depth strata in the study area. We increased the number of transects within the <100 meter stratum based on relatively high density of fishes and species richness at that depth in the earlier survey of this area. Using *ArcMap* 9.3, the appropriate number of spatially random points were generated within each depth stratum to locate transects.

During a transect, we tried to maintain a constant distance within 2 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). Those segments of a transect in which the seafloor was not clearly visible were excised and not considered as part of the 15-minute sample. The scientist estimated size of fishes using paired lasers (installed at 20 cm apart on either side of the main survey video camera) as a guide. The length of each transect was determined accurately using a Doppler velocity log and ring-laser gyrocompass attached to the outside of the submersible. Transect width of 2.5 meters was estimated by the scientific observer with the aid of a hand-held sonar device, the submersible's sonar, and a crossing laser set at 3 meters from the observer when the submersible was 1 meter above the seafloor. The submersible also was equipped with a Seabird *SBE-19* CTD and associated sensors, which continuously recorded time, temperature, salinity, depth, and oxygen concentration during each dive.

Video transects and associated audio annotations made by the observer during each dive were reviewed following the survey. Identification (to lowest possible taxon), counts, and total length (to nearest 5 cm) of fishes on or near (<2 m) the seafloor were entered into an existing MS Access relational database, along with data from navigation, CTD, and other information related to each dive. Seafloor substratum types were classified from the videotape, in order of decreasing particle size and vertical relief (as described in Greene et al. 1999): rock (R), boulder (B), cobble (C), and mud (M). A two-character code was used to quantify patches of uniform substratum type along each transect (as described in Yoklavich et al., 2000). The primary character in the code represented the substratum type that accounted for at least 50% of the patch, and the secondary character represented the substratum type accounting for at least 20% of the patch (e.g., CM represented a patch of at least 50% cobbles and at least 20% mud). The area of each substratum patch along a transect was estimated as the product of the transect width and the length of the patch.

For each depth stratum and bank, we estimated total abundance (number of fishes) of each species and some taxonomic groups, and biomass of those species for which data on length-weight relationships were available (**Appendix 1**). To estimate total abundance, we first calculated the density of each species and group on each transect as:

$$D = \frac{n}{l * w}$$

where n is the number of individuals counted within the transect, l is the transect length, and w is the transect width (2.5 meters). Mean density and variance was then calculated from transects in each depth stratum, and expanded to total abundance and variance by multiplying by the area of the depth stratum. Total abundance (N) and variance for each bank and the banks combined was estimated by summing abundance and variance for all depth strata. Coefficient of variation (CV) was calculated as:

$$CV = \frac{\sqrt{var(N)}}{N}$$

To estimate total biomass (B) of species, we used the length-weight relationship:

$$B = a * TL^b$$

where TL is total length, measured to the nearest 5 cm using reference lasers, and a and b are species-specific coefficients (Appendix 1). We substituted coefficients from closely related species for chameleon (*S. phillipsi)*, dwarf-red (*S. rufinanus)*, and pygmy (*S. wilsoni)* rockfishes and unidentified thornyheads and *Sebastomus*, because coefficients were unavailable for these taxa. We then calculated $kg/100m^2$ for each taxon on each transect by summing the weights of individuals and dividing by the transect area. Mean $kg/100m^2$ and variance were calculated from transects within each depth stratum, and expanded to total biomass and variance by multiplying by the area of the depth stratum. Total biomass and variance for each bank and the banks combined were estimated by summing biomass and variance for all depth strata. Coefficient of variation (CV) was calculated as:

$$CV = \frac{\sqrt{var(B)}}{B}$$

Results

We conducted 69 quantitative transects (mean length = 294 m [SE: 8 m]) on Footprint (n=55) and Piggy Bank (n=14) seamounts, surveying a total of 52,000 m^2 (0.05 km^2) (**Table 1**; **Figure 1**). Our survey included habitats of high-relief rock boulders and outcrops and steep slopes of soft sediments and rock rubble at depths 95-400 m.

The amount of seafloor substratum types that was quantified on these transects varied substantially among depth strata and between the two seamounts (**Figure 2** and **Figure 3**). Transects on the top of the Footprint seamount (100-m stratum) comprised 30% high relief boulders and rock and 70% lower relief cobbles. The amount of cobble substratum on the Footprint transects decreased with depth, whereas low-relief mud habitat increased from 0% on top of the seamount to 75% in the 400-m depth stratum. The summit of Piggy Bank was much deeper (300-m stratum) than that of Footprint seamount. Transects in the 300- and 400-m depth strata on the Piggy Bank comprised 75-80% boulders and rock and relatively little low-relief cobble (8-16%) and mud (9-15%).

We identified 64 unique taxa of the 25,085 fishes from all transects on both seamounts (**Table 2**). This included 29 species of rockfishes, which as a group comprised >80% of the total number of fishes. We were unable to identify only 0.5% of all rockfishes (excluding some young-of-year juveniles) to species or species group (i.e., *Sebastomus*). Of particular interest, there were 147 observations of bocaccio (*S. paucispinis*), 38 of cowcods, and 4 of the rare and elusive bronzespotted rockfish (*S. gilli*). Other noteworthy observations included many Humboldt squid at depths from 400 meters to the surface, a diverse array of deepsea corals and sponges, and a camera sled lost by NWFSC researchers at the base of a rock spire on top of the Footprint seamount. There was a surprisingly small amount of marine debris on either Footprint or Piggy Banks; we observed only a few old pieces of fishing nets and line, beverage cans, and minor amounts of other items, none of which presented significant navigational hazards to the SUB.

For subsequent comparison with results from the ROV and AUV surveys, we restricted our estimates of abundance, biomass, diversity, and size composition to 29 species of rockfishes, 3 unidentified rockfish groups, two thornyhead groups (*Sebastolobus alascanus* and *Sebastolobus* spp.), lingcod, and Pacific hake (**Table 3**). Size composition of these 32 species (excluding the groups of species) is presented in **Figure 4**; we were able to estimate size for almost all (99%) individuals of these species. Dwarf species of rockfishes, such as squarespot (*S. hopkinsi*, 20% of all rockfishes, mean length 15 cm), halfbanded (*S. semicinctus*, 17%, 12 cm), shortbelly (*S. jordani*, 12%, 19 cm), pygmy 7%, 10 cm), and swordspine rockfishes (*S. ensifer*, 7%, 16 cm), were the most numerous within the rockfish assemblage. Large rockfishes, while not relatively abundant, were bocaccio (0.7% of all rockfishes, mean length 37 cm), cowcod (0.2%, 36 cm), vermilion (*S. miniatus*, 0.1%, 35 cm), bronzespotted (<0.1%, 49 cm), and pink rockfishes (*S. eos*, <0.1%, 40 cm). Lingcod was another large species (mean length 40 cm) having low relative abundance in our survey (0.2% of all fishes). Pacific hake (mostly juveniles, with mean length 22 cm) were relatively abundant (4% of all fishes).

Fish assemblages varied among depth strata and between the two seamounts. Twenty-two species/taxa, including some of those with the greatest abundance, only occurred on the Footprint seamount (bolded taxa in **Table 3**). Lingcod, cowcod, and greenspotted rockfish (*S. chlorostictus*), found only on Footprint seamount, were in relatively high density at 100-250 m depth (**Figure 5**). Pygmy rockfishes, also only occurring at the Footprint, had highest densities on top of the seamount. Densities of bank (*S. rufus*), splitnose (*S. diploproa*), and shortbelly rockfishes were relatively high at both seamounts in depths 200-400 m (**Figure 5**).

Diversity or richness, measured as cumulative number of species (excluding groups) in transects within a depth stratum, was highest on Footprint seamount in the 100-200 m (23 species) and 200-300 m (26 species) depth strata (**Table 4**). Species richness was lowest on Piggy Bank at both depth strata (8 and 11 species at 200-300 and 300-400 m, respectively).

Total abundance, biomass, and associated coefficients of variation were calculated for the 14 species/groups that were observed on Piggy Bank (**Table 5**). We estimated a total of 414,975 fishes and 60.3 mt (1 mt = 1,000 kg) of fish biomass on this bank; biomass did not include that of unidentified adult or juvenile rockfishes and sharpchin rockfish (*S. zacentrus*) because useful length-weight relationships were not available for these taxa. Shortbelly (163,022 individuals), bank (116,040 individuals), and splitnose (64,489 individuals) rockfishes were most abundant and comprised the greatest biomass (18%, 53%, and 12% of total biomass, respectively) on the Piggy Bank.

Total abundance, biomass, and associated coefficients of variation were calculated for the 36 species/groups that were observed on Footprint seamount (**Table 6**). We estimated a total of 1,953,844 fishes representing 147.6 mt of biomass (excluding biomass estimates of unidentified rockfishes and sharpchin rockfish, as noted above) on this bank. Three dwarf species of rockfishes, shortbelly (339,855 individuals), half-banded (302,275 individuals), and unidentified *Sebastomus* (likely swordspine rockfish, 268,618 individuals) were most abundant but together comprised only 27% of the total biomass. Of the larger species, splitnose rockfish (221,329 individuals; 14.5 mt), juvenile Pacific hake (164,087 individuals; 19.5 mt), and bank rockfish (68,629 individuals; 14.9 mt) were abundant with relatively high biomass. Cowcod (4,325 individuals; 4.2 mt) comprised only 0.2% of total fish abundance and 2.8% of total biomass on Footprint seamount. Bocaccio (13,342 individuals; 8.6 mt) comprised 0.7% of total abundance and 5.8% of total biomass at this site.

Total abundance, biomass, and associated coefficients of variation were calculated for both banks combined (**Table 7**). We estimated an overall total of 2,368,819 fishes (and 207.9 mt biomass, without sharpchin and unidentified rockfishes) to a depth of 400 meters on Footprint and Piggy Bank seamounts.

Shortbelly, halfbanded, and splitnose rockfishes were most abundant overall. Juvenile Pacific hake and bank, swordspine, and squarespot rockfishes also were abundant. Unidentified *Sebastomus* likely were swordspine rockfish, which would place abundance of that species second only to that of shortbelly rockfish. Four species, bank rockfish (23% of the total biomass), shortbelly (15%), splitnose (10%), and juvenile Pacific hake (10%), together comprised over 58% of the total biomass in the study area.

Coefficient of variation (CV) ranged from 0.12 to 0.84 for total abundance and from 0.15 to 0.92 for total biomass over both banks combined (**Table 7**). Overall CV for total abundance was 0.30 for cowcod, 0.26 for bocaccio, and 0.32 for bank rockfish. Overall CV for total biomass was 0.44 for cowcod, 0.27 for bocaccio, and 0.36 for bank rockfish.

Discussion

Non-extractive visual sampling techniques such as describe in this report have proven to be especially effective when surveying fishes of relatively low abundance that live in high-relief rock areas (O'Connell et al. 2001; Yoklavich et al. 2007; Yoklavich and O'Connell 2008). Direct-observation surveys provide habitat-specific assessments, which can result in more accurate and precise estimates of some species (particularly some of the more sedentary demersal rockfishes).

As with other survey methods, visual transect sampling has associated assumptions when used to estimate fish abundance. The strip transect method that we have used in this survey assumes 100% detectability of the target fishes (e.g., rockfishes) within the strip. Our relatively narrow strip width (2.5 m), and the combination of an in situ scientific observer and two HD video cameras covering the strip area, helps to ensure that this key assumption is met. This is especially the case when counting species living on, in, and near the seafloor (i.e., cowcod, adult bocaccio, bank, greenspotted, and many other rockfishes). However, our visual survey methodology likely underestimated densities of those benthopelagic species that sometimes aggregate in the water column. In particular, we observed juvenile Pacific hake higher in the water column above the submersible on several occasions, but only counted individuals on or near the seafloor inside our transects; therefore, we consider abundance and biomass to be underestimated for this species.

Another assumption is that fish behavior is independent of the survey vehicle. With the *Dual DeepWorker* submersible, the observer is positioned sitting upright inside a large acrylic viewing dome and able to sight fishes far outside the transect, as well as in front of the submersible. From these observations during the dives, there was no indication of movement (either by avoidance or attraction) of solitary demersal fishes as the submersible executed the transects. Similar negligible reactions were reported recently for demersal rockfishes during surveys conducted with another untethered manned submersible (Laidig et al. 2013).

There are additional assumptions required for unbiased estimates of abundance during these surveys. The assumption that the fish counts are distributed randomly within the sampling strata is met by randomizing the start of each transect within each depth stratum, and then conducting each transect across substratum types. A scientific navigator aboard the support vessel tracked the submersible in real time; the pilot and observer inside the submersible did not influence the direction of travel or duration of transect. We also attempted to minimize sources of error related to the assumption that underwater measurements were exact. From past studies (Yoklavich et al. 2007), error associated with estimates of fish size was small (mean deviation = -1.1 cm, SD =1.2); underestimating fish size would result in underestimates of biomass. We assumed that length of transect and total area of each depth stratum were known without error. We used a Doppler velocity logger and ring-laser gyrocompass to insure that the length and path of transects were exact. Total area of each depth stratum includes some unknown amount of error.

Comparison of Results from SUB and ROV Surveys

The primary goal of our survey was to evaluate the capabilities of the manned submersible and resultant information on demersal fish assemblages, and to compare these results with those collected during AUV and COAST (ROV and hydroacoustics) surveys. While the results from the AUV and full COAST surveys are not yet available, we consider here the results from the submersible (SUB) and the ROV (Stierhoff et al. 2012). These comparisons could provide some valuable insights regarding these two visual surveys and will improve our understanding of the capabilities of these technologies to survey Pacific coast rockfishes.

In general, the demersal assemblages on the Piggy Bank and Footprint seamounts were characterized similarly using both the ROV and SUB. Dwarf species (shortbelly, swordspine, halfbanded, and squarespot rockfishes) and bank rockfishes numerically dominated the fish assemblages in both surveys. Species diversity generally was similar between the ROV and SUB data sets, with greater species richness on Footprint than Piggy Bank. Relatively low numbers of a few species (e.g., darkblotched, freckled, Mexican, yelloweye, and olive rockfishes) were recorded in the ROV survey but missing from the SUB survey.

Remarkably, the total abundance estimated for all fishes on both banks combined was similar from the two surveys (2.4 million fishes from the SUB survey; 2.3 million fishes from the ROV). Abundance of some of our target species was similar between both surveys (**Figure 6**). For example, there were 4,325 (CV=0.30) cowcod estimated from the SUB survey and 4,109 (CV=0.28) from ROV; 13,342 (CV=0.26) bocaccio from SUB and 12,624 (CV=0.37) from ROV; 1,070 (0.73) vermilion/sunset rockfish from SUB and 951 (CV=0.46) from ROV; and 184,669 (0.32) bank rockfish from SUB and 177,981 (CV=0.28) from ROV.

However, there also were notable differences in estimated total abundance for some species in the two surveys (**Figure 6**). Estimated total abundance of the relatively deep species (e.g., aurora, blackgill, and splitnose rockfishes and thornyheads) was 3-40 times greater in the SUB survey than in the ROV survey. This difference in abundance likely is because the ROV survey included much less sampling in the 300-400 m depth stratum on Footprint seamount and practically no sampling in that depth stratum on Piggy Bank compared to the SUB survey. This depth stratum comprised the largest area in the study frame, and 14 of 15 transects where aurora rockfishes were encountered in the SUB survey, for example, occurred in the 300-400 m depth stratum.

Abundances of several benthopelagic species, sometimes aggregating in the water column above the transect, were higher in the SUB survey than the ROV. These included juvenile Pacific hake and widow, shortbelly, and chilipepper rockfishes (whereas chilipepper abundance was quite low in the SUB survey, it didn't occur at all in the ROV survey). Abundance of other benthopelagic species (e.g., squarespot rockfishes) was higher in the ROV survey. These differences could be due to the patchy distribution of these more mobile species, or because the SUB survey was completed over 10 days in September and the ROV survey was conducted over a few months from November to January. CVs for these species were relatively high in both surveys (0.38-0.74 for SUB and 0.45-0.87 for ROV), indicating that increased sampling effort could be required to obtain more accurate and precise abundance estimates. It also has been reported that these benthopelagic rockfish species react by moving away from the ROV more so than to a SUB (Laidig et al. 2013); such movements could cause the fish to leave the transect area or shelter in or behind rocks, thereby influencing the resultant abundance estimates.

Whereas the abundance estimates for some of the target species were similar between the two survey methods, biomass estimates for those same species were quite different (**Figure 7**). For instance, estimated biomass of cowcod in the ROV (7,520 kg) survey was almost twice as large as that from the SUB (4,183 kg). Because abundance estimates of this species were similar between these two surveys, this difference in biomass results from different size compositions. Examination of the size frequency histograms from each survey revealed that there were more large fishes (40-50 cm TL) and far fewer small fishes (<30 cm TL) in the ROV survey than in the SUB survey. This also was the case for bocaccio and bank rockfishes; that is, the total abundances were relatively similar or lower in the ROV survey, but estimated biomasses in the ROV survey were larger. The size composition data demonstrate that smaller sizes were less frequent and larger sizes more frequent in the ROV survey for these species. There are two rationales (at least) for this type of outcome. It is more difficult to identify and quantify small fishes from a ROV video image than by an observer inside the submersible. Also, the surveys conducted with the ROV could be focusing on (and therefore oversampling) rocky habitats, which would yield a greater number of larger fishes for species (such as cowcod, bocaccio, and bank rockfishes) that typically associate with rock habitats.

Further comparative analyses of sampling approach and data from the ROV and SUB surveys, as well as from the AUV and optical-acoustic COAST methods, would certainly improve our understanding of the capabilities and utility of these technologies to survey Pacific coast groundfishes. Precision, and perhaps accuracy, in estimated abundance and biomass also could be greatly improved by acquiring more accurate estimates of the spatial extent and distribution of various types of seafloor substrata (e.g., rocky banks, cobble and boulder fields). Such information will improve survey design and efficiency for future monitoring of these demersal species.

References

Anderson, T.J. and M.M. Yoklavich. 2007. Multi-scale habitat associations of deep-water demersal fishes off central California. Fishery Bulletin 105:168-179.

Dark, T.A. and M.E. Wilkins. 1994. Distribution, abundance, and biological characteristics of groundfish off the coast of Washington, Oregon, and California, 1977-1986. NOAA Tech. Rep. NMFS 117. Seattle.

Dartnell, P., G. Cochrane, and M. E. Dunaway. 2005. Multibeam bathymetry and backscatter data: Northeastern Channel Islands region, Southern California, U.S. Geological Survey Open-File Report 05-1153, http://pubs.usgs.gov/of/2005/1153/

Greene, H.G., M.M. Yoklavich, R.M. Starr, V.M. O'Connell, W.W. Wakefield, D.E. Sullivan, J.E. McRea, Jr., and G.M. Cailliet. 1999. A classification scheme for deep seafloor habitats. Oceanologica Acta 22:663-678.

Hyde, J.R. and R.D. Vetter. 2007. The origin, evolution, and diversification of rockfishes of the genus *Sebastes* (Cuvier). Molecular Phylogenetics and Evolution 44:790-811.

Hyde, J.R., C.A. Kimbrell, J.E. Budrick, E.A. Lynn, and R.D. Vetter. 2008. Cryptic speciation in the vermilion rockfish (*Sebastes miniatus*) and the role of bathymetry in the speciation process. Molecular Ecology 17:1122-1136.

Laidig, T.E., L.M. Krigsman, and M.M. Yoklavich. 2013. Reactions of fishes to two underwater survey tools, a manned submersible and a remotely operated vehicle. Fishery Bulletin 111:54-67.

Love, M.S. and M.M. Yoklavich. 2006. Deep Rock Habitats, 253-266. In: Allen, L.G., D.J. Pondella, II, and M.H. Horn (eds.) The Ecology of Marine Fishes: California and Adjacent Waters. UC Press.

Love, M.S., M. Yoklavich, and L. Thorsteinson. 2002. The Rockfishes of the Northeast Pacific. UC Press.

Love, M.S., P. Morris, M. McCrae, and R. Collins. 1990. Life history aspects of 19 rockfish species (Scorpaenidae: *Sebastes*) from the Southern California Bight. NOAA Tech. Rep. NMFS 87. Seattle.

Moulton, L.L. 1977. An ecological analysis of fishes inhabiting the rocky nearshore regions of northern Puget Sound, Washington. Ph.D. diss., Univ. Wash.

O'Connell, V., D. Carlile, and C. Brylinsky. 2001. Demersal shelf rockfish stock assessment and fishery evaluation report for 2002. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau, Alaska, Regional Information Report No. 1J01-35.

RecFIN. 2009. Species Calculator and Species Database. www.recfin.org

Stierhoff, K.L., J.L. Butler, S.A. Mau, and D.W. Murfin. 2012. 2011 Comparative rockfish survey at the Footprint and Piggy Bank: results from the SWFSC's optical survey conducted using a remotely operated vehicle (ROV). Unpublished report of NMFS SWFSC, La Jolla, CA. 41 p.

Wakefield, W.W. 1990. Patterns in the distribution of demersal fishes on the upper continental slope off central California with studies on the role of ontogenetic vertical migration in particle flux. Ph.D. diss., Univ. Calif., San Diego.

Wilkins, M.E., M. Zimmerman, and K.L. Weinberg. 1998. The 1995 Pacific west coast bottom trawl survey of groundfish resources: Estimates of distribution, abundance, and length and age composition. NOAA Tech. Mem. NMFS-AFSC-89.

Yoklavich, M.M., H.G. Greene, G.M. Cailliet, D.E. Sullivan, R.N. Lea, and M.S. Love. 2000. Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge. Fishery Bulletin 98:625-641.

Yoklavich, M., M. Love, and K. Forney. 2007. A fishery- independent assessment of an overfished rockfish stock, cowcod (*Sebastes levis*), using direct observations from an occupied submersible. Canadian Journal Fisheries Aquatic Sciences 64:1795-1804.

Yoklavich, M. M. and V. O'Connell. 2008. Twenty years of research on demersal communities using the *Delta* submersible in the Northeast Pacific. In: J.R. Reynolds and H.G. Greene (eds.) Marine Habitat Mapping Technology for Alaska. Alaska Sea Grant College Program, University of Alaska Fairbanks. DOI 10.4027/mhmta.2008. 10:143-155.

Table 1. Sampling effort (area sampled and number of transects), by 100-m depth stratum, using the *Dual Deepworker* manned submersible on Piggy Bank and Footprint seamounts September 21-30 2011.

Site	Depth Stratum (m)	Total Area (km^2)	Area Sampled (km^2)	Number of 15-min Transects
Footprint	0-100	0.03	0.004	5
	100-200	1.23	0.012	15
	200-300	2.10	0.015	21
	300-400	2.78	0.011	14
Piggy Bank	200-300	0.44	0.005	7
	300-400	1.73	0.005	7

Table 2. Scientific and common names and total number of fishes for each taxa identified from visual surveys conducted from the *Dual Deepworker* manned submersible at Footprint and Piggy Bank seamounts, September 21-30, 2011.

Scientific Name	Common Name	Total Number
Sebastes hopkinsi	squarespot rockfish	4,029
Sebastomus	unidentified *Sebastomus*	3,972
Sebastes semicinctus	halfbanded rockfish	3,425
Sebastes jordani	shortbelly rockfish	2,402
Sebastes wilsoni	pygmy rockfish	1,494
Sebastes ensifer	swordspine rockfish	1,478
Agonidae	unidentified poachers	1,363
Sebastes diploproa	splitnose rockfish	1,134
Merluccius productus	Pacific hake	1,045
Sebastes rufus	bank rockfish	979
Zaniolepis frenata	shortspine combfish	772
Microstomus pacificus	Dover sole	461
Sebastes simulator	pinkrose rockfish	237
Lyconema barbatum	bearded eelpout	170
Sebastes saxicola	stripetail rockfish	169
Plectobranchus evides	bluebarred prickleback	161
Sebastes paucispinis	bocaccio	147
Sebastolobus spp.	unidentified thornyheads	139
Sebastes spp.	unidentified rockfishes	116
Sebastes ovalis	speckled rockfish	96
Sebastes spp.	unidentified young-of-year rockfishes	96
Sebastes aurora	aurora rockfish	85
Sebastes melanostomus	blackgill rockfish	78
Hydrolagus colliei	spotted ratfish	78
Sebastes chlorostictus	greenspotted rockfish	76
Icelinus spp.	unidentified *Icelinus* sculpins	76
Cottidae	unidentified sculpins	72
Sebastes constellatus	starry rockfish	59
Lycodes cortezianus	bigfin eelpout	55
Sebastes helvomaculatus	rosethorn rockfish	54
Glytocephalus zachirus	rex sole	51
Sebastes entomelas	widow rockfish	47
Ophiodon elongatus	lingcod	40
Pleuronectiformes	unidentified flatfishes	40
Sebastes levis	cowcod	38
Sebastes rosenblatti	greenblotched rockfish	37
Zoarcidae	unidentified eelpouts	36
Eptatretus stoutii	Pacific hagfish	30
Sebastes phillipsi	chameleon rockfish	30
Lyopsetta exilis	slender sole	28

Sebastes miniatus	vermilion rockfish	16
Sebastes rubrivinctus	flag rockfish	15
Sebastes elongatus	greenstriped rockfish	15
Raja rhina	longnose skate	13
Sebastolobus alascanus	shortspine thornyhead	12
Sebastes zacentrus	sharpchin rockfish	11
Anoplopoma fimbria	sablefish	10
Eopsetta jordani	petrale sole	10
Osteichthyes	unidentified fishes	10
Parophrys vetulus	English sole	9
Myctophidae	unidentified lanternfishes	9
Bathyraja interrupta	sandpaper skate	9
Citharichthys spp.	unidentified sanddabs	5
Embassichthys bathybius	deepsea sole	5
Sebastes rosaceus	rosy rockfish	4
Sebastes rufinanus	dwarf-red rockfish	4
Sebastes gilli	bronzespotted rockfish	4
Chilara taylori	spotted cusk-eel	3
Scyliorhinidae	unidentified catsharks	3
Sebastes goodei	chilipepper	3
Stichaeidae	unidentified pricklebacks	3
Sebastes eos	pink rockfish	3
Raja stellulata	starry skate	2
Leuroglossus stilbius	California smoothtongue	2
Careproctus melanurus	blacktail snailfish	2
Xeneretmus triacanthus	bluespotted poacher	2
Zalembius rosaceus	pink surfperch	2
Raja spp.	unidentified skates	2
Torpedo californica	Pacific electric ray	1
Cephaloscyllium ventrosum	swell shark	1
Rhinogobiops nicholsii	blackeye goby	1

Table 3. Number and size (mean and standard error, SE) of *selected* species of fish on 69 visual strip transects conducted from *Dual Deepworker* manned submersible at depths of 93-400 m on Footprint and Piggy Bank, September 21-30, 2011. Taxa in bold text only occurred on Footprint seamount.

Scientific Name	Common Name	Number	Mean Length (cm)	SE
Sebastes hopkinsi	squarespot rockfish	4029	15.2	0.1
Sebastomus	unidentified *Sebastomus*	3972	13.1	0.1
Sebastes semicinctus	halfbanded rockfish	3425	11.5	0.0
Sebastes jordani	shortbelly rockfish	2402	18.6	0.1
Sebastes wilsoni	pygmy rockfish	1494	10.0	0.1
Sebastes ensifer	swordspine rockfish	1478	15.5	0.1
Sebastes diploproa	splitnose rockfish	1134	19.6	0.1
Merluccius productus	Pacific hake	1045	22.0	0.1
Sebastes rufus	bank rockfish	979	26.2	0.2
Sebastes simulator	pinkrose rockfish	237	19.1	0.3
Sebastes saxicola	stripetail rockfish	169	17.5	0.3
Sebastes paucispinis	bocaccio	147	37.1	1.0
Sebastolobus spp.	unidentified thornyheads	139	19.7	0.6
Sebastes spp.	unidentified rockfishes	116	13.3	0.6
Sebastes ovalis	speckled rockfish	96	27.1	0.3
***Sebastes* spp.**	young-of-year rockfishes	96	5.3	0.1
Sebastes aurora	aurora rockfish	85	14.1	0.4
Sebastes melanostomus	blackgill rockfish	78	20.7	0.8
Sebastes chlorostictus	greenspotted rockfish	76	24.8	1.1
Sebastes constellatus	starry rockfish	59	20.9	0.8
Sebastes helvomaculatus	rosethorn rockfish	54	21.8	0.5
Sebastes entomelas	widow rockfish	47	29.9	0.6
Ophiodon elongatus	lingcod	40	40.3	2.6
Sebastes levis	cowcod	38	36.0	2.4
Sebastes rosenblatti	greenblotched rockfish	37	32.3	1.2
Sebastes phillipsi	chameleon rockfish	30	25.3	0.8
Sebastes miniatus	vermilion rockfish	16	35.3	1.5
Sebastes rubrivinctus	flag rockfish	15	23.0	1.4
Sebastes elongatus	greenstriped rockfish	15	23.0	1.4
Sebastolobus alascanus	shortspine thornyhead	12	28.3	1.7
Sebastes zacentrus	sharpchin rockfish	11	19.1	1.1
Sebastes rosaceus	rosy rockfish	4	18.8	3.8
Sebastes gilli	bronzespotted rockfish	4	48.8	6.6
Sebastes rufinanus	dwarf-red rockfish	4	10.0	0.0
Sebastes eos	pink rockfish	3	40.0	0.0
Sebastes goodei	chilipepper	3	26.7	1.7

Table 4. Species richness (number of species), by site and depth stratum, estimated from visual strip transects conducted from the *Dual Deepworker* manned submersible, September 21-30, 2011. Only species of interest (Table 3, but not groups of species) were included in this analysis.

Site	Depth Stratum (m)	Species Richness
Footprint	0-100	15
	100-200	23
	200-300	26
	300-400	13
Piggy Bank	200-300	8
	300-400	11

Table 5. Total abundance (number of individuals), biomass, and coefficients of variation (CV) for fish taxa at Piggy Bank, estimated from visual strip transects conducted from the *Dual Deepworker* manned submersible, September 21-30, 2011.

Species	Total Abundance	CV	Biomass (Kg)	CV
Merluccius productus	1,405	0.89	454	0.89
Ophiodon elongatus	0		0	
Sebastes aurora	3,868	0.30	350	0.35
Sebastes chlorostictus	0		0	
Sebastes constellatus	0		0	
Sebastes diploproa	64,489	0.41	7,083	0.40
Sebastes elongatus	0		0	
Sebastes ensifer	0		0	
Sebastes entomelas	0		0	
Sebastes eos	0		0	
Sebastes gilli	0		0	
Sebastes goodei	0		0	
Sebastes helvomaculatus	7,782	0.19	1,487	0.23
Sebastes hopkinsi	0		0	
Sebastes jordani	163,022	0.28	10,981	0.28
Sebastes levis	0		0	
Sebastes melanostomus	1,821	0.55	1,119	0.67
Sebastes miniatus	0		0	
Sebastes ovalis	0		0	
Sebastes paucispinis	0		0	
Sebastes phillipsi	438	1.00	97	1.00
Sebastes rosaceus	0		0	
Sebastes rosenblatti	549	0.72	302	0.87
Sebastes rubrivinctus	0		0	
Sebastes rufinanus	0		0	
Sebastes rufus	116,040	0.48	32,077	0.51
Sebastes saxicola	0		0	
Sebastes semicinctus	0		0	
Sebastes simulator	9,667	0.20	1,306	0.21
Sebastes spp.	3,444	0.27	-	
Sebastes spp. young-of-the-year	0		-	
Sebastes wilsoni	0		0	
Sebastes zacentrus	0		-	
Sebastolobus alascanus	3,353	0.59	1,140	0.67
Sebastolobus spp.	10,067	0.53	1,346	0.47
unidentified *Sebastomus*	29,030	0.20	2,518	0.21

Table 6. Total abundance (number of individuals), biomass, and coefficients of variation for fish species at Footprint, estimated from visual strip transects conducted from the *Dual Deepworker* manned submersible, September 21-30, 2011.

Species	Total Abundance	CV	Biomass (Kg)	CV
Merluccius productus	164,087	0.38	19,538	0.28
Ophiodon elongatus	3,236	0.29	2,716	0.35
Sebastes aurora	19,875	0.31	949	0.30
Sebastes chlorostictus	8,692	0.26	3,675	0.39
Sebastes constellatus	2,461	0.27	511	0.30
Sebastes diploproa	221,329	0.34	14,485	0.38
Sebastes elongatus	1,690	0.41	327	0.45
Sebastes ensifer	161,134	0.34	7,731	0.31
Sebastes entomelas	4,894	0.71	1,895	0.64
Sebastes eos	459	0.74	466	0.74
Sebastes gilli	608	0.46	1,302	0.54
Sebastes goodei	336	0.74	75	0.71
Sebastes helvomaculatus	2,950	0.34	410	0.35
Sebastes hopkinsi	152,971	0.44	8,169	0.43
Sebastes jordani	339,855	0.65	20,956	0.68
Sebastes levis	4,325	0.30	4,183	0.44
Sebastes melanostomus	17,080	0.20	2,542	0.33
Sebastes miniatus	1,070	0.73	628	0.72
Sebastes ovalis	5,310	0.55	1,124	0.56
Sebastes paucispinis	13,342	0.26	8,553	0.27
Sebastes phillipsi	7,824	0.70	1,951	0.68
Sebastes rosaceus	178	0.84	45	0.92
Sebastes rosenblatti	5,398	0.28	3,420	0.37
Sebastes rubrivinctus	1,200	0.44	318	0.53
Sebastes rufinanus	392	0.57	6	0.57
Sebastes rufus	68,629	0.31	14,906	0.35
Sebastes saxicola	22,882	0.33	1,820	0.36
Sebastes semicinctus	302,275	0.41	6,792	0.45
Sebastes simulator	27,517	0.22	2,548	0.23
Sebastes spp.	16,830	0.14	-	
Sebastes spp. young-of-the-year	6,978	0.43	-	
Sebastes wilsoni	68,861	0.43	1,042	0.39
Sebastes zacentrus	1,866	0.48	-	
Sebastolobus alascanus	990	0.78	283	0.68
Sebastolobus spp.	27,702	0.28	3,086	0.29
unidentified *Sebastomus*	268,618	0.20	11,184	0.17

Table 7. Total abundance (number of individuals), biomass, and coefficients of variation for fish species at the combined Piggy Bank and Footprint seamounts, estimated from visual strip transects conducted from the *Dual Deepworker* manned submersible, September 21-30, 2011.

Species	Total Abundance	CV	Biomass (Kg)	CV
Merluccius productus	165,492	0.38	19,991	0.28
Ophiodon elongatus	3,236	0.29	2,716	0.35
Sebastes aurora	23,743	0.26	1,299	0.24
Sebastes chlorostictus	8,692	0.26	3,675	0.39
Sebastes constellatus	2,461	0.27	511	0.30
Sebastes diploproa	285,818	0.28	21,568	0.28
Sebastes elongatus	1,690	0.41	327	0.45
Sebastes ensifer	161,134	0.34	7,731	0.31
Sebastes entomelas	4,894	0.71	1,895	0.64
Sebastes eos	459	0.74	466	0.74
Sebastes gilli	608	0.46	1,302	0.54
Sebastes goodei	336	0.74	75	0.71
Sebastes helvomaculatus	10,733	0.16	1,897	0.20
Sebastes hopkinsi	152,971	0.44	8,169	0.43
Sebastes jordani	502,877	0.45	31,937	0.46
Sebastes levis	4,325	0.30	4,183	0.44
Sebastes melanostomus	18,901	0.19	3,661	0.31
Sebastes miniatus	1,070	0.73	628	0.72
Sebastes ovalis	5,310	0.55	1,124	0.56
Sebastes paucispinis	13,342	0.26	8,553	0.27
Sebastes phillipsi	8,262	0.66	2,049	0.65
Sebastes rosaceus	178	0.84	45	0.92
Sebastes rosenblatti	5,946	0.26	3,722	0.35
Sebastes rubrivinctus	1,200	0.44	318	0.53
Sebastes rufinanus	392	0.57	6	0.57
Sebastes rufus	184,669	0.32	46,983	0.36
Sebastes saxicola	22,882	0.33	1,820	0.36
Sebastes semicinctus	302,275	0.41	6,792	0.45
Sebastes simulator	37,184	0.17	3,854	0.17
Sebastes spp.	20,273	0.12	-	
Sebastes spp. young-of-the-year	6,978	0.43	-	
Sebastes wilsoni	68,861	0.43	1,042	0.39
Sebastes zacentrus	1,866	0.48	-	
Sebastolobus alascanus	4,343	0.49	1,423	0.55
Sebastolobus spp.	37,769	0.25	4,432	0.25
unidentified *Sebastomus*	297,648	0.18	13,702	0.15

Appendix 1. Coefficients used to compute weight (g) from total length (cm) using the equation Weight = a $Length^b$. For species that lack total length-weight coefficients, substitutions (see comment field) were made from closely related species as described in Hyde and Vetter (2007, 2008).

Scientific Name	Common Name	a coeff	b coeff	Sex	Reference	Comment
Merluccius productus	Pacific hake	0.034700	2.556000	males	Dark 1975	
Ophiodon elongatus	lingcod	0.011310	2.990000	both	RecFIN 2009	
Sebastes aurora	aurora rockfish	0.024400	2.832000	both	Wilkins et al. 1998	
Sebastes chlorostictus	greenspotted rockfish	0.009050	3.163210	both	Love et al. 1990	
Sebastes constellatus	starry rockfish	0.009670	3.159790	both	Love et al. 1990	
Sebastes diploproa	splitnose rockfish	0.004070	3.244000	both	Love et al. 2002	
Sebastes elongatus	greenstriped rockfish	0.007930	3.127480	both	Love et al. 1990	
Sebastes ensifer	swordspine rockfish	0.013200	2.970210	both	Love et al. 1990	
Sebastes entomelas	widow rockfish	0.016420	2.942560	both	Love et al. 1990	
Sebastes eos	pink rockfish	0.018556	2.957300	both	Love et al. 2002	
Sebastes gilli	bronzespotted rockfish	0.017711	2.980700	both	Love et al. 2002	
Sebastes goodei	chilipepper	0.007580	3.120300	both	Love et al. 1990	
Sebastes helvomaculatus	rosethorn rockfish	0.016567	2.994300	both	Love et al. 2002	
Sebastes hopkinsi	squarespot rockfish	0.014640	2.984000	both	Love et al. 1990	
Sebastes jordani	shortbelly rockfish	0.005613	3.160000	both	Love et al. 2002	
Sebastes levis	cowcod	0.010090	3.093320	both	Love et al. 1990	
Sebastes melanostomus	blackgill rockfish	0.012250	3.042030	both	Love et al. 1990	
Sebastes miniatus	vermilion rockfish	0.021570	2.923390	both	Love et al. 1990	
Sebastes ovalis	speckled rockfish	0.005200	3.217000	females	Love et al. 1990	
Sebastes paucispinis	bocaccio	0.016200	2.881000	females	Love et al. 1990	
Sebastes phillipsi	chameleon rockfish	0.024400	2.832000	both	Wilkins et al. 1998	borrowed from *S. aurora*
Sebastes rosaceus	rosy rockfish	0.005200	3.385730	both	Love et al. 1990	
Sebastes rosenblatti	greenblotched rockfish	0.011030	3.105720	both	Love et al. 1990	
Sebastes rubrivinctus	flag rockfish	0.020586	2.943100	both	RecFIN 2009	
Sebastes rufinanus	dwarf-red rockfish	0.014640	2.984000	both	Love et al. 1990	borrowed from *S. hopkinsi*
Sebastes rufus	bank rockfish	0.007790	3.146850	both	Love et al. 1990	
Sebastes saxicola	stripetail rockfish	0.009318	3.120100	both	Love et al. 2002	
Sebastes semicinctus	halfbanded rockfish	0.012700	3.016000	females	Love et al. 1990	
Sebastes simulator	pinkrose rockfish	0.005639	3.278513	both	Love unpublished data	
Sebastes wilsoni	pygmy rockfish	0.011912	3.023000	both	Moulton 1977	borrowed from *S. emphaeus*
Sebastolobus alascanus	shortspine thornyhead	0.003900	3.357000	both	Wakefield 1990	
Sebastolobus spp.	unidentified thornyhead	0.003900	3.357000	both	Wakefield 1990	borrowed from *S. alascanus*
Sebastomus	unidentified *Sebastomus*	0.013200	2.970210	Both	Love et al. 1990	borrowed from *S. ensifer*

Figure 1. The study site (inside yellow box), areas sampled (in 100-m gradations of blue), and locations of visual strip transects (pale yellow) conducted from the *Dual Deepworker* manned submersible at Footprint and Piggy Bank, September 21-30, 2011. Green dots indicate the randomly selected start points of transects. Area (km^2) of each 100-meter depth stratum is listed in Table 2. Underlying map of multibeam bathymetry from Dartnell et al. (2005).

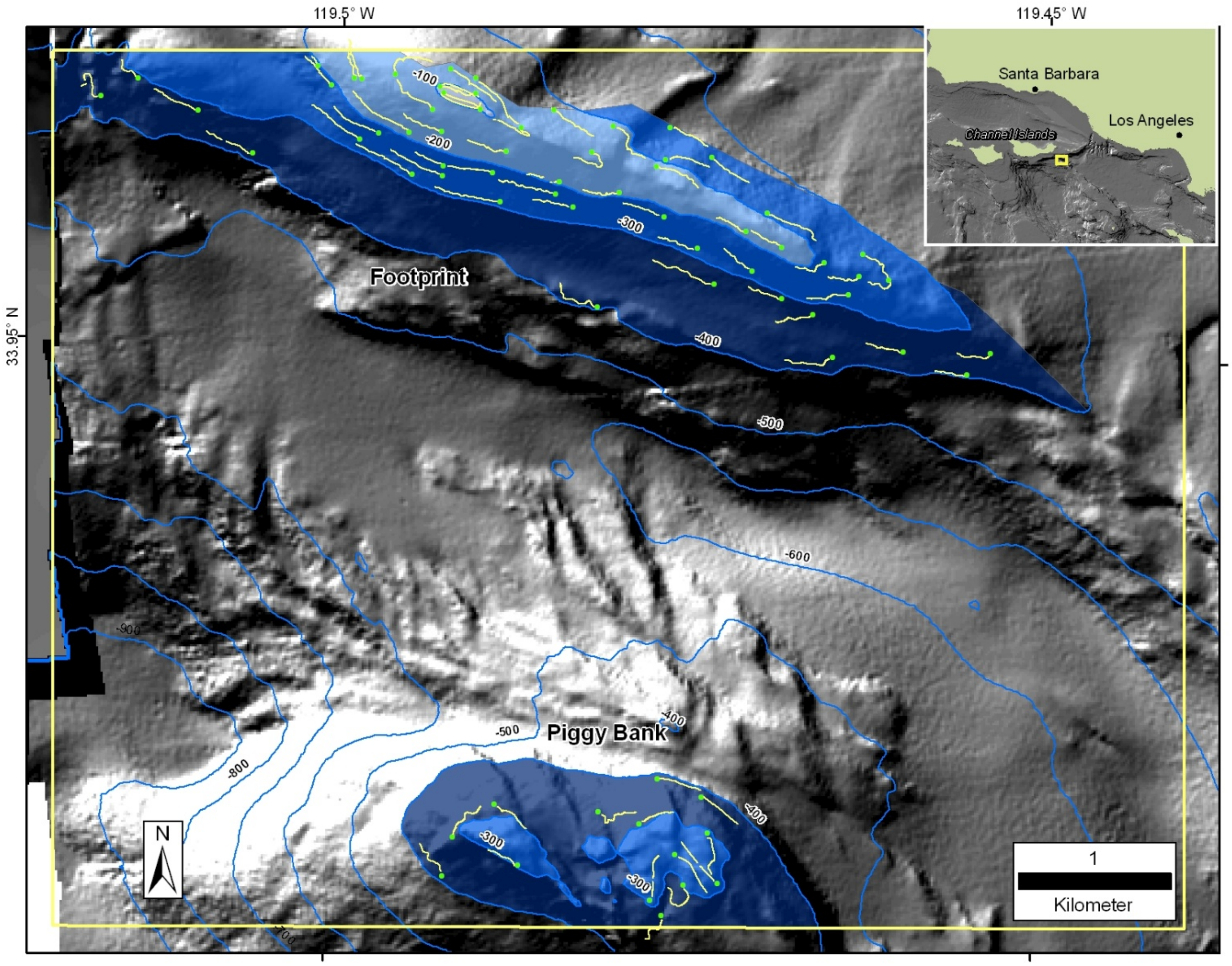

Figure 2. Primary substratum types (>50% of a habitat patch) quantified along visual strip transects conducted from the *Dual Deepworker* manned submersible in 100-m depth strata (gradations of blue) at Footprint and Piggy Bank, September 21-30, 2011.

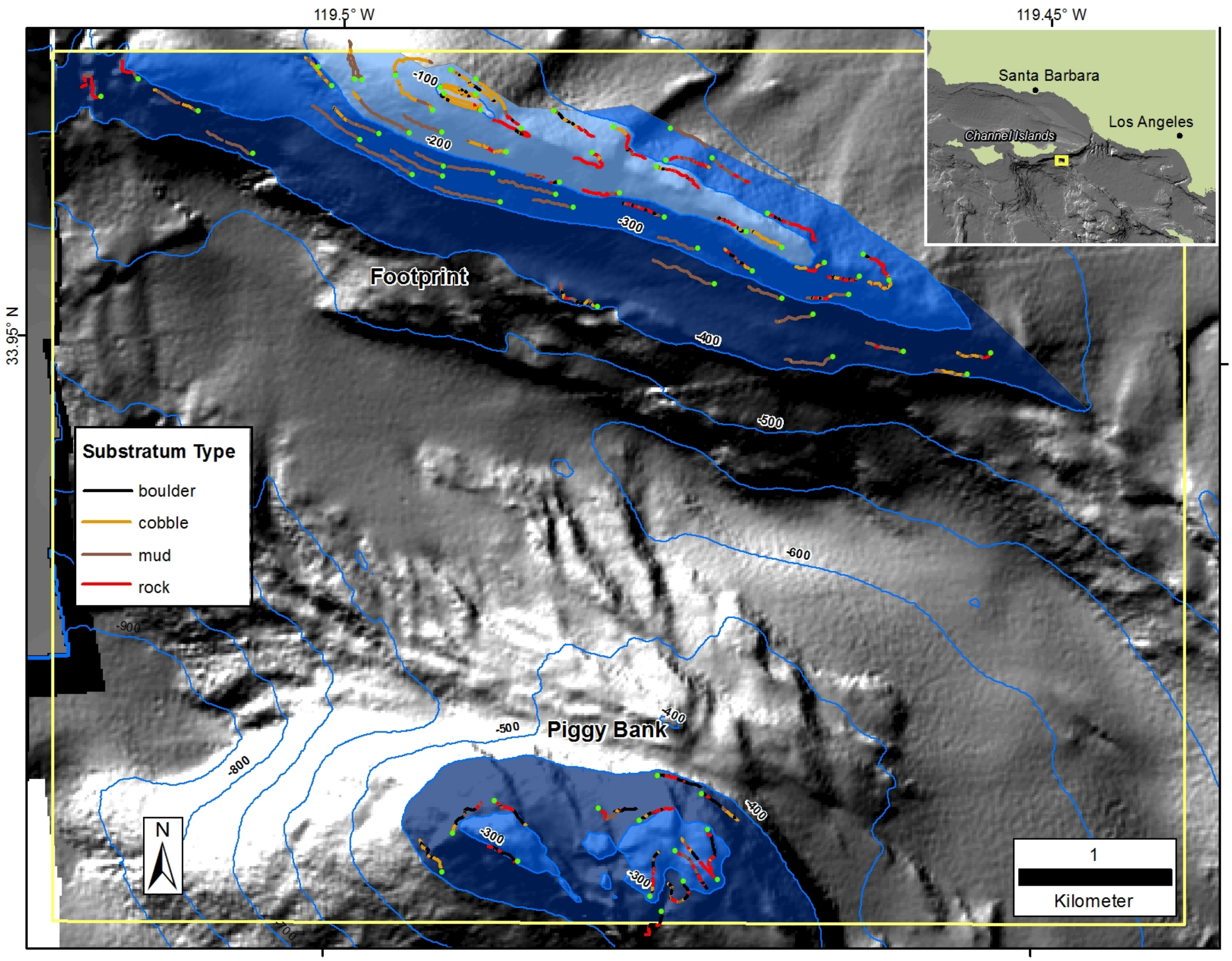

Figure 3. Percentage of the total primary substratum types (> 50% of a habitat patch) quantified along visual strip transects conducted from *the Dual Deepworker* manned submersible in 100-m depth strata at Footprint and Piggy Banks, September 21-30, 2011.

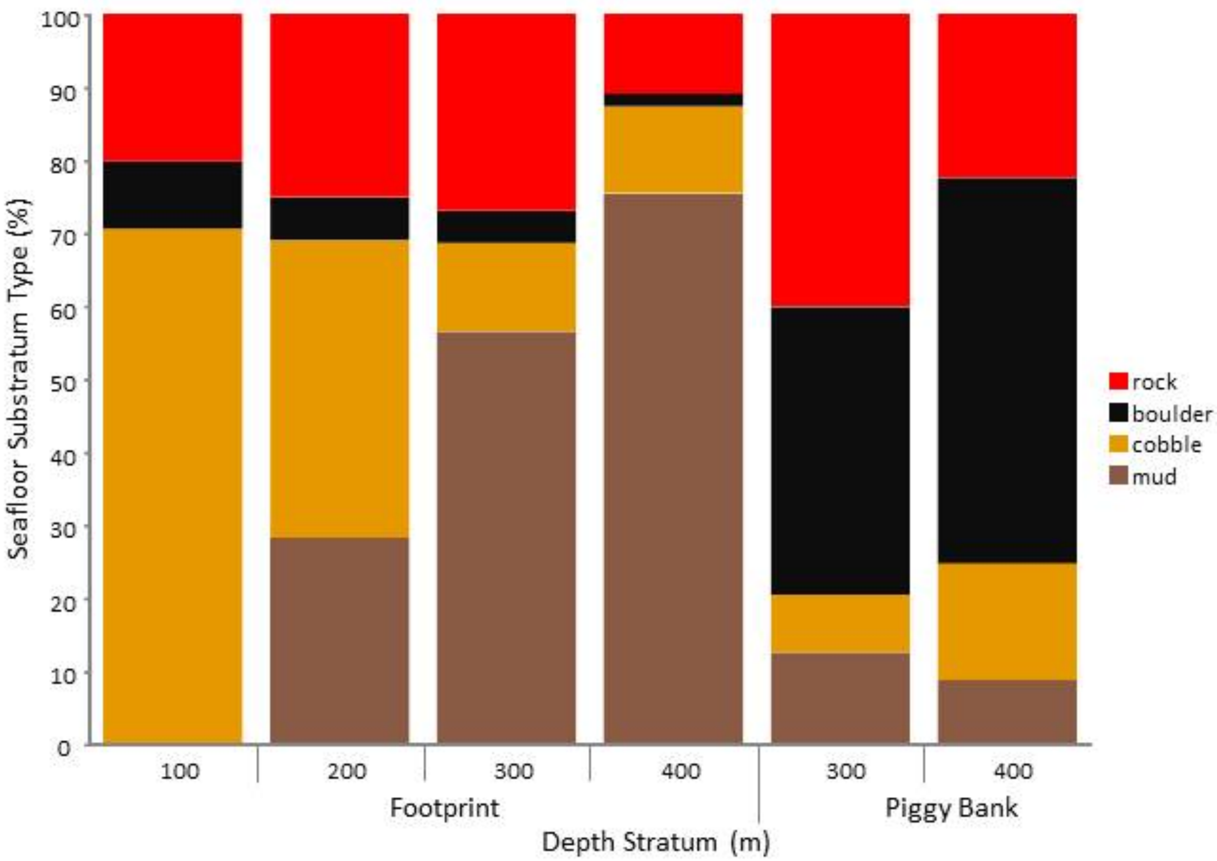

Figure 4. Length frequency distributions for *Sebastes* species, *Sebastolobus alascanus*, *Ophiodon elongatus*, and *Merluccius productus*, measured during visual strip transects conducted from the *Dual Deepworker* manned submersible at Footprint and Piggy Bank, September 21-30, 2011.

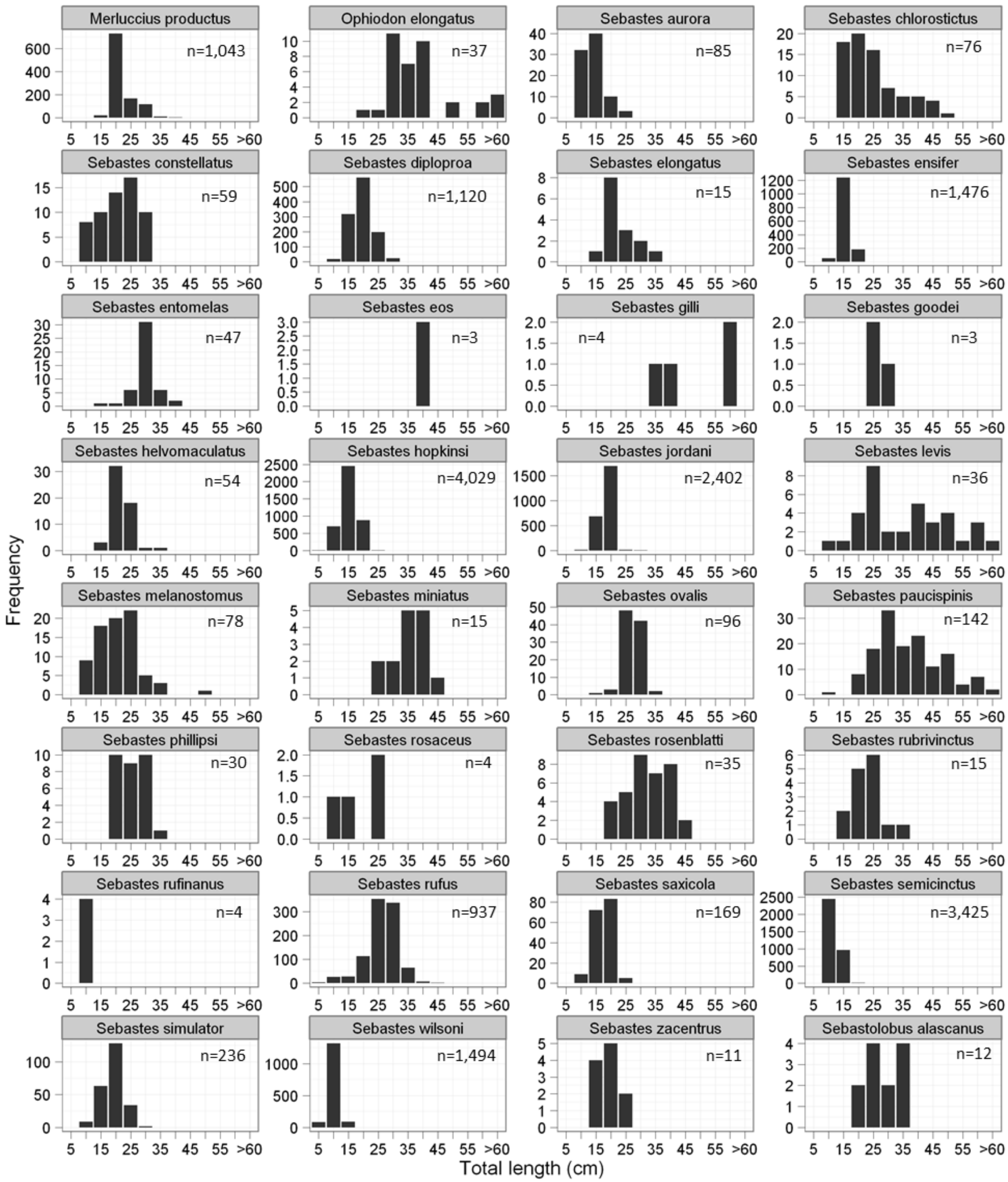

Figure 5. Densities (number/100 m^2 transect) of selected rockfishes and lingcod observed at the Footprint and Piggy Bank during 69 visual strip transects conducted from the *Dual Deepworker* manned submersible, September 21-30, 2011. A) *Ophiodon elongatus*; B) *Sebastes levis*; C) *S. chlorostictus*; D) *S. rufus*; E*) S. wilsoni*; F*) S. jordani*; G) *S. diploproa*.

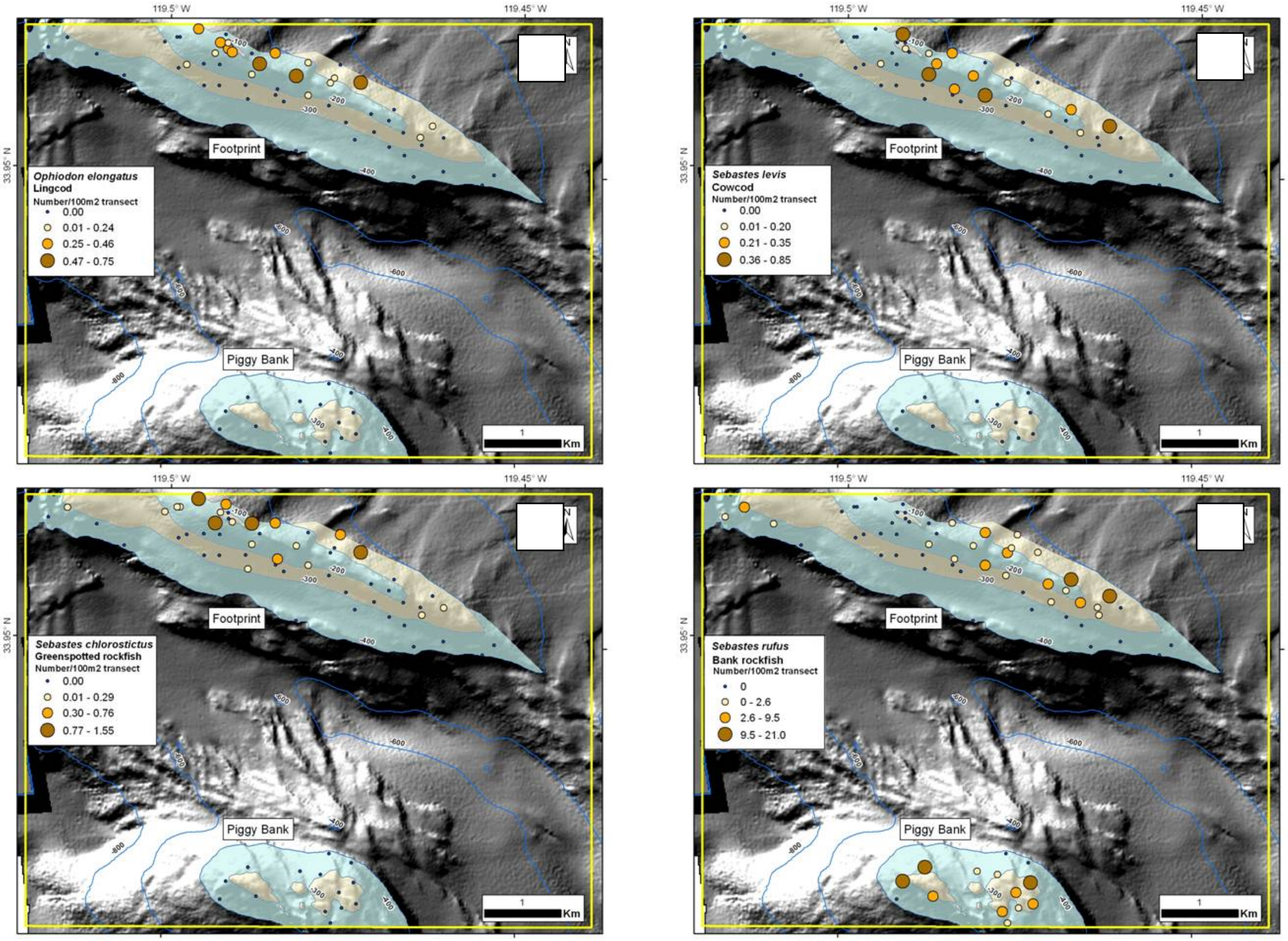

Figure 5 (continued).

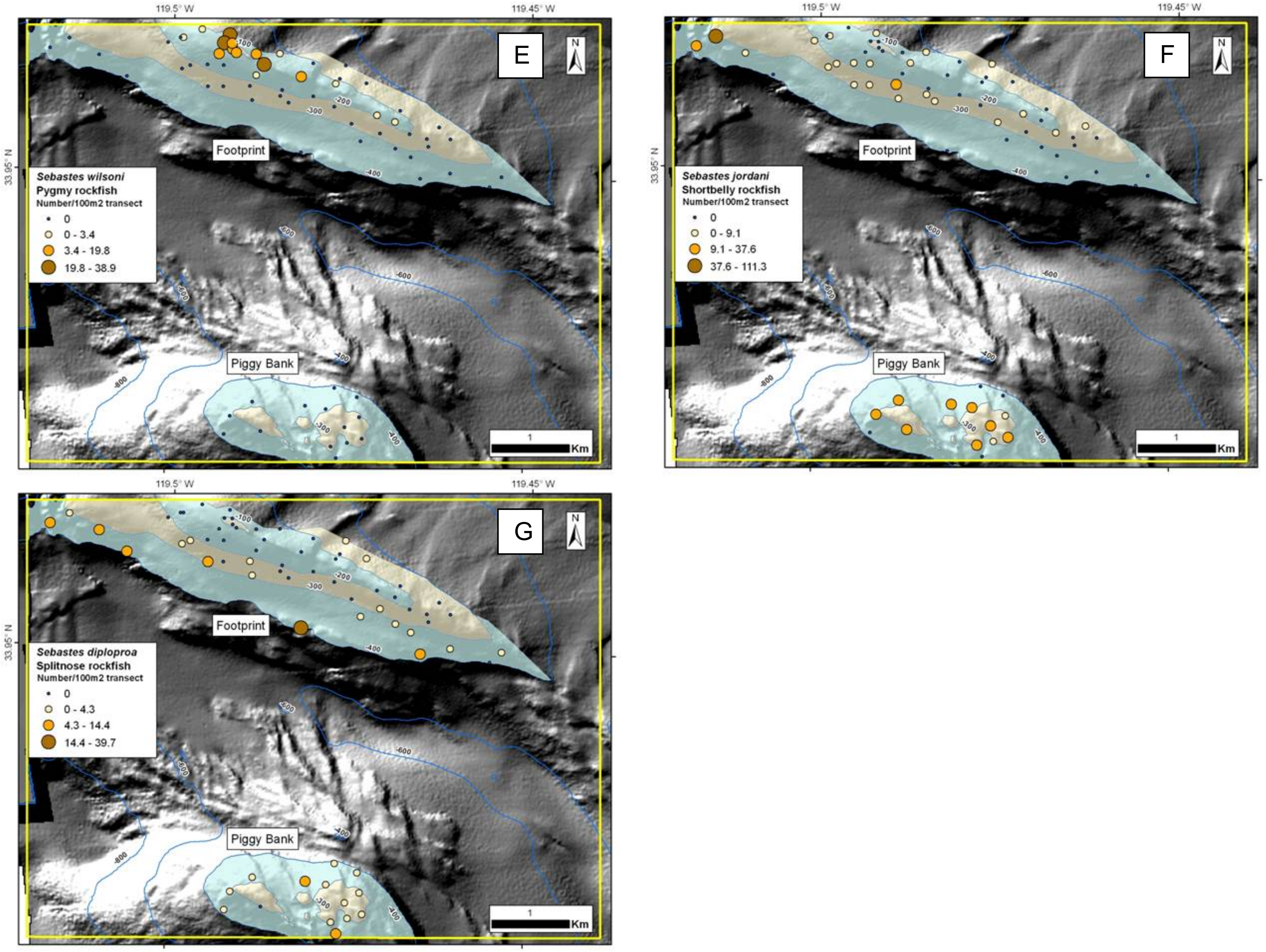

Figure 6. Total abundance (number of individuals) for fish species at the combined Piggy Bank and Footprint seamounts, estimated from visual strip transects conducted from the *Dual Deepworker* manned submersible (DDW) and SWFSC remotely operated vehicle (ROV), September 21-30, 2011. Bold text indicates benthopelagic species. * indicates combined *Sebastes ensifer, S. helvomaculatus*, and unidentified *Sebastomus*. ** indicates adult and juvenile *Sebastes* spp. Note the break in scale of the x-axis (at 10,000 fishes), to better view estimates at low end of abundance.

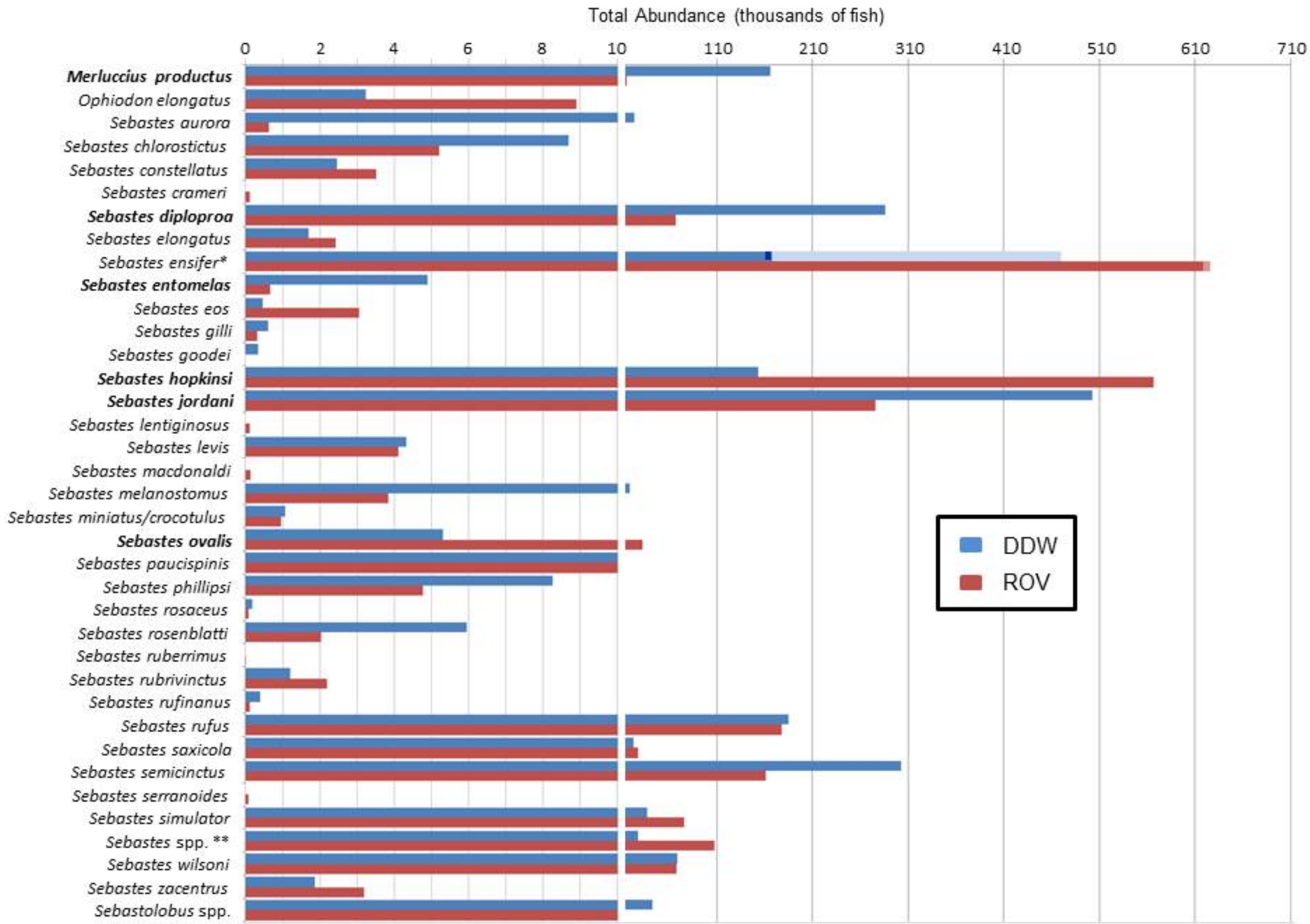

Figure 7. Total biomass (kg) for fish species at the combined Piggy Bank and Footprint seamounts, estimated from visual strip transects conducted from the *Dual Deepworker* manned submersible (DDW) and SWFSC remotely operated vehicle (ROV), September 21-30, 2011. Bold text indicates benthopelagic species. * indicates combined *Sebastes ensifer, S. helvomaculatus*, and unidentified *Sebastomus*. Note the break in scale of the x-axis (at 500 kg), to better view estimates at low end of biomass.