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ECOLOGICAL PERFORMANCE OF YOUNG-OF-THE-YEAR BLUE ROCKFISH (*SEBASTES MYSTINUS*) ASSOCIATED WITH OIL PLATFORMS AND NATURAL REEFS IN CALIFORNIA AS MEASURED BY DAILY GROWTH RATES

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ABSTRACT

Decommissioning alternatives regarding offshore oil platforms include leaving some or all of the platform structure in place. However, despite the high numbers of fishes that can reside around offshore platforms, little is known about the comparative ecological performance of fishes living on platforms compared to those inhabiting natural habitats. It would be expected that sites where fishes exhibited better growth, increased reproduction, or greater survival rates would be beneficial to regional fish populations. We determined and compared the birthdate distributions and daily growth rates of 116 young-of-the-year (YOY) blue rockfish (*Sebastes mystinus* Jordan and Gilbert, 1881) among two platforms and two natural reefs in the Santa Barbara Channel region. We found a significant though modest lunar pattern in birthdates where blue rockfish produced (or successfully recruited) more larvae in the week leading up to the full moon. Mean growth rates were significantly different across sites. At one of the two site pairs (platform-natural reef), YOY rockfish growth rates were significantly higher at the platform habitat; there was no statistical difference in growth rates between fish living at the other site pair. This study demonstrates that, as measured by daily growth rates, blue rockfish living around oil and gas production platforms may perform at least as well as those fish living on natural reefs, and supports previous research implying that some platforms may benefit regional fish populations.

All 27 oil and gas platforms located off the coast of southern and central California will at some time reach the end of their economic life spans. California platforms are located in both state and federal waters and are sited in bottom depths ranging from 11 to 363 m. The largest of these structures has a footprint of 10,606 m^2 (Love et al., 2003). While platform operators are responsible for the costs of disposition of an uneconomical platform, managers must decide what to do with that structure, a process known as decommissioning. Ultimately, a decommissioned platform could be left in place, removed to some point below the sea surface, toppled to lie on the sea floor, or totally removed (Schroeder and Love, 2004). Decommissioning can be a lengthy process, as it requires input from state and federal agencies, corporate entities, and such stakeholders as recreational and commercial fishermen, and non-consumptive users. It may involve extensive analyses of the biological, economic, and other sociological impacts of retaining or removing these structures (Schroeder and Love, 2004).

Since 1995, much of our research has focused on the potential biological impacts of platforms as fish habitats. A number of economically important fishes, particularly rockfishes (genus *Sebastes*), are found at high densities around some California platforms. Rockfishes, a group that dominates many of the shelf and slope habitats of southern and central California (Love et al., 2002), often comprise over 90% of all fishes observed around these structures (Love et al., 2003).

Platforms are open steel structures composed of vertical pilings and pipes and horizontal and diagonal crossbeams. These horizontal beams are placed every 20–30 m from near the ocean surface to next to the sea floor. Platform midwaters (defined as waters from 2 m above the sea floor to the ocean surface) and the bottoms of some shallow-water structures often act as nursery grounds for rockfishes and other species; densities of many rockfish species are almost always higher than at nearby natural outcrops (Love et al., 1999; Carr et al., 2003; Love et al., 2003). It is likely that, compared to most natural reefs, a platform's size, structural complexity, and high vertical profile provides pelagic juvenile rockfishes and larvae of other species with a relatively strong stimulus to trigger settlement (Carr et al., 2003).

While we have observed young-of-the-year (YOY) of at least 28 rockfish species at platforms, five rockfish species (bocaccio, *Sebastes paucispinis* Ayres, 1854; widow, *Sebastes entomelas* Jordan and Gilbert, 1880; squarespot, *Sebastes hopkinsi* Cramer, 1895; olive, *Sebastes serranoides* Eigenmann and Eigenmann, 1890; and blue, *Sebastes mystinus* (Jordan and Gilbert, 1881) recruit to many of these structures in particularly large numbers (Carr et al., 2003; Love et al., 2003). As an example, we estimated that during 2003, Platform Grace (located in the Santa Barbara Channel) harbored more than 350,000 YOY bocaccio (Love et al., 2006). Young-of-the-year rockfish recruitment to both platforms and natural reefs varies greatly from year to year.

The high densities of YOY rockfishes inhabiting platform midwaters notwithstanding, there remain questions regarding the importance of these young fishes to regional fish populations. The relative ecological contribution of fishes living around artificial and natural habitats (as measured by fish growth, survival, and reproduction) is a major determinant of that habitat's quality and, ultimately, of its importance (Carr and Hixon, 1997; Beck et al., 2001; Carr et al., 2003; Mason, 2003). In 1999, a relatively strong recruitment of YOY blue rockfish to both platforms and natural reefs in southern and central California allowed us to compare lunar parturition dates and daily growth rates of these young fishes.

Blue rockfish are found from southeastern Alaska to northern Baja California and reach a maximum length of 53 cm. They are a nearshore schooling species that usually lives over rocky sea floors, in kelp beds, and around many oil and gas platforms. (Love et al., 2002, 2003). Like all of the rockfishes, this species is viviparous with larvae extruded into the water column and metamorphosing into pelagic juveniles within about one month. This pelagic stage lasts between 3.5 and 4.5 mo (T. Laidig, NOAA Fisheries, pers. comm.).

Methods

Sample Collections.—During the fall of 1999, YOY blue rockfish were collected by pole spear at two platforms and two natural reefs (Fig. 1). We selected our collection sites based on where YOY blue rockfish were sufficiently abundant to allow for inter-site growth rate comparisons. Comparisons were made between fish at Platform Irene and a reef at Santa Rosa Island (both are in the California Current and are 84 km apart) and Platform Holly and Naples Reef (in the same water mass and located within 8 km of each other). Collections were made during one d at each site.

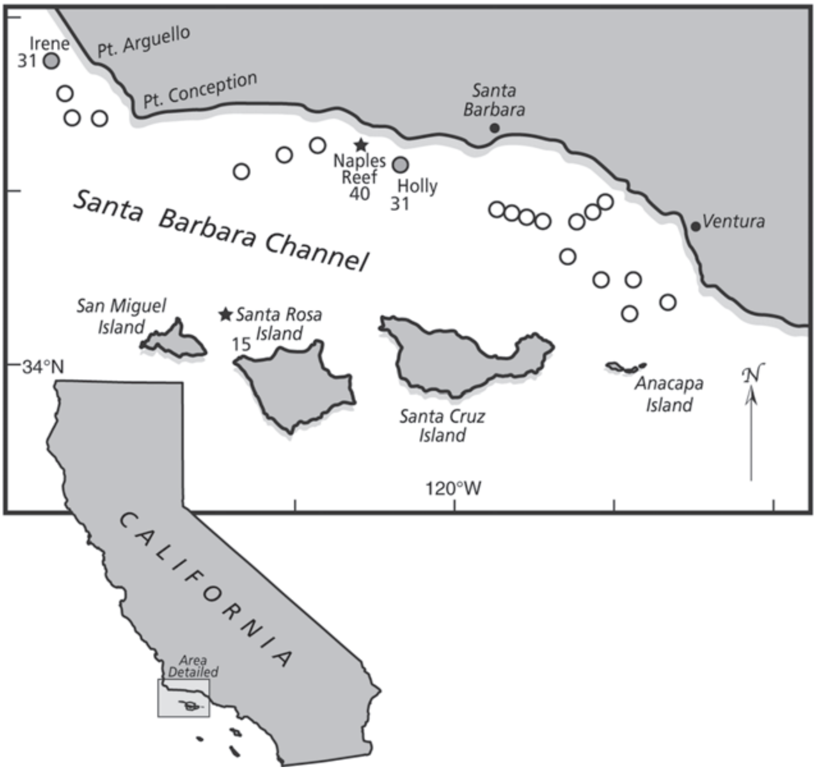

Figure 1. Location and number of young-of-the-year blue rockfish collected at four sites in southern and central California, September–November 1999. Circles represent all of the oil platforms in the region, closed circles are the two platforms surveyed in this study. Stars represent the two natural reefs surveyed.

In the laboratory, each fish was measured (standard length, SL) to the nearest millimeter and its sagittal otoliths removed. After removal, sagittae were cleaned in water, soaked in a solution of 50% household bleach and 50% water for a few minutes, then rinsed in water, air dried, and stored in vials. Prior to their being read, each otolith was embedded in Spurr's low viscosity epoxy medium before wet grinding with 800 grit aluminum oxide. A mid-sagittal section was prepared to preserve both the otolith margin and as well as early growth around the primordium. The final curvilinear (convex) surface was produced by applying variable pressure and tilt during the grinding process. The samples were polished with diamond paste (3 μm followed by 1 μm). Microincrements were counted with the aid of a video microscope (to about 1500× magnification). The typical counting path was from the primordium to the dorsal otolith margin. Methods generally followed techniques outlined in Brothers (1987) and Ralston et al. (1996).

We did not validate the daily nature of the sagittal increments. However, in the eastern Pacific, increments in rockfish otoliths have been determined to be produced daily in the YOYs of black (*Sebastes melanops* Girard, 1856) (Yoklavich and Boehlert, 1987), pygmy (*Sebastes wilsoni* Gilbert, 1915) (Laidig et al., 2004), shortbelly (*Sebastes jordani* Gilbert, 1896) and brown (*Sebastes auriculatus* Girard, 1854) rockfishes (Laidig et al., 1991). In the western Pacific, similar studies have shown this to be true for *Sebastes thompsoni* (Jordan and Hubbs, 1925) (Kokita and Omori, 1998) and *Sebastes inermis* Cuvier, 1829 (Plaza et al., 2001). Increments were inferred to be daily in studies of larval, pelagic juvenile, or benthic YOY blue (Yoklavich et al., 1996), stripetail (*Sebastes saxicola* Gilbert, 1890) and greenstriped (*Sebastes elongatus* Ayres, 1859) rockfishes and cowcod (*Sebastes levis* Eigenmann and Eigenmann, 1889) (Johnson et al., 2001), and widow and yellowtail (*Sebastes flavidus* Ayres, 1862) rockfishes, bocaccio and chilipepper (*Sebastes goodei* Hilgendorf, 1880) (Woodbury and Ralston, 1991).

Analytic Methods.—We estimated average growth (mm d^{-1}) of each fish by dividing its standard length by its age. This metric includes both growth prior to and after benthic settlement. Since most blue rockfish settle between early May and late June (Love et al., 2002) and our collections were made from September to November, our measurement of total growth includes a significant period of benthic growth.

We used one-way ANOVAs to test the hypotheses that mean birthdate (day of the year), age, standard length, and growth did not vary among sites. We chose to use one-way ANOVAs rather than models with site nested in site type because a nested model would require site to be treated as a random factor and sites were not randomly chosen. ANOVAs are robust to minor deviations from the assumption that observations are normally distributed. We compared the results of the ANOVAs using untransformed data with ANOVAs using log-transformed data and the F values were very close, thus we chose to use untransformed data for the analyses. We used Scheffé's Post Hoc Test (Kleinbaum, 1978) to contrast means of the six sites, and Rayleigh's test (Zar, 1984) to test if parturition dates were uniformly distributed over the lunar cycle.

Results

We collected a total of 117 blue rockfish; collections ranged in number from 15 fish at Santa Rosa Island to 39 fish at Naples Reef (Table 1, Fig. 1). Fish were sampled between 25 September and 16 November 1999. Otoliths of all fish collected, except for one individual from Naples Reef, were readable and were included in this study.

Lengths of individual fish sampled ranged from 67 to 111 mm and mean lengths of fish sampled at each site ranged from 85 to 100 mm (Fig. 2, Table 1). ANOVA revealed that lengths were significantly different among sites ($F = 33.83$, df = 3115, $P < 0.01$). Scheffé's contrasts were significant for the site pair Platform Holly–Naples Reef, but not for the site pair Platform Irene–Santa Rosa Island (Table 2). Young-of-the-year blue rockfish ranged in age from 221 to 315 d and mean ages of fish at each site varied between 240 to 275 d (Fig. 3; Table 1). Mean ages were statistically different between almost all sites (one-way ANOVA, $F = 46.59$, df = 3115, $P < 0.01$, and Scheffé's test, Table 2); a notable exception was the site pair Platform Irene–Santa Rosa Island.

Back-calculated birth or parturition dates (Ralston et al., 1996) for individual fish ranged from early January to mid-March (Table 1, Fig. 4). While mean parturition dates varied considerably between sites ($F = 21.28$, df = 3115, $P < 0.01$), they were similar for the site pairs Platform Irene–Santa Rosa Island (mean = mid-February) and Platform Holly-Naples Reef (mean = late January) (Scheffé's Test, $P > 0.05$, Table

Table 1. Data on collections and biological parameters of blue rockfish used in the study. Minimum and maximum values in parentheses. Note that the otoliths of one of the fishes collected from Naples Reef was not readable, thus the total usable fish from that site was 39.

Site	n	Date of sample	Mean date of birth	Mean age (d)	Mean length (SL cm)	Mean growth (mm d^{-1})
Platform Irene	31	16 Nov 99	18 Feb	270	8.6	0.32
			(5 Jan–16 Mar)	(245–315)	(7.4–10.5)	(0.27–0.39)
Santa Rosa Is.	15	16 Nov 99	14 Feb	275	8.5	0.31
			(10 Jan–21 Mar)	(240–310)	(6.7–9.5)	(0.27–0.36)
Platform Holly	31	15 Oct 99	26 Jan	262	10.0	0.38
			(9 Jan–19 Feb)	(238–279)	(8.7–11.1)	(0.33–0.46)
Naple Reef	40	25 Sep 99	30 Jan	240	8.6	0.36
			(3 Jan–16 Feb)	(221–265)	(7.5–9.7)	(0.33–0.40)

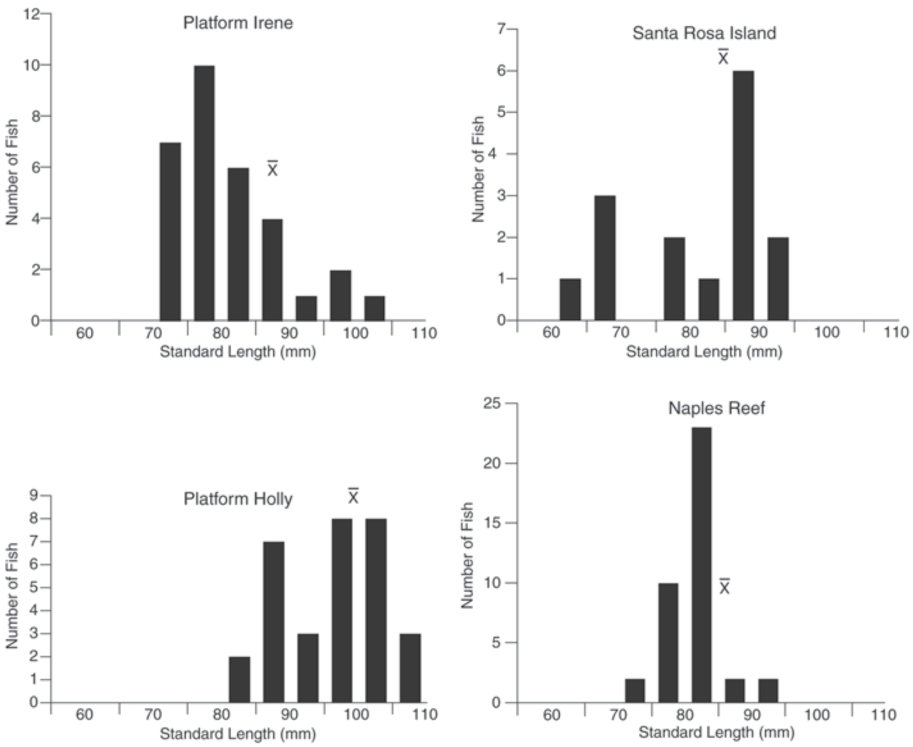

Figure 2. Size distribution of young-of-the-year blue rockfish collected at four sites in southern and central California, September–November 1999.

2). In both instances, mean birthdates were within 4 d of each other (Table 1). Similarity in birthdates of fish at Platform Irene and Santa Rosa Island was notable in that parturition in March was only observed in fish inhabiting these two sites (Fig. 4).

There was some indication that the timing of larval release was related to moon phase (Fig. 5; Table 3). While at most sites parturition dates were statistically uniform over a lunar cycle ($Z = 0.61–2.97$, NS), when data were pooled it appeared that larvae tended to be extruded during the week of the full moon ($Z = 5.08$, $P = 0.01$, mean day = 14.64).

Calculated mean daily growth rates of individuals ranged from 0.27 to 0.46 mm d^{-1} and mean growth rates at each site varied between 0.31 and 0.38 mm d^{-1} (Fig. 6, Table 1). Mean growth rates were statistically different among most sites (ANOVA, $F = 54.30$, df = 3115, $P < 0.01$), including between fish living at Platform Holly and Naples Reef (Table 2) where fish grew more rapidly at the platforms. There was no statistical difference between blue rockfish growth rates at Platform Irene and Santa Rosa Island (Scheffé's Test, $P > 0.05$, Table 2).

Discussion

For blue rockfish, we identified a number of patterns in growth and birthdate distribution across the sampling region. We observed a significant, albeit subtle, lunar pattern in blue rockfish birthdates. In 1999, blue rockfish appeared to produce more larvae in the week of the full moon. Because parturition has not been observed in

Table 2. Differences (column–row), as contrasted by Scheffé's Post Hoc Test, between pairs of sites in mean length, mean age, mean birthdate, and mean growth of YOY blue rockfish. Fish collected between September and November 1999. * P < 0.05; **P < 0.01. Platform and natural reef site pair contrasts are denoted in bold.

	Mean length (mm, SL)		
	Naples Reef	Platform Irene	Platform Holly
Platform Irene	–0.03		
Platform Holly	**–1.46****	–1.43**	
Santa Rosa Island	0.07	**0.1**	1.53**
	Mean age (d)		
	Naples Reef	Platform Irene	Platform Holly
Platform Irene	–32.44**		
Platform Holly	**–24.05****	8.39	
Santa Rosa Island	–36.85**	**–4.41**	–12.8
	Mean birthdate (day of year)		
	Naples Reef	Platform Irene	Platform Holly
Platform Irene	–19.56**		
Platform Holly	**4.05**	23.61**	
Santa Rosa Island	–15.15**	**4.41**	–19.20**
	Mean growth rate (mm d^{-1})		
	Naples Reef	Platform Irene	Platform Holly
Platform Irene	0.042**		
Platform Holly	**–0.023***	–0.065**	
Santa Rosa Island	0.052**	**0.01**	–0.074**

Eastern Pacific rockfishes, it is not possible to compare our data with direct observations of the timing of blue rockfish (or any other rockfish species) larval release. Thus we do not know if the pattern we observed represents reduced parturition following the new moon or if there is no lunar parturition pattern, but rather increased larval mortality (e.g., from increased predation or lowered food availability) on those larvae produced during that time. Studies of tropical reef fishes, by both direct observation and back-calculations from otolith daily growth rings, demonstrate that spawning by many species is closely linked to lunar phase (Thresher, 1984; Robertson et al., 1988; Sponaugle and Cowen, 1994). However, studies on gray snapper (*Lutjanus griseus* (Linnaeus, 1758)) imply that lunar spawning patterns may occur in some years but not in others (Denit and Sponaugle, 2004). Only one other study has examined lunar parturition periodicity in rockfishes. Pastén et al. (2003), using back calculations of daily growth rings of *Sebastes inermis* collected off Japan, found that parturition occurred significantly more often around the new and full moons.

The growth rates of YOY blue rockfish in our studies (with mean per site ranging from 0.31 to 0.38 mm d^{-1}) are similar to those found in other young rockfishes. Summarizing a range of rockfish studies of both larval and pelagic juvenile phases, including both field and laboratory studies, Love et al. (1991) calculated a mean growth rate of 0.29 mm d^{-1} in field studies and 0.27 mm d^{-1} in laboratory experiments. However, only one other study, Johnson et al. (2001), examined the daily growth rates of benthic YOY rockfishes integrated over the life of the animals from larval extru-

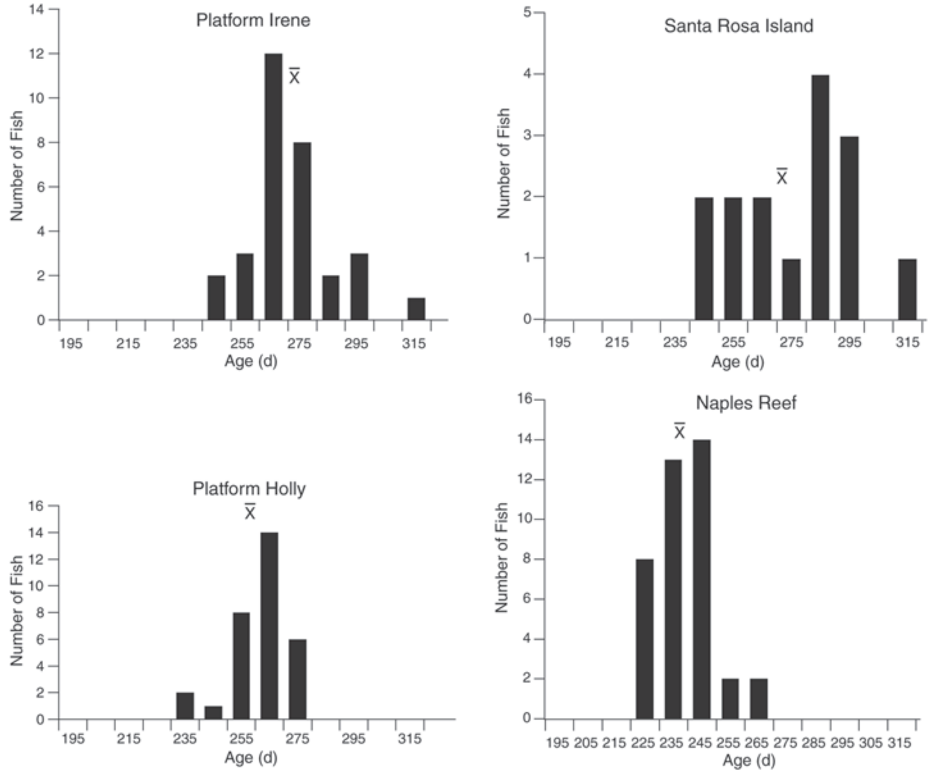

Figure 3. Age distribution of young-of-the-year blue rockfish collected at four sites in southern and central California, September–November 1999.

sion to post settlement. In that study, growth rates were 0.17 mm d^{-1} in greenstriped rockfish (*Sebastes elongatus* Ayres, 1859), 0.25 mm d^{-1} in cowcod (*Sebastes levis* (Eigenmann and Eigenmann, 1889)), and 0.32 mm d^{-1} in stripetail rockfish (*Sebastes saxicola* (Gilbert, 1890)). The growth rates of young rockfishes are low compared to a wide range of other fishes (e.g., European hake, *Merluccius merluccius* (Linnaeus, 1758), 0.71–0.74 mm d^{-1}, Kacher and Amara, 2005; gray snapper, *L. griseus*, 0.62–0.88 mm d^{-1}, Denit and Sponaugle, 2004; greater amberjack, *Seriola dumerili* (Risso, 1810), 1.65–2.00 mm d^{-1}, Wells and Rooker, 2002; blue marlin, *Makaira nigricans* Lacépède, 1802, 16.6 mm d^{-1}, Prince et al., 1991).

In this admittedly limited study, we found that there was no evidence that fish at platforms grew more slowly than those living on natural reefs. Comparison of growth rates between fishes living at Platform Holly and Naples Reef implied that YOY blue rockfish may, in some instances, grow faster at platforms. Growth might be accelerated at platforms for several reasons. Young-of-the-year blue rockfish are midwater feeders; they prey on such zooplankters as barnacle larvae, larvaceans, and copepods (Singer, 1985; Gaines and Roughgarden, 1987), and zooplankton density may be greater around Platform Holly than over Naples Reef. Zooplankton living in the nearshore waters flowing along and over the extensive kelp beds and rock reefs associated with Naples Reef may have been exposed to many more predators than organisms inhabiting the open ocean waters flowing into the platform jacket. In addition, the waters inside the platform may harbor higher densities of barnacle

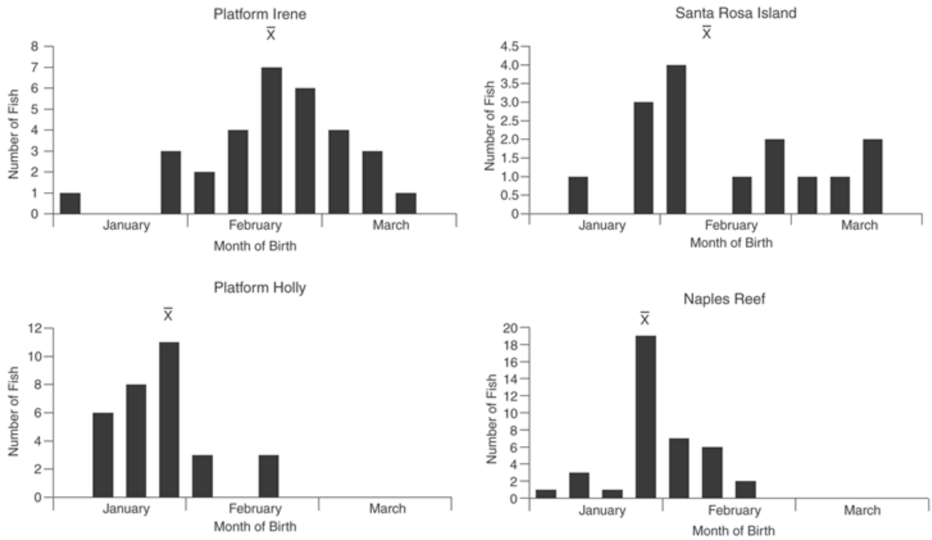

Figure 4. Parturition date distribution of young-of-the-year blue rockfish collected at four sites in southern and central California, September–November 1999.

and other invertebrate larvae because the platform jacket is heavily encrusted with these forms (Love et al., 2003). Lastly, compared to natural reefs, the midwaters of most California platforms harbor low densities of piscivorous fishes (e.g., kelp bass, *Paralabax clathratus* (Girard, 1854); cabezon, *Scorpaenichthys marmoratus* (Ayres, 1854); Pacific barracuda, *Sphyraena argentea* (Girard, 1854) and yellowtail, *Seriola lalandi* Valenciennes, 1833) that are common on natural reefs. As an example, predation rates on small fishes at Platform Holly are significantly lower than those at Naples Reef (Schroeder et al., 2005). This may allow YOY blue rockfish (and other YOY rockfishes) inhabiting the platform midwaters to spend more time in foraging activities rather than predator avoidance.

It has been argued that if the YOY rockfishes that recruit to California oil and gas platforms experience relatively poor ecological performance, compared to fish living on natural reefs, these structures might act as biological sinks (Krop, 1997). This would occur because those young fishes that recruited to these structures would be

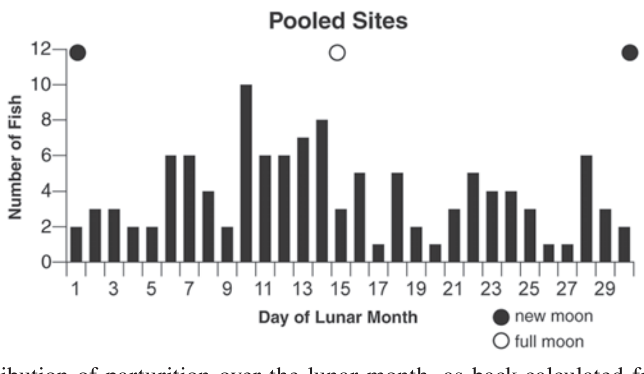

Figure 5. Distribution of parturition over the lunar month, as back-calculated from otoliths of young-of-the-year blue rockfish. Three lunar cycles were pooled. Arrow indicates the mean lunar day of parturition. New moon (filled circle) was set as the first day, full moon (open circle) as the 15th day.

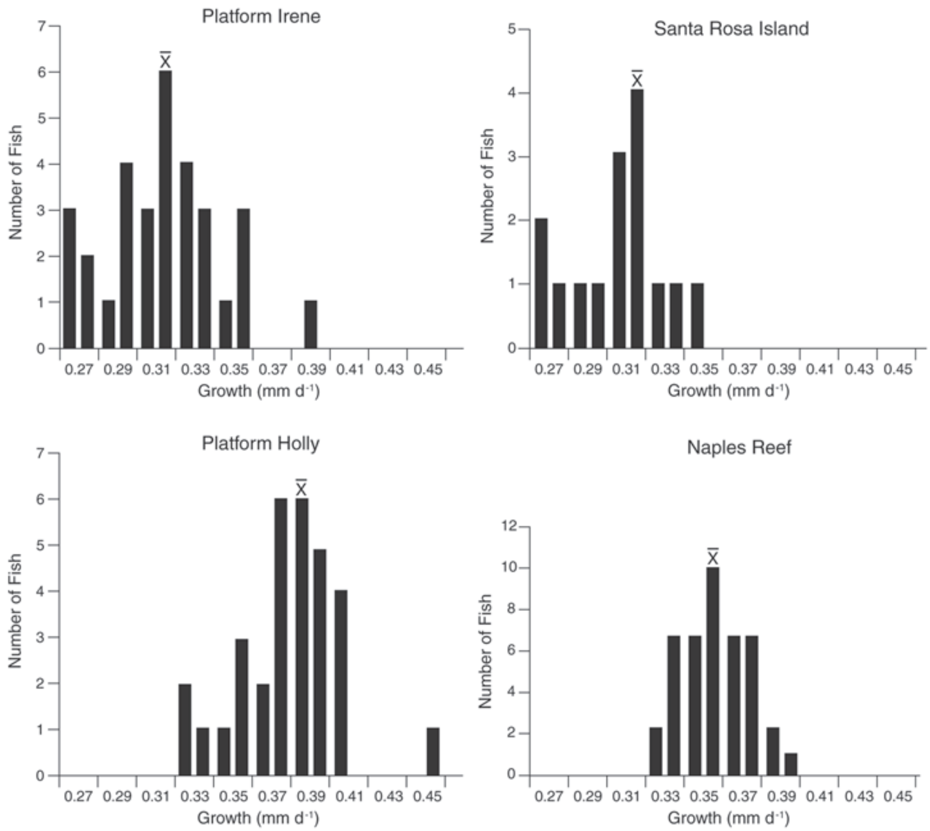

Figure 6. Distribution of growth rates of young-of-the-year blue rockfish collected at four sites in southern and central California, September–November 1999.

less likely to survive to adulthood than individuals that settled on natural reefs. On the other hand, as noted by Carr et al. (2003), "If species perform equivalently or better on artificial reefs than they do on natural reefs, it is most likely that presence of an artificial habitat will benefit the regional population of that species." Although limited in scope, the current study demonstrates that, as measured by daily growth rates, young blue rockfish living around oil and gas platforms performed at least as well as those fish living on natural reefs. Several previous studies have examined the fate of YOY rockfishes that recruited to California platforms. Love et al. (2006) presented data showing the survival and ultimate maturation of a year-class of YOY bocaccio at a platform in the Santa Barbara Channel. In a separate study, YOY bocaccio tagged at several Channel platforms were recovered on natural reefs as adults years later as much as 150 km from the tagging sites (Hartmann, 1987). Results of our current study are consistent with previous research implying that at least some platforms may benefit regional fish populations.

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