Abstract—Although bocaccio (*Sebastes paucispinis*) was an economically important rockfish species along the west coast of North America, overfishing has reduced the stock to about 7.4% of its former unfished population. In 2003, using a manned research submersible, we conducted fish surveys around eight oil and gas platforms off southern California as part of an assessment of the potential value of these structures as fish habitat. From these surveys, we estimated that there was a minimum of 430,000 juvenile bocaccio at these eight structures. We determined this number to be about 20% of the average number of juvenile bocaccio that survive annually for the geographic range of the species. When these juveniles become adults, they will contribute about one percent (0.8%) of the additional amount of fish needed to rebuild the Pacific Coast population. By comparison, juvenile bocaccio recruitment to nearshore natural nursery grounds, as determined through regional scuba surveys, was low in the same year. This research demonstrates that a relatively small amount of artificial nursery habitat may be quite valuable in rebuilding an overfished species.

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Potential use of offshore marine structures in rebuilding an overfished rockfish species, bocaccio (*Sebastes paucispinis*)

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Beginning in 1995, annual surveys of fish assemblages at oil and gas platforms and natural reefs throughout southern California were conducted with a research submersible (summarized in Love et al., 1999, 2000, 2003). Many California oil and gas platforms harbor three fish assemblages: those that occupy the shell mound area surrounding the base of the platform; those that occupy the waters adjacent to the platform bottom, and those that occupy the midwater. Rockfishes (genus *Sebastes*), of about 35 species, dominate these assemblages. The shell mound assemblage is composed primarily of juvenile rockfishes, dwarf rockfishes, and other species; the platform bottom assemblage is composed of adult and subadult fishes; and the midwater assemblage of most platforms (and the bottoms of some mid-depth platforms) is dominated by young-of-the-year (YOY) and older juvenile rockfishes that comprise at least 28 species. These fishes are rarely more than 20 cm long (total length). In the midwaters of most California platforms, there are only low densities of predatory reef fish species, such as kelp bass (*Paralabax clathratus*) and cabezon (*Scorpaenichthys marmoratus*), or semipelagic, large predatory species, such as Pacific barracuda (*Sphyraena argentea*) and yellowtail (*Seriola lalandi*). The proper disposition of the approximately 6000 marine offshore oil and gas platforms and associated structures now in service worldwide is in dispute. There are 27 platforms off California and, as in other parts of the world, there is considerable debate over the ultimate fate of these structures once they are uneconomical to operate (Schroeder and Love, 2004). In this article, we focus on the role that some artificial structures play as rockfish nursery habitat off California.

During some years, we have noted particularly high densities of YOY bocaccio (*Sebastes paucispinis*), widow (*S. entomelas*), squarespot (*S. hopkinsi*), and blue (*S. mystinus*) rock-

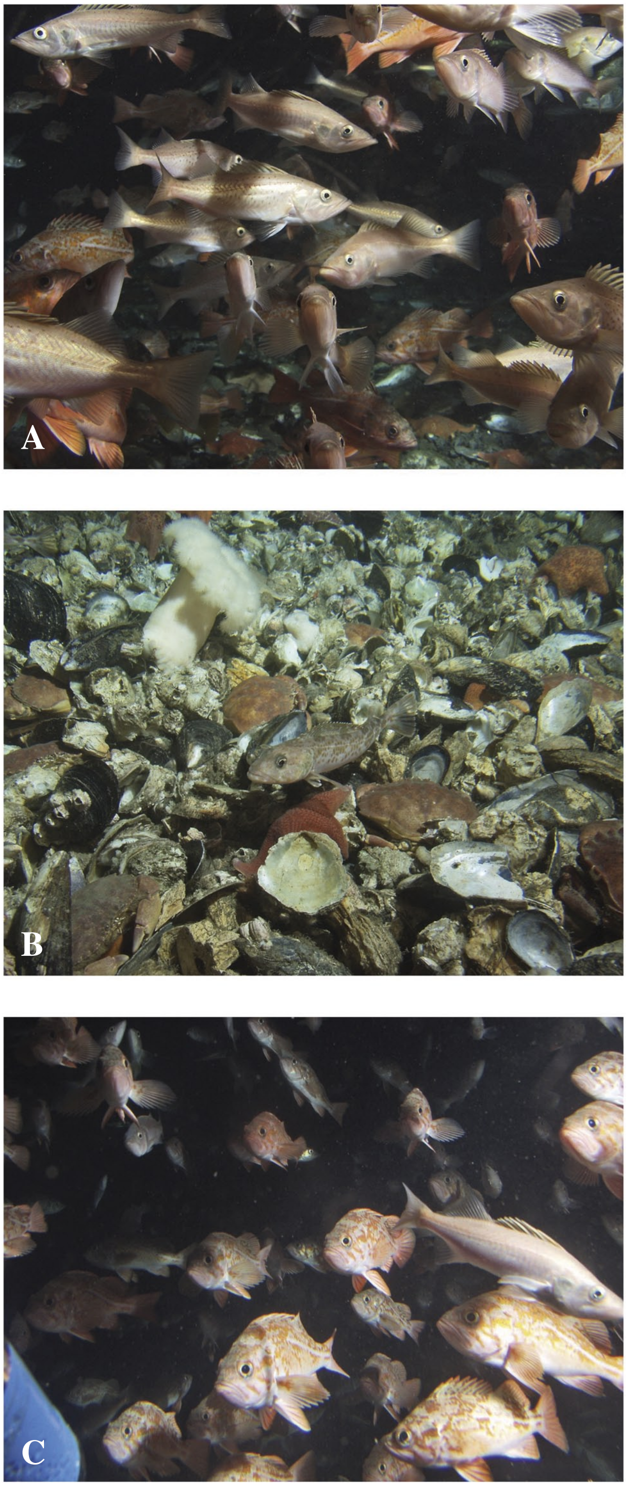

Figure 1

Examples of young-of-the-year (YOY) and other juvenile fishes found in high densities at platform Gilda, October 2003. (**A**) YOY bocaccio (*Sebastes paucispinis*); (**B**) a YOY lingcod (*Ophiodon elongatus*); (**C**) one-year-old vermilion rockfish (*Sebastes miniatus*).

fishes around a number of these platforms. Similar high densities of young rockfishes were noted in the late 1950s at two nearshore platforms off Santa Barbara (Carlisle et al., 1964). The densities of YOY rockfishes are usually higher at platforms than at most natural outcrops (Schroeder et al., 2000; Love et al., 2003). As on natural outcrops, however, YOY rockfish recruitment to platforms is highly variable from year to year.

In 2003, while conducting fish surveys around eight oil platforms in southern California, we observed high densities of YOY rockfishes (e.g., bocaccio and widow rockfish), YOY lingcod (*Ophiodon elongatus*), and one-year-old vermilion rockfish (*S. miniatus*) (Fig. 1). Given the uncertainty regarding the role that platforms might play as fish habitat, we were interested in understanding how important young bocaccio, and by extension the platforms, might be to the stock and populations of this species in the region. Because of the severely overfished status of bocaccio and because a stock assessment model had been developed by NOAA Fisheries, we focused our attention on this species.

Along the Pacific Coast of North America, bocaccio have been reduced to about 7.4% of their unfished population (MacCall[1]). Bocaccio are relatively long-lived (to over 50 years) and have extremely variable annual juvenile recruitment success; over natural outcrops, large year classes are found about once a decade (Tolimieri and Levin, 2005). YOY bocaccio settle from a juvenile micronektonic stage to shallow high-relief habitats (such as kelp beds) and usually migrate into deeper waters within one year. Historically, the species was abundant from Oregon to at least northern Baja California (Love et al., 2002).

In this article we focus on the large recruitment of YOY bocaccio observed at platforms in the Santa Barbara Channel in 2003. We estimate the minimum number of YOY bocaccio at eight platforms in the Santa Barbara Channel, southern California, and estimate the contribution these juveniles may make (as surviving adults) to the rebuilding of the overfished stock. We also compare the densities of YOY bocaccio around the platforms with those determined during the same year in studies on natural reefs throughout southern, and parts of central, California.

Material and methods

Between 10 and 15 October 2003, we surveyed the jacket (horizontal beams and vertical supports)

[1] MacCall, A. D. 2003. Status of bocaccio off California in 2003. *In* Status of the Pacific coast groundfish fishery through 2003 stock assessment and fishery evaluation (vol. 1), v+56 p. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR 97220.

of eight platforms in the Santa Barbara Channel (Fig. 2) using the *Delta* research submersible, a 4.6-meter, 2-person vessel operated by Delta Oceanographics of Oxnard, California. In the platform midwater, we conducted surveys along each of the platform's horizontal beams, located at 20- to 30-m intervals between near-surface waters and the bottom. The shallowest beams were situated at depths of 15–34 m; thus the uppermost parts of the platform were not surveyed. On the seafloor, fish surveys were conducted next to the platform bottom and over the shell mounds that surround platforms. Because of poor water visibility, we were unable to survey either the platform bottoms or the shell mounds of four platforms (i.e., A, B, C, and Hillhouse). We conducted belt transects on the shell mound at an average distance of approximately 7.75 m from the platform and around the platform base and horizontal beams at a distance of approximately 2 m from the platform, while the submersible maintained a speed of about 0.5 knots. Divers estimated transect lengths by first estimating velocity over a short course, using twin laser beams as an aid to estimate their lengths. Submersible surveys were conducted during daylight hours between one hour after sunrise and two hours before sunset. During each transect, the researcher made observations from a viewing port on the starboard side of the submersible. An externally mounted hi-8-mm video camera with associated lights filmed the same viewing fields as seen by the observer. Images recorded by the camera were laid down on tape. The observer identified, counted, and estimated the lengths of all fishes and verbally recorded those data on the videotape. All fishes within two meters of the submersible were counted. Fish lengths were estimated by using a pair of parallel lasers mounted on either side of the external video camera. The projected reference points were 20 cm apart and were visible both to the observer and in the video camera image. We assumed that bocaccio 20 cm or less were YOY, in accordance with growth studies of bocaccio.

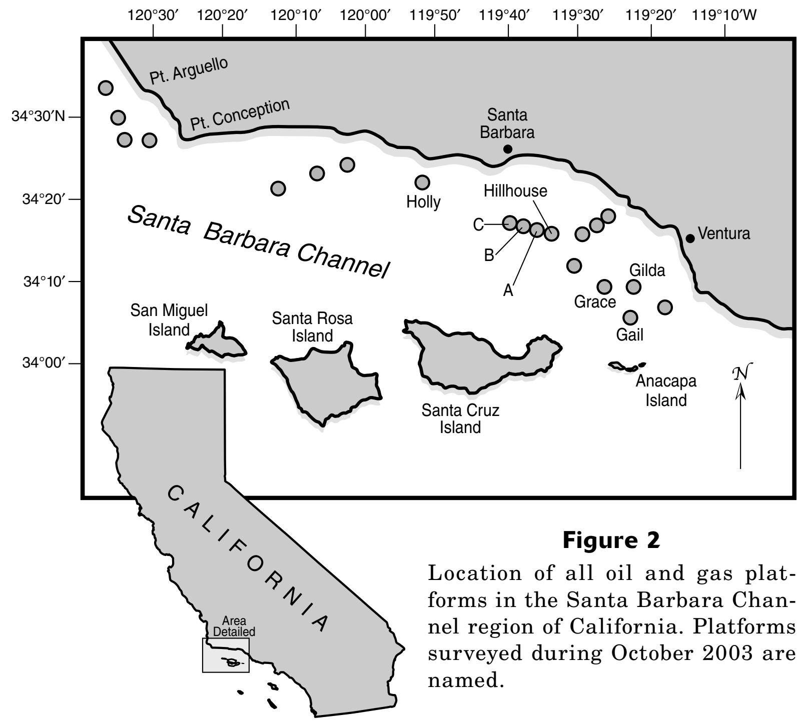

Figure 2

Location of all oil and gas platforms in the Santa Barbara Channel region of California. Platforms surveyed during October 2003 are named.

Many years of experience along the Pacific Coast have shown that if the *Delta* is moving at a constant and slow rate of speed, as in these surveys, there is very little obvious effect on most fishes, particularly rockfishes (M. Love[2]; O'Connell[3]; Yoklavich[4]). Certainly, we noticed virtually no movement from most of the fishes in our study as the research submersible passed by. Unless hidden in complex substrate, fishes as small as about 5 cm in length are readily visible within two meters of the submersible.

Using the data from these surveys, we computed the densities (number of fish per m^2) of YOY bocaccio at the midwater horizontal beams, bottom (when surveyed), and shell mounds (when surveyed) of each platform. From these density estimates, we calculated the abundance of YOY bocaccio at each platform (for protocols see Love[5]).

These abundance estimates are conservative for four reasons. First, we conducted the platform surveys about two meters from the platform and our belt transects count only those YOY bocaccio within two meters of the submersible. Particularly in platform midwaters, densities of YOY rockfishes tend to be lower outside the platform framework (the zone traversed by the submersible) than inside. Second, beginning a few months after settling on platforms, the more open water species, such as bocaccio, blue, widow, squarespot, and yellowtail rockfishes, become less closely associated with structure. There appears to be an ontogenetic shift away from a close association with habitat to a wider association, where these fish wander away from the immediate vicinity of the platform. This shift is particularly true during years with high densities (as in 2003), when large schools wander freely within the relatively open waters of the platform jacket. Third, as noted above, at each

[2] Love, M. 2002. Unpubl. data. Marine Science Institute, University of California, Santa Barbara, CA, 93160.

[3] O'Connell, V. 2004. Personal commun. Alaska Department of Fish and Game, 304 Lake St. Room 103 Sitka, AK 99835.

[4] Yoklavich, M. 2004. Personal commun. NOAA/NMFS Santa Cruz Laboratory, 110 Shaffer Road Santa Cruz, CA 95060.

[5] Love, M. 2005. Methods used to estimate abundance in numbers of young-of-the-year (YOY) bocaccio. Website: http://www.id.ucsb.edu/lovelab [accessed on 26 September 2005].

platform we did not survey in the midwaters above the shallowest horizontal beam (at depths of 15–34 m). Thus, some of the potential bocaccio nursery grounds were not sampled. Fourth, for those platforms where visibility was too poor for us to sample the bottom or shell mound (A, B, C, and Hillhouse), we estimated YOY bocaccio abundances only for that part of the platform (the midwater) that could be surveyed. However, although visibility was too poor to conduct operations on the bottom, we could see high densities of bocaccio inside the platform below the submersible at several platforms when we conducted midwater surveys. Thus, on these platforms, it is highly likely that the YOY bocaccio aggregation extended well below the level of our surveys and that these aggregations contained substantially more of these fishes than we estimated.

We also estimated the level of recruitment of YOY bocaccio in 2003 to natural reefs using data from a variety of sources. In this overview, we included 1) our submersible surveys conducted at depths at which YOY bocaccio may reasonably recruit (down to about 100 m), 2) a scuba survey conducted by D. M. Schroeder, and 3) data from nearshore rocky reef fish surveys conducted by other researchers. The latter surveys were conducted by using scuba at depths of 25 m or less.

Table 1

Densities of young-of-the-year bocaccio (*Sebastes paucispinis*) at eight platforms in the Santa Barbara Channel, October 2003. Because of poor visibility, the zones of some platforms were not surveyed; these are marked N/A.

Platform	Platform zone surveyed	Depth (m)	Number of fish	Density (fish/100 m^2)
A	midwater	15	0	0
		32	0	0
	no base or shell mound	N/A	N/A	N/A
B	midwater	20	0	0
		30	13	4.8
		40	165	57.7
	no base or shell mound	N/A	N/A	N/A
C	midwater	20	0	0
		30	62	17
		45	127	32.1
	no base or shell mound	N/A	N/A	N/A
Gail	midwater	32	2	0.6
		47	27	6.7
		69	18	4.1
		90	3	0.8
		111	25	5.6
		138	1	0.2
		164	1	0.2
		195	4	0.7
	base	226	0	0
	shell mound	226	0	0
Gilda	midwater	25	55	13
		42	24	6.2
	base	62	1023	242.4
	shell mound	62	1078	169.6
Grace	midwater	26	4006	476.8
		45	1537	193.1
		68	1124	258
		70	845	171
		80	92	221.5
	base	96	13	2.6
	shell mound	96	0	0
Hillhouse	midwater	20	0	0
		35	506	140
	no base or shell mound	N/A	N/A	N/A
Holly	midwater	34	18	4
	base	60	12	2.1
	shell mound	60	4	0.4
Total			10,785	

Results

YOY bocaccio were observed at seven of the eight platforms we surveyed. We observed a total of 10,785 YOY bocaccio in the survey (Table 1). We saw no YOY bocaccio at depths of 20 m and less, none at 226 m, and relatively high densities at depths between about 25 and 80 m. Mean YOY bocaccio densities varied between platforms. Platform Grace (368.0 fish/100 m^2) and Gilda (95.2 fish/100 m^2) harbored the highest densities, whereas no YOY bocaccio were observed at Platform A (Fig. 3). Using the methods detailed in Love,[5] we estimated that there was a minimum of 433,682 YOY bocaccio at the seven platforms (Table 2).

Using the model STATC (details of the model are given in MacCall[1]), which is the current basis for fishery management under the Pacific Fisheries Management Council, we determined that the 433,682 YOY bocaccio living around these platforms constitute about 20% of

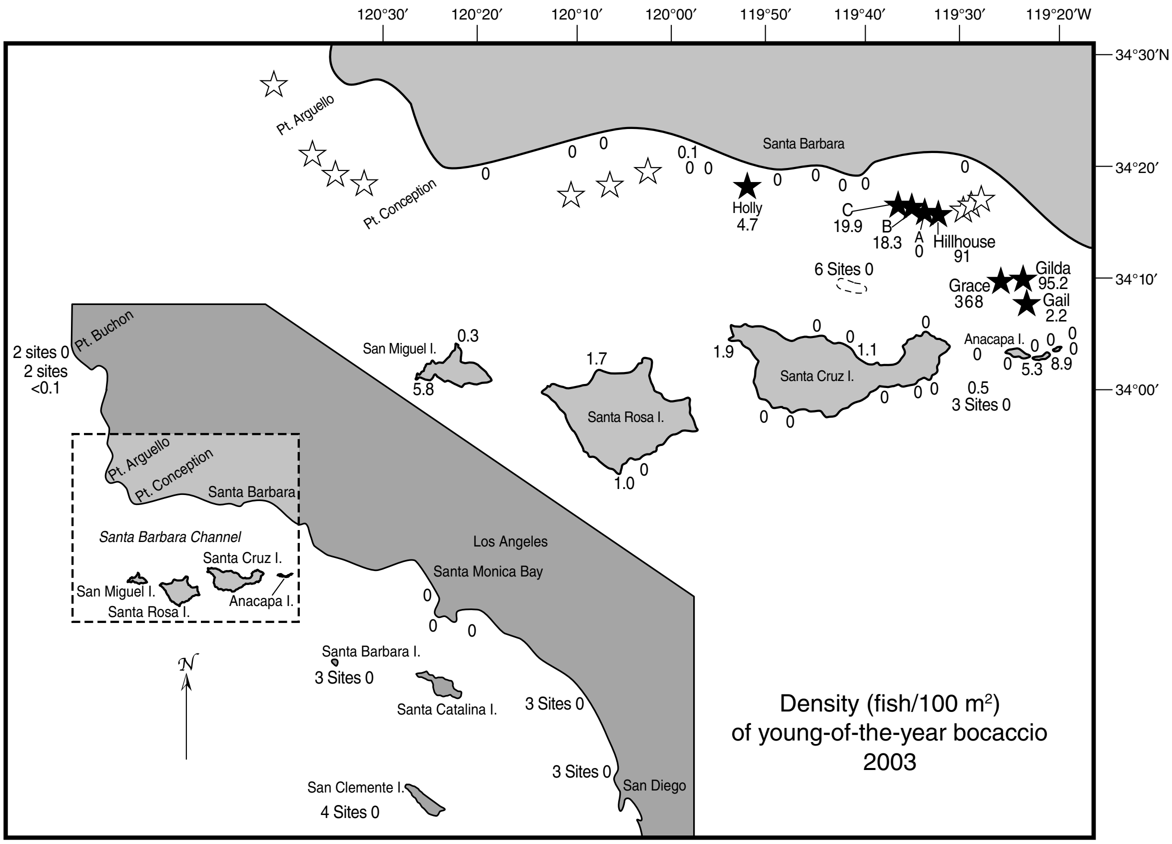

Figure 3

Densities of YOY bocaccio (*Sebastes paucispinis*) (fish/100 m^2) in southern and parts of central California in 2003. Surveys were conducted at sites that were likely YOY bocaccio recruitment habitats, primarily at nearshore kelp beds and rocky outcrops. Surveys by M. Love were conducted from the research submersible *Delta*; the others were conducted by scuba divers. The open stars represent platforms that were not surveyed; the closed stars represent platforms that were surveyed.

the average yearly value, and 40% of the median value for the entire range of the species (based on YOY estimated abundances between 1990 and 2003). From the same model, we estimated that these young fish will eventually contribute slightly less (0.8%) than one percent of the additional amount of fish needed to rebuild the Pacific Coast stock.

By comparison with most of the platforms we surveyed, there was low or no YOY bocaccio recruitment to natural reefs in southern and parts of central California during 2003 (Fig. 3). During 2003, surveys were conducted at 64 sites and no YOYs were observed at 50 of these reefs; most of the other 14 sites harbored very low densities. The highest density noted at any natural outcrop (8.9 fish/100 m^2), observed at a small kelp bed at Anacapa Island, was much lower than that at five of the surveyed platforms.

Table 2

Estimated numbers of young-of-the-year bocaccio (*Sebastes paucispinis*) inhabiting eight platforms in the Santa Barbara Channel, 2003. Note that the surveys of four platforms, Hillhouse, C, B, and A, did not include the bottom of the platform and its surrounding shell mound.

Platform name	Estimated abundance
Grace	353,411
Gilda	39,854
Hillhouse (partial)	22,171
C (partial)	5977
B (partial)	5911
Gail	5521
Holly	837
A (partial)	0
Total	433,682

Discussion

According to our estimates, the YOY bocaccio living around seven platforms in the Santa Barbara Channel were important to the regional bocaccio population, and it appears that a substantial portion of the YOY bocaccio recruitment that occurred in the Santa Barbara Channel during 2003 took place at the surveyed platforms.

Because it is likely that most reefs both attract and produce fishes, discussions of reef function have evolved from the single issue of attraction versus production to an evaluation of the ecological performance of fishes at natural and human-made habitats. Reviews and studies that compare natural and human-made reefs as juvenile fish habitats should address: 1) a comparison of the survival rate of young fishes (including predation, growth rates, and survival after emigration, if that occurs) at the two habitat types, 2) the density of recruiting juveniles at a human-made reef versus that at surrounding natural reefs, 3) the possibility that a human-made reef is drawing recruiting juvenile fishes from nearby natural reefs, 4) the source of juvenile fishes found on a human-made reef—either from the plankton or from natural reefs (discussed in a number of papers including Bohnsack et al., 1994; Carr and Hixon, 1997; Pickering and Whitmarsh, 1997).

What is the survival rate of young fishes that recruit from the plankton to platforms and those that recruit to natural reefs? What appears to be a unique feature of the midwaters of many California platforms (compared to both natural reefs and to Gulf of Mexico platforms) is that many may act as juvenile (particularly YOY) fish refuges. The midwaters of platforms do not act as structural refuges. That is, they are not dotted with crevices, caves, and other complexities that allow fish to hide (Hixon and Beets, 1993). Rather, platforms may afford spatial refuges because, in general, concentrations of adult reef fishes tend to be found at the bottom of platforms (except for those platforms that harbor almost no adult fishes at all) rather than in the midwaters. Transitory and migrating piscivorous species, such as jacks and barracuda (taxa that are abundant around Gulf of Mexico platforms [Stanley and Wilson, 2000]) are also not common around most California platforms (Love et al., 2003). We have also not observed high densities of either fish-eating pinnipeds or sea birds around these structures. In addition, studies (Schroeder et al., 2005) demonstrate that predation rates on small fishes are lower in platform midwaters than at natural reefs.

Several lines of evidence demonstrate that YOY bocaccio recruit to platforms from the plankton and that the platforms do not attract previously settled fish from natural reefs. Studies of the seasonal timing of platform recruitment pulses and the size of the recruiting individuals are consistent with the hypothesis that young bocaccio settle on the platforms from the pelagic environment (Nishimoto et al., 2005; Schroeder[6]; Nishimoto[7]). Are these platforms, then, drawing away pelagic juveniles that would have settled instead on natural outcrops? Although it is possible that some pelagic juveniles that had settled on platforms would have found natural reefs, it is likely that most of these fish would not have survived in the absence of these structures. As an example, Emery et al. (2006) simulated near-surface drift trajectories from high-frequency radar current measurements to model movements of pelagic juvenile bocaccio in the vicinity of a platform off Pt. Arguello, central California. They estimated that for 1999 and 2002, a minimum of 76% and 69% of the modeled pelagic juvenile bocaccio would not have found natural habitat on which to settle. Although the platforms we surveyed were east of the platform examined in the Emery et al. (2006) study, it is unreasonable to conclude that these relatively small platforms are filtering the majority of pelagic juvenile bocaccio from the pelagic environment to the exclusion of natural reefs. Rather, it is possible that some platforms provide recruitment habitat for fishes that would otherwise be lost from the population.

What is the fate of YOY bocaccio that settle around platforms? In general, YOY bocaccio emigrate from shallower platforms within two years. At least some of these fish migrate to natural reefs, because young bocaccio tagged around Platforms A and B in 1978 and 1979 were recaptured on natural reefs as adults as much as 150 km from the tagging sites (Hartman, 1987). Our observations of bocaccio on the deeper Platform Gail demonstrate that many of the YOY bocaccio that recruited to that platform from the plankton in 1999 remained in the area (migrating to the bottom in 2000) and matured into adults (Fig. 4).

To summarize, the weight of evidence implies that some of the platforms in southern California produce bocaccio. During some years, young bocaccio settle from the plankton to the platforms in large numbers. This settlement may occur even when juvenile recruitment to natural reefs in the same region is low. Compared to the structure of most natural reefs, the structural complexity and high vertical profile of platforms probably provide pelagic juvenile rockfishes with a relatively strong stimulus to trigger settlement. Mortality on platform YOY bocaccio from predation may be relatively low because of a relative scarcity of predators. There is also evidence that platforms retain pelagic bocaccio juveniles that would otherwise have been carried into inhospitable offshore waters. At least some bocaccio that emigrate from platforms survive to populate natural reefs, whereas, as in the case of one platform, some YOY bocaccio remain and mature into adults. Thus, there is the likelihood that many of the YOY bocaccio we observed at platforms will either emigrate and seed natural reefs or will reside at the platforms and reproduce.

Clearly, our research was subject to a number of assumptions and the ambiguities that may be associated with these assumptions. These assumptions add some degree of uncertainty both to our estimates of YOY bocaccio abundances and their subsequent contribution to stock rebuilding. However, we consider this research to be sufficiently strong to demonstrate the importance of

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[6] Schroeder, D. M. 2002. Unpubl. data. Marine Science Institute, University of California, Santa Barbara, CA 93106.

[7] Nishimoto, M. 2005. Personal commun. Marine Science Institute, University of California, Santa Barbara, CA 93106.

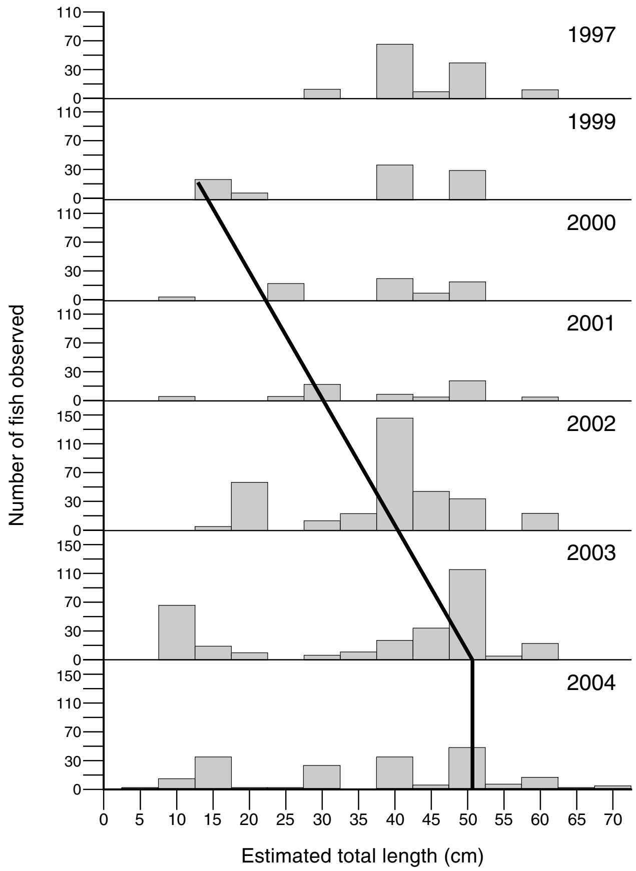

Figure 4

Size-frequency histogram of all bocaccio (*Sebastes paucispinis*) observed in all depths at Platform Gail from the research submersible *Delta*, 1995 to 2004. A relatively strong year class recruited in 1999 to the platform midwaters. We observed these fishes at the bottom in 2000 and they remained there through 2004. The near cessation of growth of these fishes between 2003 and 2004 approximates the size at which 100% of the fish are mature (Love et al., 2002).

spatial structure in driving marine population dynamics, where a small amount of nursery habitat, either human-made or natural, may disproportionately impact a widely distributed species. It also highlights the importance of understanding the potential role of any marine habitat before that habitat is altered, either purposefully or unintentionally.

Acknowledgments

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