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Habitat characteristics of juvenile cowcod, *Sebastes levis* (Scorpaenidae), in Southern California

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Abstract We characterized habitat requirements of juvenile cowcod, *Sebastes levis*, using information from surveys conducted aboard the manned research submersible *Delta*. We conducted 303 dive surveys on rocky banks and outcrops in water depths between 28 and 365 m in southern and central California, covering 483 km (963,940 m^2) of seafloor. We counted 549,263 fishes from at least 134 species; 216 individuals were juvenile cowcod, *S. levis*, of 45 cm or less in total length (TL). Juvenile cowcod occupied depths between 52 and 330 m and demonstrated ontogenetic shifts in their habitat associations. Small fish (5–20 cm TL) lived primarily among cobbles or cobbles and small boulders. As fish grew, they moved into high-relief rock habitats, including boulder fields and rock ridges. Small cowcods were found with pygmy, *Sebastes wilsoni*, and swordspine, *Sebastes ensifer*, rockfishes. Larger juveniles often associated with juvenile bocaccio, *Sebastes paucispinis*, juvenile widow rockfish, *Sebastes entomelas*, and squarespot rockfish, *Sebastes hopkinsi*. Our study resulted in a characterization of seafloor habitats on a small spatial scale that is relevant to juvenile cowcod nursery areas, which is important when considering effective management strategies for this overfished species.

Keywords Essential fish habitat · Nursery · Recruitment · Rockfishes

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Introduction

The cowcod, *Sebastes levis*, is one of the largest of the rockfishes (family Scorpaenidae), attaining a total length of at least 94 cm (Love et al. 2003a). The species is found from Newport, Oregon to Ranger Bank, central Baja California, and historically was most abundant in southern California (Moser et al. 1994). For many years, cowcod were of significant commercial and recreational importance in both central and southern California (Barnes 2001). Catches in the recreational fishery peaked in 1973–1974, however, and the maximum commercial catch occurred in 1984 (Butler et al. 2003). The species has been declared overfished by NOAA Fisheries and is now under a rebuilding program.

Habitat of adult cowcod is well known; they are found almost exclusively in areas of rock ledges, caves, and other complex habitats (Yoklavich et al. 2000; Love et al. 2003b). By comparison, knowledge of juvenile cowcod habitat is quite limited, largely because it is logistically difficult to study young cowcod and their habitats at the depths of their occurrence. Most information on juvenile cowcod has been derived from trawl surveys. In southern California, these nets have captured small numbers of juveniles in waters between 50 and 190 m deep over soft seafloor (Mearns et al. 1980; Allen 1982; Stull and Tang 1996). From a trawl study in Monterey Bay, California (Johnson et al. 2001), young-of-the-year (YOY) cowcod (standard length [SL] of 50–60 mm) recruited to fine-sediment habitat in late summer. In the Monterey Bay survey, young cowcod were captured in all three of the sampled depth strata (40–60, 60–80, and 80–100 m), with highest densities in the 60–80 m stratum. These young cowcod moved into deeper water during their first year.

Evidence that juvenile cowcod also occupy relatively hard, low-relief habitat comes from direct underwater observations using research submersibles. Both Allen et al. (1976) and Love and York (2005) observed juveniles living on pipelines at 60–235 m depth in southern California. Young-of-the-year cowcod also occur on shell mounds surrounding some southern and central California platforms, and older juveniles inhabit the bottom of the platform jackets at 64–224 m depth (Love et al. 2003b; Love and Yoklavich 2006).

Characterizing nursery habitat is important when evaluating survival and recruitment strength of juvenile cowcod and the subsequent persistence of local cowcod populations. Careful delineation of essential nursery habitats for young cowcod is especially critical when considering effective management strategies related to implementation and monitoring of marine protected areas. Disturbance and loss of such nursery areas could have long-lasting effects on rebuilding this declining species.

Beginning in 1995, we have conducted surveys of demersal fishes using a research submersible in a wide variety of habitats and depths in southern and central California. From this large dataset comprising more than 300 dives and 260 h of transects, we have more completely interpreted the species assemblages and habitat characteristics of fishes living at depths (i.e., >30 m) beyond typical scuba surveys. We presently use these data to characterize aspects of the ecological relationships among young cowcod, their habitat, and other members of a seafloor community.

Materials and methods

Field surveys

Between 1995 and 2004 we conducted 303 dive surveys on rocky banks and outcrops in water depths 28–365 m in southern and central California (Fig. 1). These surveys were conducted aboard the small (4.8 m in length) research submersible *Delta*, which accommodates one scientific observer and one pilot, and has a maximum operating depth of 365 m. 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 knot, depending on substratum type. Dives were made in the fall of the year, during daytime hours, and were documented with an externally mounted hi-8 video camera positioned above the middle viewing-porthole on the starboard side of the submersible. The scientific observer conducted a 2-m wide belt-transect survey through this same starboard viewing port, verbally recording onto the videotape all fishes observed. The observer estimated the total length of these fishes using reference light points from two parallel lasers installed 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 long. These lasers also helped delineate the width (2 m) of the transects. We used personal dive sonar from inside the submersible to measure distance underwater, thereby training the observers eye and verifying the swath width of the transect.

Between 1995 and 2002, transect length was estimated by measuring sub-samples of the transect using the 20-cm intervals from the parallel lasers. By viewing these lasers frame-by-frame in the video, and using a time code overlain onto the video screen, an observer counted the number of 20-cm segments that were included in a 15-s interval. This was repeated once per minute for the duration of the transect. If either laser beam was not visible for a portion of the interval, then that interval was rejected and the next usable interval was sampled. The speed of the submersible was estimated using the mean number of 20-cm segments per 15-s interval, and this mean speed was used to calculate the length of the transect as well as lengths of individual habitat patches. In 2003 and 2004, navigation fixes (latitude and longitude coordinates) were received from a Thales GeoPacific Winfrog ORE Trackpoint 2 USBL system at two-second intervals, and a Winfrog DAT file was generated for each dive. Distance and duration between fixes were calculated to obtain a point-to-point submersible speed; errant navigation fixes were removed when speed exceeded 2 m/s. The navigation fixes were then smoothed using a nine-point moving

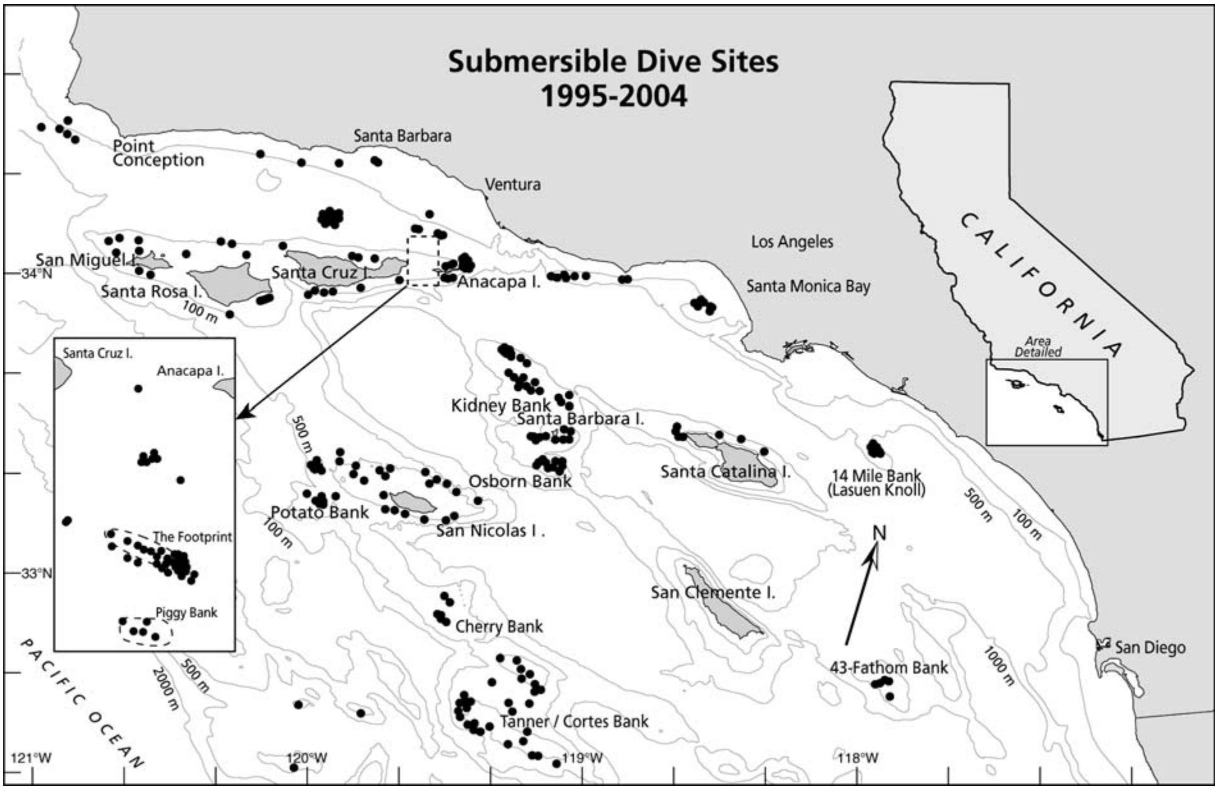


Fig. 1 Location of the 303 dive surveys conducted in southern and central California between 1995 and 2004 using the research submersible *Delta*. Note that *some dots* represent more than one dive made in the same general area

average, and transect length was estimated from the total distance between the smoothed points. Transect length was divided by transect duration to obtain an average transect speed. Length of individual habitat patches was estimated from average speed of the submersible during each transect.

Analyses

For our analyses, we stratified juvenile cowcod into four size classes, 5–10 cm, 15–20 cm, 25–35 cm, and 40–45 cm. Young-of-the-year cowcod grow to about 10 cm in their first year (Johnson et al. 2001; Butler et al. 2003), and 50% of all cowcod are mature at about 45 cm TL and perhaps 10 years (Love et al. 2003a).

We characterized nine habitat categories within the 2-m swath along each dive track (Table 1), based on images from the external video camera. The categories were based on substratum types including mud (code M), sand (S), gravel (G), pebble (P), cobble(C), boulder (B), continuous flat rock (F), rock ridge (R), and pinnacle top (T) (Greene et al. 1999). A two-character code was assigned each time a distinct change in substratum type was noted along the dive tract. The first character in this code accounted for at least 50% of a substratum type and the second character accounted for at least 20% of the substrate type (e.g. 'BC' comprised at least 50% boulders and at least 20% cobble). We characterized relief as low (1) (<25 cm in height) or high (2) (≥25 cm in height) based on criteria in Greene et al. 1999). We stratified depth into shallow (30–150 m) and deep (151–365 m) categories.

We used a chi-square goodness of fit test to determine the relative importance of the various habitats to young cowcod. We hypothesized that if a particular size class of cowcod was neither attracted to nor repelled by a habitat, then the expected proportion of those fish on that habitat would be related to the amount of that habitat available in the survey. Negative values of $X_{j.i}$ indicated that the species was found less often than expected, whereas positive values indicated it was found more often than expected.

In determining the relative importance of habitat types to young cowcod, the asymptotic assumptions for the chi-square test are not valid if the expected

Table 1 Nine habitat categories were based on substratum types: low relief (lr) mud (M) and sand (S); low relief gravel (G), pebble (P), cobble (C), and continuous flat rock; and high relief (hr), boulder (B), rock ridge (R), and pinnacle top (T)

Habitat categories	Substratum types	Total length (km)
Soft–Soft	SS, MM, SM, MS	132
Soft–Hard (lr)	SC, MC, SG, MG, MF, SF, MP, SP	75
Soft–Hard (hr)	SR, MR, SB, MB, ST, MT	22
Hard (lr)–Soft	CS, CM, FS, FM, GS, GM, PS, PM	37
Hard (hr)–Soft	RS, RM, BS, BM, TS, TM	42
Hard (hr)–Hard (lr)	BG, RG, BP, RP, BC, RC, TG, TP, TC, TF, BF, RF	43
Hard (lr)–Hard (hr)	CB, CR, GB, GR, PB, PR, FB, FR, FT	36
Hard (lr)–Hard (lr)	CC, FC, FF, PP, GG, CF, CG, CP, FP, GC, GP, PC	29
Hard (hr)–Hard (hr)	BB, BR, BT, RR, RB, RT, TT, TB, TR	67
Total		483

Low relief is <25 cm in height, high relief is ≥25 cm in height

value of many cells is small. Koehler and Larntz (1980) suggest that the chi-square test is reasonable if the total number of observations is greater than 10, the number of categories is at least 3, and the square of the number of observations is greater than 10 times the number of categories. These criteria were satisfied for all size groups of young cowcod; the sample size for each group was greater than 20, the number of categories was 18, and $20^2=400>10\times18=180$.

We also used a chi-square goodness of fit test to determine which fish species occurred within 1 m of juvenile cowcod. We compared the observed numbers of fishes of a particular species within one meter of the cowcod with the expected number. The null hypothesis was that fish densities outside the 1-m neighborhood were the same as those inside the 1-m neighborhood.

Results

The 303 dive surveys covered 483 km (963,940 m^2) of seafloor (Table 1). Total linear length of the various habitat categories ranged from 132 km (soft–soft) to 22 km (soft–hard: high relief).

We counted 549,263 fishes of at least 134 species. Of these, 216 individuals were cowcod of 45 cm or less in TL (83 fish, 5–10 cm; 54 fish, 15–20 cm; 29 fish, 25–35 cm; 50 fish, 40–45 cm). Juvenile cowcod occurred in depths between 52 and 330 m. In particular, YOY (5–10 cm long) cowcod settled at depths between 52 and 277 m (mean=155 m, s.d.± 46.8). All of the juvenile cowcod were either resting on or very close to the seafloor (Fig. 2).

Juvenile cowcod occupied a wide range of habitats, including both hard and soft substrata. However, the null hypothesis that cowcod are uniformly distributed among the habitats was rejected for all age groups ($P<0.0001$). For instance, compared with the relative amount of available habitats in the survey (Fig. 3a), the smallest fish (5–10 cm TL) occurred disproportionately over hard substrata, either of low relief in deep and shallow depth categories or of mixed high and low relief in deep water (Fig. 3b). In practice, this meant that YOY cowcod lived over seafloors covered either by cobbles or by a mixture of cobbles and small boulders. Fish that were 15–20 cm long mostly occupied habitats similar to those of YOYs (Fig. 3c). Both of the two smallest size groups avoided low-relief soft sediments, especially at shallow depths. Larger juveniles (those 25–35 and 40–45 cm long) also occurred primarily on hard habitats. However, compared to smaller fish, they were found more often in habitats dominated by high relief (Fig. 3d, e). These fish had moved into boulder fields and rock ridges.

Of the 133 other species observed in this study, several commonly associated with juvenile cowcod. YOY cowcod associated with pygmy rockfish, *Sebastes wilsoni* ($X^2=3.5$, $p<0.01$), while pygmy and swordspine rockfish, *Sebastes ensifer*, were often found close to 15−20 cm-long cowcod ($X^2=2.1$, $p<0.03$; $X^2=4.1$, $p<0.01$, respectively). As larger juvenile cowcod moved into more complex habitats, there were some changes in the associated species assemblage. Cowcod of 25–35 cm were commonly found with juvenile bocaccio, *Sebastes paucispinis* ($X^2=$

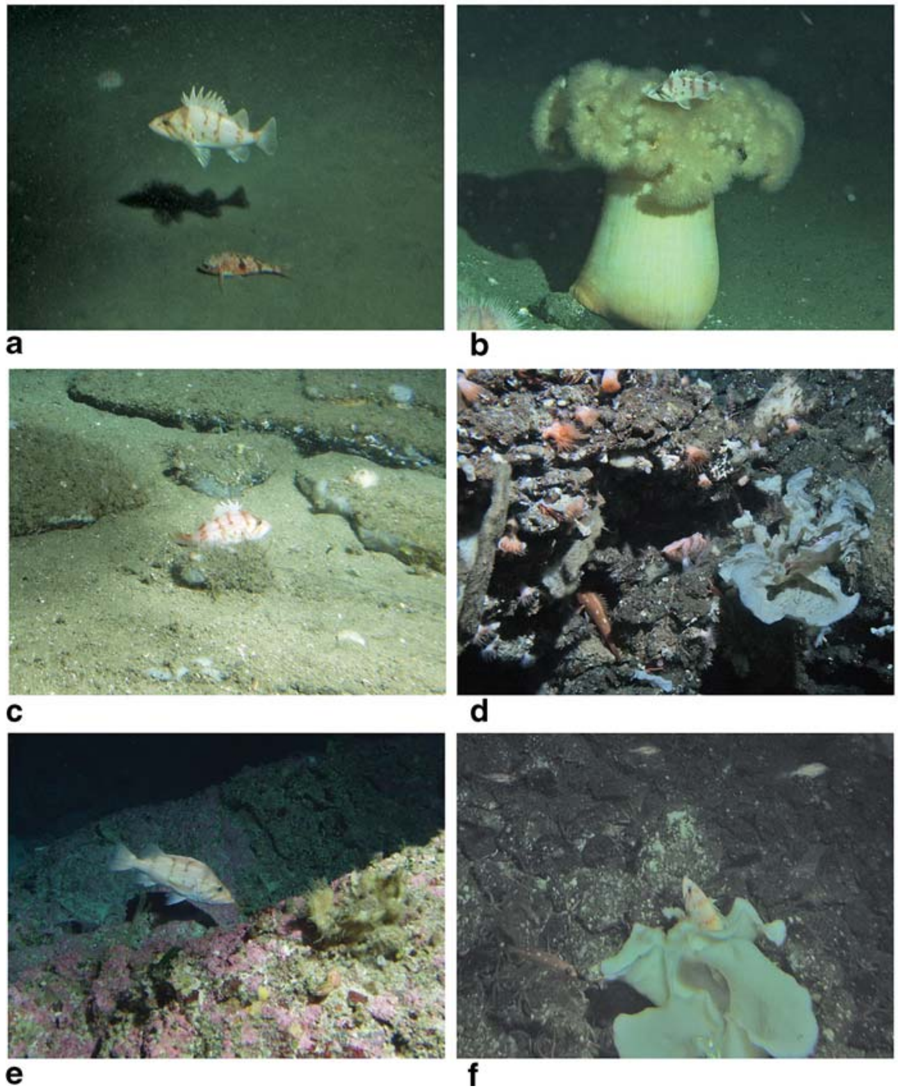


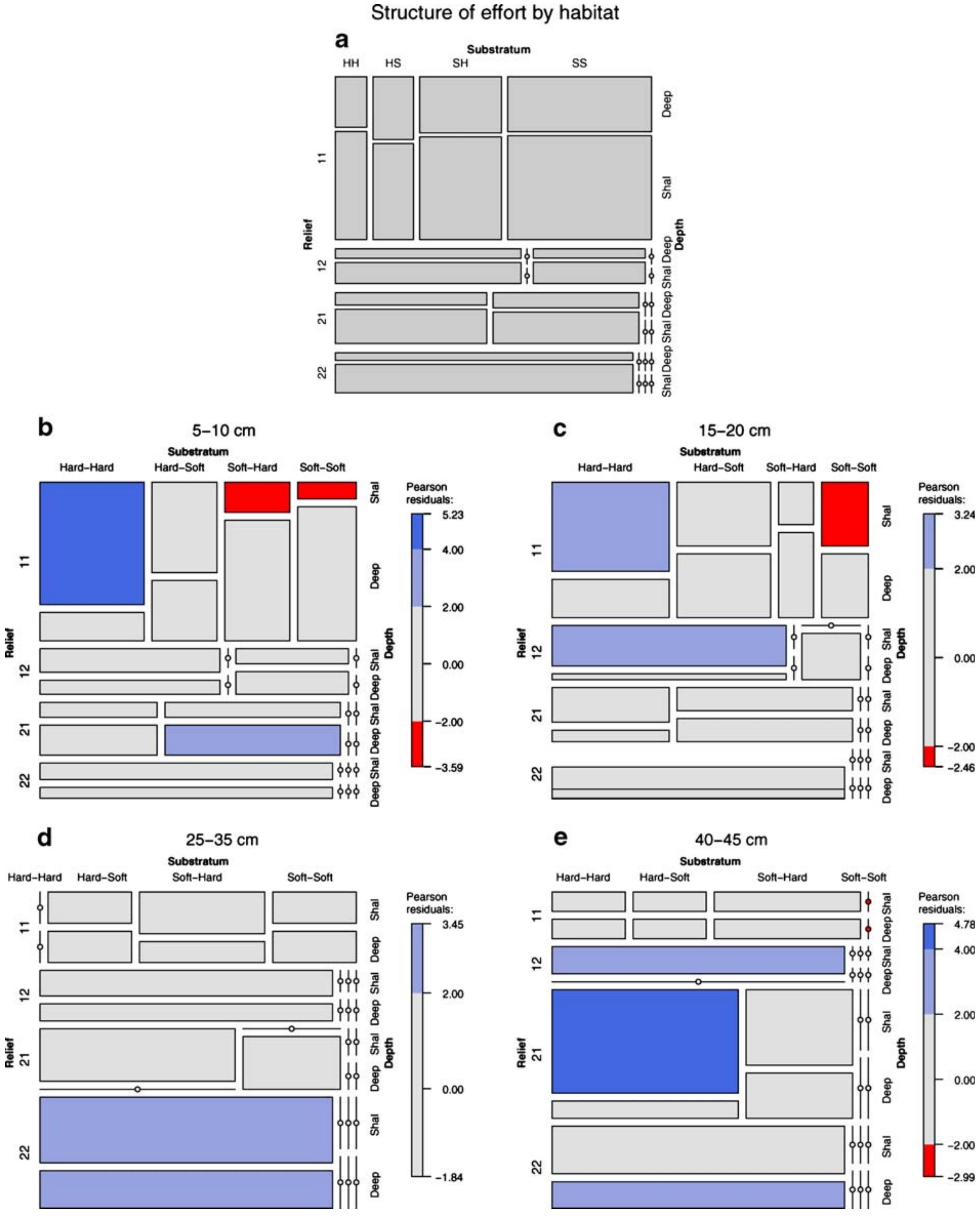
Fig. 2 Juvenile cowcod and some of their habitats: **a** Approximately 10 cm TL young-of-the-year (YOY) over muddy seafloor (soft–soft habitat category). Also present is a halfbanded rockfish, *Sebastes semicinctus*; **b** Approximately 10 cm TL YOY associating with the sea anemone, *Metridium* spp.; **c** Approximately 15 cm TL fish in hard (low-relief)–soft habitat of small boulders and sand; **d** juvenile in boulder habitat (hard (high relief)–hard (high relief) category); **e** 30 cm TL older juvenile over rock ridge (hard (high relief)–hard (high relief) category); **f** 30 cm older juvenile in foliose sponge associated with hard (high relief)–hard (high relief) habitat

17.8, $p<0.01$), and now were negatively associated with small species such as pygmy rockfish. The largest juvenile cowcod (40–45 cm) were found with both juvenile bocaccio and widow rockfishes, *Sebastes entomelas* ($X^2=31.3$, $p<0.01$ and $X^2=19.9$, $p<0.01$, respectively) and squarespot rockfish, *Sebastes hopkinsi* ($X^2=2.3$, $p>0.02$), and were negatively associated with such small species as pygmy and swordspine rockfishes.

Discussion

Based on our study, juvenile cowcod are solitary, benthic animals that settle out of the plankton over a wide depth range and most often occupy hard habitat. Juvenile cowcod often begin their benthic lives living on relatively low relief, hard substrata such as cobblestones and along the ecotonal interfaces of low and high relief.

Within a few years of settling to a benthic habitat, juvenile cowcod move from low relief to complex high-relief rock. It is likely that settling out of the plankton to low-relief substrata evolved as a way to avoid the high densities of large predators (in southern California this would have included adult cowcod, bocaccio, and lingcod, *Ophiodon elongates*, that historically occupied high-relief rock outcrops. However, densities of large fishes over rocky outcrops in southern and central California presently are very


Structure of effort by habitat
a
Substratum
HH
HS
SH
SS
Relief
11
12
21
22
Depth
Deep
Shal
b
5–10 cm
Substratum
Hard–Hard
Hard–Soft
Soft–Hard
Soft–Soft
Pearson residuals:
5.23
4.00
2.00
0.00
−2.00
−3.59
c
15–20 cm
Pearson residuals:
3.24
2.00
0.00
−2.00
−2.46
d
25–35 cm
Pearson residuals:
3.45
2.00
0.00
−1.84
e
40–45 cm
Pearson residuals:
4.78
4.00
2.00
0.00
−2.00
−2.99

◀ **Fig. 3** Mosaic plot of habitat factors (relief, habitat categories, and depth). In Fig. 3a, the size of each panel is proportional to the amount of survey effort in the corresponding habitat type. In Figures b–e (referring to cowcod size classes 5–10, 15–20, 25–35, and 40–45 cm respectively) the size of each panel is proportional to the numbers of juvenile cowcod in the corresponding habitat type. Thus, if juvenile cowcod were randomly distributed the expected proportions in each habitat type would look like that Fig. 3a. Relief height is coded as 1 (low relief, <25 cm high) and 2 (high relief, ≥25 cm high). *Circles with vertical bars* through them designate no observations of habitat of that type. For instance, the category 22 (high relief–high relief) and soft–soft, has such a symbol because, by our definition, soft bottom is low relief. The *panels* are color coded in the following way: 1) *red* if the numbers of cowcod in that habitat are significantly smaller ($0.01<P<0.95$) than expected based on the proportion of the given habitat in the survey; 2) *light blue* if the observed value is larger than expected ($0.01<P<0.05$); 3) *dark blue* if the corresponding observed value is much larger than predicted ($P>0.001$). The figure was constructed using the statistics system R (R Development Core Team 2005), with the add-on package (vcd) for the display of contingency tables (Meyer et al. 2005). Mosaic plots were developed after Friendly (1994)

low, probably the result of long-term, intense fishing and adverse oceanographic conditions (Love and Yoklavich 2006). In turn, this has coincided with a large increase in the numbers of small "weedy" rockfish species, such as pygmy, squarespot, and swordspine rockfishes, that now reside in habitat previously occupied by larger fishes (Stein et al. 1992; Yoklavich et al. 2000; Love and Yoklavich 2006). Similarly, the current dearth of large predators may have allowed cowcod juveniles to move into and occupy complex habitats at a younger age and smaller size than occurred before their predators had been removed. Direct evidence for this comes from observations of an unfished and rugose outcrop in deep water off central California. Although this feature is in the appropriate depth and habitat for juvenile cowcod, it harbors no small fishes of any species, but rather is occupied by high densities of large cowcod, bocaccio, yelloweye rockfish, *S. ruberrimus*, lingcod, and other species (Yoklavich et al. 2000).

Because cowcod stocks are severely reduced, we saw relatively few juveniles. Thus, while our characterization of juvenile cowcod habitat and behavior is accurate, the relative scarcity of these young fish throughout the southern California Bight may influence some generalizations. In particular, our data clearly imply that young cowcod rarely associate with other young congeners. However, it is not clear if this reflects the natural behavior of this species or rather is a recent artifact of the paucity of juveniles.

While this research focused on natural reefs, it should be noted that juvenile cowcod also are found around artificial structures. Relatively high densities have been observed associated with submarine pipelines (Allen et al. 1976; Love and York 2005), the shell mounds that surround oil and gas platforms (Love et al. 1999) and the bottom of platform jackets (M. Love, unpublished data). When we compared our data from surveys on natural reefs with similar data from surveys conducted around oil and gas platforms, we found that the 10 sites with highest juvenile cowcod densities were associated with oil and gas platforms (M. Love, unpublished data).

From previous research based on trawl studies, low relief, soft sediments were suggested to be primary habitat for the youngest benthic stages of cowcod (Johnson et al. 2001). From our visual surveys, we describe more complex habitat associations with young cowcod and demonstrate one of the limitations of trawl surveys. We observed that YOY cowcod occasionally live over soft sediment; these fish would be susceptible to capture by trawl. However, most of these young fish inhabit hard, low-relief habitat that is poorly sampled by trawls. Also, the distribution of these habitats is patchy, which makes it impossible to delineate their association with cowcod within the broad spatial coverage of a trawl survey. Juveniles of some fish species may have quite subtle habitat requirements (Stunz et al. 2002a,b), which cannot be easily distinguished by any survey technique other than direct observations. In their study of the abundance and habitat associations of shortspine thornyheads, *Sebastolobus alascanus*, which are found over both soft and hard substrata, Else et al. (2002) noted that direct observations yielded higher estimates of abundance than did trawl surveys. They, too, speculated that the limitations of trawls as survey devices on complex hard seafloor led to biased results. Thus, we suggest that surveys using direct observations will result in the most accurate assessment of habitat requirements for those species, such as cowcod, that associate with varied rock substrata.

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