Pacific Outer Continental Shelf Region

OCS Study
MMS 2004-005

ECOLOGICAL PERFORMANCE OF OCS PLATFORMS AS FISH HABITAT OFF CALIFORNIA

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Pacific OCS Region

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ECOLOGICAL PERFORMANCE OF OCS PLATFORMS AS FISH HABITAT OFF CALIFORNIA

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TECHNICAL SUMMARY

Study Title: Ecological Performance of OCS Platforms as Fish Habitat off California

Report Title: Ecological Performance of OCS Platforms as Fish Habitat off California

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Background and Objectives:

There are 27 oil and gas platforms in the waters off California. All platforms have a finite economic life and the life spans of some California platform may be nearing an end. Once an industrial decision is made to cease oil and gas production at a platform, managers must decide what to do with the structure, a process known as decommissioning. During the decommissioning process, the MMS conducts detailed environmental reviews of any proposed projects to evaluate the impacts from platform removal on regional fish populations. Removing platforms removes potentially useful habitat, kills numerous fishes, and may have adverse impacts on regional populations of rockfishes and other species on the Pacific OCS. Thus, the assessing of habitat quality greatly bears upon platform decommissioning issues, as questions about Essential Fish Habitat and the ecological role of Pacific OCS platforms are still unresolved.

Previous federal government funded investigations found that platform fish assemblages are similar to those of natural reefs and differences were due almost entirely to the greater numbers of more species of fishes around platforms, rather than differences in species composition. At least 85 species of fish were observed at platforms and 94 species at the outcrops. Rockfishes dominated both habitats, comprising 89.7% of all fishes at platforms and 92.5% at outcrops. Almost all of the more abundant species that the researchers observed were more common around platforms. Species that were more common at one or more platforms than at natural reefs included cowcod and bocaccio (young-of-the-year (YOY), juvenile, and adult), copper, greenspotted, greenstriped, YOY widow, vermilion, canary and flag rockfishes and YOY juvenile and adult lingcod.

In particular, these studies found that (1) platforms tended to have higher abundances of large fishes, particularly of such economically important species as cowcod, bocaccio, and lingcod, than did most or all natural reefs and that (2) in general, platforms harbored higher densities of young-of-the-year (YOY) rockfishes than did nearby natural outcrops or, indeed, most other outcrops surveyed in central and southern California.

However, less well known is how important these fishes are on a regional basis and how well they fare around these artificial habitats compared to natural reefs. This is often referred to as "ecological performance." Among the key issues in the Pacific OCS platform reefing debate is defining the ecological performance of fishes, and by extension the role that these fishes may play in the recovery of fish populations.

Thus, the goal of this study was to determine certain aspects of the ecological performance of fishes living on offshore platforms compared to those living on natural reefs.

Description:

The comparative ecological performance of fishes at oil platforms and natural outcrops was measured through three tasks.

***Task One*: Larval production of bocaccio and cowcod at platforms and natural reefs**

In this task, the amount of larvae per unit area produced by bocaccio and cowcod was estimated and compared with that produced by both species on natural outcrops in the same general area. This was done by determining the densities and sizes of bocaccio and cowcod at platforms and natural reefs and, knowing the size-specific fecundity of each species, computing the larval production of the fishes at each location.

***Task Two:* Ecological performance of young-of-the-year blue rockfish associated with oil platforms and natural reefs.**

Comparing the growth rates of fishes living around platforms with those on natural reefs is one method of contrasting the overall health of these animals. If growth rates of juvenile rockfish at platforms are similar (or better) than those from reefs, it implies that the young rockfishes at the platforms are at least as likely to grow and develop as those from reefs. In this task, the daily growth rates of young-of-the-year blue rockfish living around three platforms and three natural outcrops were compared.

***Task Three:* Predation Rate on Painted Greenling Between Natural Habitat and an Offshore Oil Platform.**

Another measure of ecological performance is mortality rate. In this task we compared the mortality rate of young painted greenling at a platform with that of fish at a natural outcrop.

Significant Results:

Task 1: In this study, we used data from manned submersible studies conducted between 1995 and 2002 around seven platforms and over 80 deeper water reefs in southern and central California. We focused our analyses on bocaccio and cowcod, species that had been economically important to recreational and commercial fishermen and were declared over-fished by the National Marine Fisheries Service.

Overall, we observed 1,054 bocaccio of all sizes at platforms and 976 at reefs, and 125 cowcod at platforms and 134 at reefs. Among bocaccio estimated to be mature, we observed 313 bocaccio at platforms and 313 at natural reefs and 38 mature cowcod at platforms and 61 at reefs. Adult fishes were patchily distributed among both platforms and natural reefs. Fifty-seven percent of the natural reefs had mature bocaccio, as did four of seven platforms. Forty-two percent of natural reefs harbored mature cowcod, as did two of five platforms. Two platforms, Gail and Hidalgo, harbored relatively high densities of both species. Individuals of both species tended to be larger at the platforms, particularly those inhabiting Platform Gail.

Because both densities and mean lengths of both species were higher at Platform Gail than at any natural reef, their potential larval production at that platform was far higher than at any natural reef. We estimated that if Platform Gail (whose footprint is 0.5337 ha) were removed, it would be the equivalent of removing 12.57 ha of average-producing natural habitat in southern California for cowcod, or equivalent to removing 29.24 ha of average-producing natural habitat in southern California for bocaccio.

This study demonstrated that, in some instances, fishes at platforms provide significant amounts of larvae, numbers that may be of regional importance.

Task 2: The daily growth rates of YOY blue rockfish collected during the fall of 1999 at three platforms and three natural reefs were compared. 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.

Task 3: This research was conducted at two sites, Platform Holly and Naples Reef, that are located near each other in the Santa Barbara Channel using the painted greenling, *Oxylebius pictus* (Hexagrammidae), a small reef fish common to offshore platforms and kelp beds off California. The experiment showed that juvenile painted greenling residing at Naples Reef experienced a relative predation rate more than 2.5 times greater than the estimated rate experienced by juveniles residing at Platform Holly. This is likely due to the relatively low density of predators that live in platform midwaters compared to natural reefs. This implies that the large numbers of young fishes living around the platforms of southern California have lower mortality rates due to predation, than do these fishes inhabiting natural reefs.

STUDY PRODUCTS

PAPERS

2005 Love, M. S. D. M. Schroeder, and W. H. Lenarz. Distribution of bocaccio (*Sebastes paucispinis*) and cowcod (*Sebastes levis*) around oil platforms and natural outcrops off California with Implications for larval production. Bull. Mar. Sci. 77:397-408.

2005 Love, M. S., E. Brothers, D. M. Schroeder, and W. H. Lenarz. 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. Bull. Mar. Sci. Submitted for Publication.

PAPERS PRESENTED

Presentations by Milton Love:

Oil platforms as fish habitat. Minerals Management Service Symposium, Oceanology International, New Orleans, Louisiana. May 2003.

Fish Assemblages of southern California oil platforms. Mineral Management Service, Decommissioning Offshore Platforms and Pipelines: Environmental Studies Workshop, Catalina Island. October 2003.

Fish Assemblages of southern California oil platforms. Cabrillo Marine Aquarium, San Pedro, CA. November 2003.

Oil platforms as fish habitat. Pt. Lobos Association, Monterey, California. January 2004.

For now we see through a glass, darkly: a potpourri of observations on the fish assemblages of oil/gas platforms and natural reefs in southern California. Western Groundfish Conference, Victoria, British Columbia. February 2004.

Oil platforms as fish habitat. Centro de Investigacion Cientifica y de Educacion Superior Ensenada (CICESE), Ensenada, Mexico. March 2004.

The role of oil and gas platforms in fish production and aggregation in southern and central California. Friends of Moss Landing, Moss Landing, California. July 2004.

The role of oil and gas platforms in fish production and aggregation in southern and central California. University of Alaska, Juneau. July 2004.

The role of oil and gas platforms in fish production and aggregation in southern and central California. Plains Oil Company, Santa Maria, CA. Oct. 2004.

The role of oil and gas platforms in fish production and aggregation in southern and central California. Ocean Explorers, 27 January 2005.

The role of oil and gas platforms in fish production and aggregation in southern and central California. Environmental Defense, Oakland, CA. 24 March 2005.

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An overview of fish assemblages of offshore oil and gas platforms and natural reefs in southern and central California. American Fisheries Society, Anchorage, Alaska, 11 September 2005.

Presentations by Donna Schroeder:

Comparative juvenile reef fish recruitment and mortality between offshore oil/gas platforms and natural reefs. CARAH, Biloxi, Miss.12 April 2005.

Patterns in juvenile reef fish recruitment to offshore oil/gas platforms and natural reefs in relation to upwelling. American Fisheries Society, Anchorage, Alaska, 11 September 2005.

POSTERS

Emery, B.M., M.M. Nishimoto L. Washburn, M. Love, 2003, “Alternative fate estimation of oil rig bocaccio recruits using HF radar,” Eastern Pacific Ocean Conference, Catalina Island, CA, 24-27 Sept., poster presentation

Emery, B., M. Nishimoto, L. Washburn, and M. Love. Do offshore platforms affect the fate of recruiting bocaccio? An analysis based on HF radar derived surface trajectories. Western Groundfish Conference, Victoria, British Columbia, Feb. 2004.

ECOLOGICAL PERFORMANCE OF OCS PLATFORMS AS FISH HABITAT OFF CALIFORNIA

EXECUTIVE SUMMARY

Information Needed

There are 27 oil and gas platforms in the waters off California. These platforms are located between 1.2 and 10.5 miles from shore and at depths ranging from 11 to 363 m (35-1,198 ft.). All platforms have a finite economic life and the life spans of some California platform may be nearing an end. Once an industrial decision is made to cease oil and gas production at a platform, managers must decide what to do with the structure, a process known as decommissioning. Regarding oil and gas platforms, the Minerals Management Service (MMS) defines decommissioning as the process of ending operations and returning the lease or pipeline right-of-way to a condition that meets the requirements of the regulations. The MMS works to ensure that wells are plugged to prevent pollution; that pipelines are decommissioned to prevent seepage of hydrocarbons and removed to minimize conflicts with other uses of the Outer Continental Shelf (OCS); and that all sites are cleared of obstructions to minimize use conflicts. During the decommissioning process, the MMS conducts detailed environmental reviews of any proposed projects to evaluate the impacts from platform removal on regional fish populations. Removing platforms removes potentially useful habitat, kills numerous fishes, and may have adverse impacts on regional populations of rockfishes and other species on the Pacific OCS. Thus, the assessing of habitat quality greatly bears upon platform decommissioning issues, as questions about Essential Fish Habitat and the ecological role of Pacific OCS platforms are still unresolved

Several MMS- and USGS-funded investigations and a number of pilot studies have been completed and provide background for the present effort. The habitat value of a number of platforms on the Pacific OCS was determined under OCS Study MMS 99-0015, *The Ecological Role of Natural Reefs and Oil and Gas Production Platforms on Rocky Reef Fishes in Southern California* [available as a pdf at www.lovelab.id.ucsb.edu]. In that study, researchers from the University of California at Santa Barbara (UCSB) compared fish assemblages from eight platforms and many natural outcrops throughout southern California.

Overall, the study found that platform fish assemblages are similar to those of natural reefs and differences were due almost entirely to the greater numbers of more species of fishes around platforms, rather than differences in species composition. At least 85 species of fish were observed at platforms and 94 species at the outcrops. Rockfishes dominated both habitats, comprising 89.7% of all fishes at platforms and 92.5% at outcrops. Almost all of the more abundant species that the researchers observed were more common around platforms. Species that were more common at one or more platforms than at natural reefs included cowcod and bocaccio (young-of-the-year (YOY), juvenile, and adult), copper, greenspotted, greenstriped, YOY widow, vermilion, canary and flag rockfishes and YOY juvenile and adult lingcod.

Two of the major conclusions from this study were:

1) Platforms tended to have higher abundances of large fishes, particularly of such economically important species as cowcod, bocaccio, and lingcod, than did most or all natural reefs. It is likely that this is due to the relatively low fishing effort around many platforms in southern California, thus the platforms are acting as de facto marine protected areas. The study compared densities of all rockfishes (of all sizes), all rockfishes greater than or equal to 30 cm, and adult bocaccio and cowcod that they observed at platforms and at natural outcrops. In most instances, fishes 30 cm or larger were less abundant, or sometimes absent, from many natural reefs compared to most platforms. Platform Gail, in particular, held some of the highest densities of the important but severely depleted cowcod and bocaccio that were seen anywhere during the

observations. The study speculated that platforms, such as Platform Gail, might be a major source of cowcod and bocaccio larvae and thus might be important fish habitat on a regional level.

2) The research also found evidence that, in general, platforms harbored higher densities of young-of-the-year (YOY) rockfishes than did nearby natural outcrops or, indeed, most other outcrops surveyed in central and southern California. The study pointed out that platforms occupy more of the water column than do most natural outcrops and presettlement pelagic juvenile rockfishes are much more likely to encounter these tall structures than the relatively low-lying natural structures. The researchers also observed that many of the major predators of young rockfishes are species that live and stay close to the bottom and that, in general, these species do not ascend the platform jacket up into the water column, and thus are absent from the platform midwaters.

However, while it is undisputed that large numbers of both YOY and adult fishes populate platform habitats, less well known is how important these fishes are on a regional basis and how well they fare around these artificial habitats compared to natural reefs. This is often referred to as "ecological performance." Among the key issues in the Pacific OCS platform reefing debate is defining the ecological performance of fishes, and by extension the role that these fishes may play in the recovery of fish populations.

One way to determine the ecological performance and relative importance of a platform as fish habitat is to compare the amount of larvae produced by fishes at platforms with that produced on natural outcrops in the same general area. This may indicate whether a platform is a significant source of larvae when compared to natural reefs

Regarding YOY rockfishes, some observers have suggested that, while settlement of young rockfish may be high around some platforms, these structures may not supply suitable habitat or sufficient food for adequate growth and maturity. One way of addressing these concerns is to examine the health of young rockfishes around platforms and compare this to the health of young rockfish of the same species living on natural reefs. Comparing the growth rates of fishes living around platforms with those on natural reefs is one method of contrasting the overall health of these animals. If growth rates of juvenile rockfish at platforms are similar (or better) than those from reefs, it implies that the young rockfishes at the platforms are at least as likely to grow and develop as those from reefs.

A third way of approaching ecological performance is by comparing the mortality rate of young fishes at platforms with those at natural reefs. If survival and mortality rates of at platforms are similar (or better in the case of survival) than those from reefs, it implies that fishes at the platforms are at least as likely to survive to adulthood or to enter a fishery as those from natural reefs.

Thus, the goal of this study was to determine certain aspects of the ecological performance of fishes living on offshore platforms compared to those living on natural reefs.

Research Summary

Task 1. Distribution of bocaccio (*Sebastes paucispinis*) and cowcod (*Sebastes levis*) Around Oil Platforms and Natural Outcrops off California with Implications for Larval Production

In this study, we used data from manned submersible studies conducted between 1995 and 2002 around seven platforms and over 80 deeper water reefs in southern and central California. We focused our analyses on bocaccio and cowcod, species that had been economically important to recreational and commercial fishermen and were declared over-fished by the National Marine Fisheries Service.

We considered a reef site appropriate for inclusion in this study if it was in a depth of least 60 m for bocaccio and 80 m for cowcod and was categorized as "rocky high relief," "rocky low relief," or "boulders." Based on these parameters, 63 reefs and seven platforms (Gail, Grace, Harvest, Hermosa, Hidalgo, Holly, and

Irene) were used in the bocaccio analyses and 52 reefs and five platforms (Gail, Grace, Harvest, Hermosa, and Hidalgo) in the cowcod dataset. At each survey site, we computed the adult densities and the length frequencies of both species. From these densities and length frequencies and from published data on fecundity at length, we then computed the potential larval production of each species at each site. In general, because densities of both species were quite low or nonexistent, particularly at natural reefs, there was little or no potential larval production.

Overall, we observed 1,054 bocaccio of all sizes at platforms and 976 at reefs, and 125 cowcod at platforms and 134 at reefs. Among bocaccio estimated to be mature, we observed 313 bocaccio at platforms and 313 at natural reefs and 38 mature cowcod at platforms and 61 at reefs. Adult fishes were patchily distributed among both platforms and natural reefs. Fifty-seven percent of the natural reefs had mature bocaccio, as did four of seven platforms. Forty-two percent of natural reefs harbored mature cowcod, as did two of five platforms. Two platforms, Gail and Hidalgo, harbored relatively high densities of both species. Individuals of both species tended to be larger at the platforms, particularly those inhabiting Platform Gail.

Because both densities and mean lengths of both species were higher at Platform Gail than at any natural reef, their potential larval production at that platform was far higher than at any natural reef. We estimated that if Platform Gail (whose footprint is 0.5337 ha) were removed, it would be the equivalent of removing 12.57 ha of average-producing natural habitat in southern California for cowcod, or equivalent to removing 29.24 ha of average-producing natural habitat in southern California for bocaccio.

This study demonstrated that, in some instances, fishes at platforms provide significant amounts of larvae, numbers that may be of regional importance.

Task 2. 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

In this study, we compared the daily growth rates of YOY blue rockfish collected during the fall of 1999 at three platforms and three natural reefs. 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), Platform Holly and Naples Reef (in the same water mass and located with 8 km of each other) and Platform Gilda and Anacapa Island (in different water masses and within 16 km of each other). Collections were made during one day at each site. In the laboratory, each fish was measured (standard length, SL) to the nearest millimeter and its sagittal otoliths removed. A mid-sagittal section was prepared to preserve both the otolith margin and as well as early growth around the primordium. Microincrements were counted with the aid of a video microscope (to about 1500x magnification). The typical counting path was from the primordium to the dorsal otolith margin.

We collected a total of 187 blue rockfish; collections ranged in number from 15 fish at Santa Rosa Island to 39 fish at Naples Reef. Fish were sampled between 15 September and 23 November 1999. Calculated mean daily growth rates of individuals ranged from 0.27 to 0.46 mm/day and mean growth rates at each site varied between 0.30 and 0.38 mm/day. Mean growth rates were statistically different among most sites. Growth rates were significantly different between fish living at Platform Holly and Naples Reef and those living at Platform Gilda and Anacapa Island. In both instances, fish grew more rapidly at the platforms. However, because fish at Gilda and Anacapa were collected two months apart, growth comparisons were not considered valid. There was no statistical difference between blue rockfish growth rates at Platform Irene and Santa Rosa Island. We combined the growth rates of fish from Platform Irene and Holly and compared the mean growth rate with that of fish living at Naples Reef and Santa Rosa Island. Blue rockfish living at the platforms grew 0.016mm/day more quickly.

In this study 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.

Task 3. Comparative Predation Rate on Painted Greenling Between Natural Habitat and an Offshore Oil Platform

We conducted this study at two sites, Platform Holly and Naples Reef that are located near each other in the Santa Barbara Channel. We conducted our study at Platform Holly on the shallowest (9 m) horizontal crossbeams and at Naples Reef in 10 m depth. Our model organism, the painted greenling, *Oxylebius pictus* (Hexagrammidae), is a small reef fish common to offshore platforms and kelp beds off California. We employed a tethering approach to compare relative predation rates on juvenile painted greenling between the platform and natural habitat. This benthic fish lacks a swim bladder, and its most frequently observed daytime behavior is to simply rest on the bottom, making tethering a suitable experimental technique.

Relative predation rate on painted greenling was significantly higher at Naples Reef than at Platform Holly. Naples Reef also had higher painted greenling density and higher predator density. We also found that the number of predator species was much greater at Naples Reef than at Platform Holly.

The tethering experiment shows that juvenile painted greenling residing at Naples Reef experienced a relative predation rate more than 2.5 times greater than the estimated rate experienced by juveniles residing at Platform Holly. This is likely due to the relatively low density of predators that live in platform midwaters compared to natural reefs. This implies that the large numbers of young fishes living around the platforms of southern California have lower mortality rates due to predation, than do these fishes inhabiting natural reefs.

Conclusions

We conducted three studies that measured and compared various aspects of the ecological performance of fishes living on platforms and natural reefs. From this research, it is apparent that fishes living around platforms perform at least as well as those inhabiting natural reefs and, in some instances, better.

For instance, it is clear that Platform Gail, and to a lesser extent Platform Hidalgo, are very important regional sources of larvae for both cowcod and bocaccio. This is likely to remain the case for as long as these platforms act as *de facto* marine reserves and for as long as stocks of these two species remain depressed. Parenthetically, our unpublished density patterns of other species, for instance greenspotted, greenblotched, and flag rockfishes, strongly imply that platforms are also major exporters of these larvae.

Our research also has considerable bearing on the issue of the extremely heavy densities of young-of-the-year rockfishes living around oil platforms. In many years, platform midwaters harbor tens or even hundreds of thousands of young blue, olive, squarespot, widow, and yellowtail rockfish and bocaccio. Some observers have questioned the fate of these fishes, implying that their mortality rates might be higher than congeners living on natural reefs. Our research demonstrates that, in some instances, young rockfishes living around oil platforms suffer less mortality than those living over natural reefs and there is no evidence that mortality rates of fishes living around oil platforms is greater than that of natural reef fishes.

While these studies were limited in scope, we consider our results to be sufficiently strong to demonstrate the importance of some artificial structure in driving marine population dynamics. It is now arguable that fishes living around oil platforms may be quite important to regional fish production.

Task 1: Distribution of Bocaccio *(Sebastes paucispinis)* and Cowcod *(S. levis)* around Oil Platforms and Natural Outcrops off California with Implications for Larval Production

Milton S. Love, Donna M. Schroeder, and William H. Lenarz

Abstract

There is increasing evidence that some California oil platforms form important habitats for a number of economically important fishes. We asked to what extent might platforms be important as producers of larvae of several overfished species (bocaccio, *Sebastes paucispinis* Ayres, 1854 and cowcod, *S. levis* Eigenmann and Eigenmann, 1889) on a local or regional basis. We compared adult densities and potential larval production of these species at platforms and natural outcrops in California. Densities of mature bocaccio and cowcod were highly variable among survey sites, but were generally very low at both natural reefs and platforms. However, the mean densities for both species were higher around platforms than at natural reefs. Two of the three platforms (Gail and Hidalgo) that harbored mature bocaccio had larger mature individuals than did any natural reef. Platform Gail had by far the highest densities of both mature bocaccio and cowcod of any natural or human-made habitat and the potential larval production of both species at Platform Gail was much higher than at any other site surveyed. We estimated the removal of Platform Gail would be the equivalent of removing 12.57 ha of average- producing natural habitat in southern California for cowcod or 29.24 ha of average-producing natural habitat for bocaccio. These results may have implications for the platform decommissioning process.

Introduction

There are 27 oil and gas platforms off the coast of southern and central California. Located in both state and federal waters, these structures are situated in bottom depths ranging from 11 to 363 m and can have footprints as large as 10,606 m^2 (Love et al., 2003). While all of these platforms are currently either pumping oil or gas or are being used as transfer stations for these products, platforms have a finite economic life span. Once an industrial decision is made to cease oil and gas production, managers must decide what to do with the structure, a process known as decommissioning. Decommissioning is a complex process, involving state and federal agencies, corporate entities, and such stakeholders as recreational and commercial fishermen and non-consumptive users (Schroeder and Love, 2004). 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).

One issue in the decommissioning process is the role that platforms may play as fish habitat. There is increasing evidence that some California platforms form important habitats for many economically important fishes. This is particularly true of the rockfishes (genus *Sebastes*) that often comprise over 90% of all fishes observed around platforms in southern and central California waters (Love et al., 2003). Platform habitat may serve at least two functions for these fishes. First, the midwaters of many platforms serve as nursery habitat for a suite of rockfishes and other fish species, often harboring higher densities of these species than do nearby natural outcrops (Love et al., 1999; Carr et al., 2003; Love et al., 2003). Compared to most natural reefs, a platform's size, structural complexity, and high vertical profile probably provide pelagic juvenile rockfishes and larvae of other species with a relatively strong stimulus to trigger settlement. In addition, most platforms have few large fishes in the midwaters and thus predation on young fishes is likely to be low (Schroeder et al., 2000; Love et al., 2003). Platform bottoms, where the jacket and conductor pipes meet the seafloor, may harbor high densities of subadult and adult fishes, again usually comprised primarily of rockfishes (Love et al., 1999; Carr et el., 2003; Love et al., 2003). The high densities of larger fishes at the platform bottoms is due to both acceptable habitat and because some platforms are rarely fished and thus act as de facto marine reserves (Schroeder and Love, 2002; Love et al., 2003).

Off southern California, fishing pressure by both recreational and commercial fishermen on natural outcrop species has been very heavy for many decades (Love et al., 1998, 2002). In particular, the adults of economically important species such as bocaccio (*Sebastes paucispinis* Ayres, 1854) and cowcod (*S. levis* Eigenmann and Eigenmann, 1889) are now uncommon or even absent on many natural outcrops in southern California (Love et al., 1998, 2003; Love and Yoklavich, unpubl. data).

Given the depleted state of many rockfish species on natural reefs (seven species have been declared overfished by NOAA Fisheries), and the relative abundance of some of these species on some platforms, we asked to what extent might platforms be important as producers of larvae on a local, or even regional, basis? That is, how important are adult populations of rockfishes on platforms? To help answer that question, we conducted a pilot study that focused on cowcod and bocaccio (Fig. 1), two species declared overfished by NOAA Fisheries and the two overfished species that are most abundant as adults around California platforms. We compared adult densities and potential larval export of these species at both offshore platforms and natural outcrops in central and southern California. A knowledge of the relative importance of these human-made structures as fish habitat could play a role in decommissioning decisions.

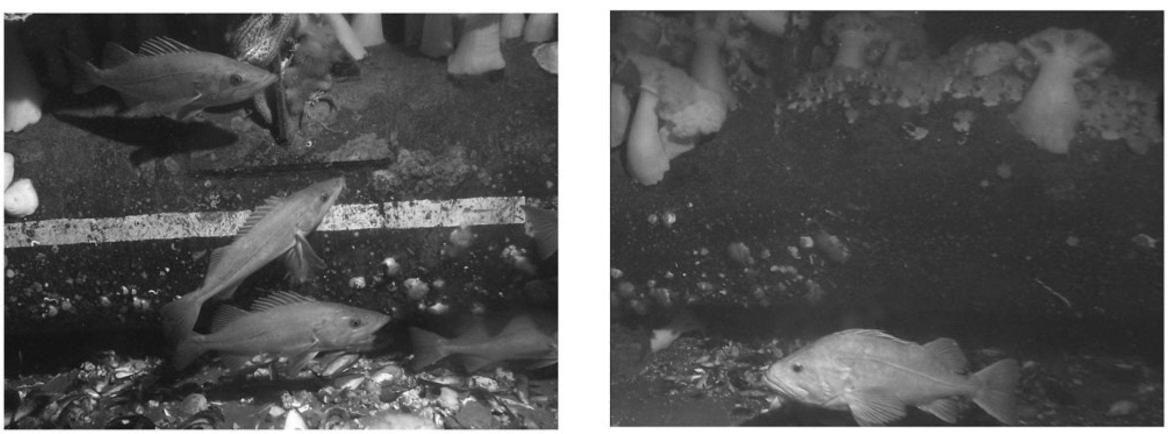

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Figure 1. a) Adult bocaccio (*Sebastes paucispinis*) and b) cowcod (*S. levis*) at the bottom of Platform Gail, eastern Santa Barbara Channel. Note the undercut area below the bottom-most cross beam, this provides shelter for both species.

Materials and Methods

Fish surveys

Between 1995 and 2002, we surveyed platforms sited over a wide range of bottom depths, ranging between 29 and 224 m, and sited from north of Point Arguello to off Long Beach, southern California. Most of our platform surveys were conducted at seven structures (Platforms Irene, Hidalgo, Harvest, Hermosa, Holly, Grace, and Gail) located in the Santa Barbara Channel and Santa Maria Basin. In addition, we surveyed over 80 deeper-water outcrops (many in the vicinity of platforms), in waters between 30 and 360 m deep. Most of these deeper-water natural sites were visited once, a few were surveyed during as many as four years and, one outcrop, North Reef near Platform Hidalgo, was sampled annually.

We surveyed fish assemblages using the *Delta* submersible, a 4.6-meter, 2-person vessel, operated by Delta Oceanographics of Oxnard, California. Aboard the *Delta,* we conducted belt transects about two meters from the substrata, while the submersible maintained a speed of about 0.5 knots. At the platforms, transects were made around the bottom of the platform and around each set of crossbeams to a minimum depth of 20-30 m below the surface (e. g., midwater habitat). The belt transect was also used to sample the shell mounds surrounding the platforms and natural rock outcrops. The shell mounds and outcrops were sampled in consistently the same fashion as the platform method described above.

Submersible surveys were conducted during daylight hours between one hour after sunrise and two hours before sunset. During each transect, observations were taken from one viewing port on the starboard side of the submersible. An externally mounted hi-8 mm or digital video camera with associated lights filmed the same viewing fields as seen by the observers. The observer identified, counted, and estimated the lengths of all fishes and verbally recorded those data on the video. All fishes within 2 m of the submarine were counted. All fish larger than the size of first maturity were observed within 2 m of the bottom (none were seen in midwater transects). Thus, densities were calculated as fish per m^2. Fish lengths were estimated 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 the video camera. An environmental monitoring system aboard the submarine continuously recorded date and time, depth and altitude of the vessel above the sea floor. The environmental data were overlaid on the original videotape upon completion of each survey.

Transect videos were reviewed aboard the research vessel or in the laboratory. Field observations were transcribed into a database. For each fish, we recorded the following information: 1) species (if known); 2) its estimated total length; and 3) in the surveys over natural reefs, the habitat it occupied (e.g., rock, sand, mud, cobble, or boulder).

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 demersal rockfishes (M. Love, pers. obs., V. O'Connell, per. obs., Alaska Department of Fish and Game, and M. Yoklavich, NOAA Fisheries, pers. obs.). Certainly, we noticed virtually no movement at all from most of the fishes in this study as the research submersible passed by.

Data analyses

While our surveys estimated size for most observed fish, we were not able to estimate sex ratios. Cowcod are not sexually dimorphic and it seemed reasonable to assume an equal female to male ratio. Bocaccio are sexually dimorphic and sex ratios of commercial catches are not 1:1 and are related to size. We obtained data to estimate length-specific sex ratios for bocaccio from Mark Wilkins (NOAA Fisheries, AFSC, Seattle, WA), in the form of length compositions by sex from the triennial bottom trawl survey conducted by the AFSC. The trawl survey uses finer meshed nets than commercial operations and all captured fish are sampled for length compositions. Commercial operations also discard some fish due to market demand or regulations.

Our submersible survey estimated fish size to the nearest 5 cm. Observers were not able to estimate size for a small proportion of fish (0.006 for bocaccio and 0.048 for cowcod). These fish were assumed to be smaller than the size of maturity and not included in the estimates. The trawl survey measured size to the nearest 2 cm. We converted the trawl survey length compositions to 5 cm intervals. NOAA Fisheries estimated the total abundance of bocaccio off southern and central California in numbers of fish by size and sex for each year of the survey. The estimates of total numbers of fish varied considerably among years. Since growth is sexually dimorphic for bocaccio and there is considerable variation in year-class strength, we decided it would be best to calculate the ratios of females to total fish at each year and then average the ratios, in order to give equal weight to each year's estimates. The results indicated that ratios varied without trend through 60 cm and then rapidly increased to 1 (all females) at 70 cm. We concluded that because females grow faster and to larger size than males it would be reasonable to apply the average female to total fish ratio, 0.44, between 25 and 60 cm, the observed value, 0.82, for 65 cm, and 1 for larger fish (Table 1).

We used estimates of maturity schedules for bocaccio and cowcod obtained from the study area (M. Love, unpubl. data). We believe it was more appropriate to use these data than other published results from fish that were collected from more northern waters. These data are summarized in Love et al. (1990), but the published results were not in sufficient detail for the purpose of the present study. We converted to maturity data in 1-5 cm intervals. We estimated maturity schedules for combined sexes by sum for each sex of proportion mature weighted by proportion for that sex (Table 2).

We used the size fecundity estimates of Love et al. (1990) to estimate number of eggs of mature females as these were derived from fishes collected from the study area. The bocaccio estimates are similar to those estimated by Phillips (1964) from fish that were collected from more northern waters.

For bocaccio, Fecundity = 1.15 (L^3.2696), and for cowcod, Fecundity = 1.702(L^3.1542), where L is total length in centimeters.

To calculate the number of larvae that could be produced by resident bocaccio and cowcod at a given area, we first segregated all observed fish during a survey into size classes. For bocaccio, we estimated the number of females in each size class using the sex ratio data in Table 1 (cowcod are assumed to have a 1:1 ratio). Next, for each species in each size class, we used maturity schedules (Table 2) to estimate the proportion of mature females in each class. Length-fecundity equations were then used to determine the number of larvae each female could produce. Larval production is therefore linked to fish density and rates are scaled appropriately across sites.

We estimated area surveyed by multiplying transect distance by 2, because survey width was 2 m, and then calculated densities per area for each species and size. Transect lengths were estimated 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 the video camera. Transect lengths were computed by counting the number of 20 cm laser segments in 15 s subsamples (one per min) throughout the transect, calculating speed based on those counts and averaging them over the whole transect, and multiplying that average speed by the transect duration. The 15 s subsamples were made during the first 15 s of each minute of the transect in which the laser points were visible. We first summed all data for a dive. Sometimes there was more than one dive for a station in a year. In this case, we averaged the results of the dives for estimates of the station-year. In many cases a station was surveyed in more than one year and we averaged the results over years for each of those stations. We also grouped stations that were adjacent to each other.

Estimates of footprint areas for the platforms come from Love et al. (2003). We estimated area of natural reefs needed to produce the same amount of larvae as an average platform by multiplying the average area of a platform by the ratio of average platform production to average reef production.

Table 1. Estimated ratio of female to total bocaccio, in 5 cm intervals, in southern California.

	Female:Total	
Size cm	**Observed**	**Estimated**
25	0.40	0.44
30	0.45	0.44
35	0.48	0.44
40	0.45	0.44
45	0.55	0.44
50	0.34	0.44
55	0.40	0.44
60	0.48	0.44
65	0.82	0.82
70	1.00	1.00
75	1.00	1.00

Table 2. Maturity schedules, in 5 cm intervals, estimated for bocaccio and cowcod in southern California.

		Bocaccio			Cowcod	
Size cm	**Female**	**Male**	**Combined**	**Female**	**Male**	**Combined**
30	0.00	0.00	0.00	0.00	0.00	0.00
35	0.22	0.33	0.29	0.00	0.07	0.03
40	0.78	0.92	0.86	0.02	0.35	0.19
45	0.99	1	1	0.64	0.70	0.67
50	1.00	1	1	0.95	1.00	0.97
55	1.00	1	1	1.00	1.00	1

Results

In comparing larval production, fish densities, and ultimately habitat equivalence between platforms and natural outcrops we restricted our analyses to habitats and depths most likely to harbor adult cowcod and bocaccio (based on data from Love et al., 2002 and Yoklavich et al., 2000). A site was considered to be appropriate habitat and retained for analyses if any starting depth was ≥ 60 m for bocaccio or ≥ 80 m for cowcod and if any patch bottom in that site was classified as "rocky high relief", "rocky low relief", or "boulders". Based on these parameters, 63 reefs and seven platforms (Gail, Grace, Harvest, Hermosa, Hidalgo, Holly, and Irene) were used in the bocaccio dataset and 52 reefs and five platforms (Gail, Grace, Harvest, Hermosa, and Hidalgo) in the cowcod dataset.

Overall, we observed 1054 bocaccio of all sizes at platforms and 976 at reefs, and 125 cowcod at platforms and 134 at reefs. Among bocaccio estimated to be mature, we observed 313 individuals around platforms and 313 at reefs, and 38 mature cowcod at platforms and 61 at reefs. Adult fishes were patchily distributed among both platforms and natural reefs. Fifty-seven percent of surveyed natural reefs (36 out of 63) with appropriate habitat (as defined above) had mature bocaccio on them and 42% (23 out of 54) of

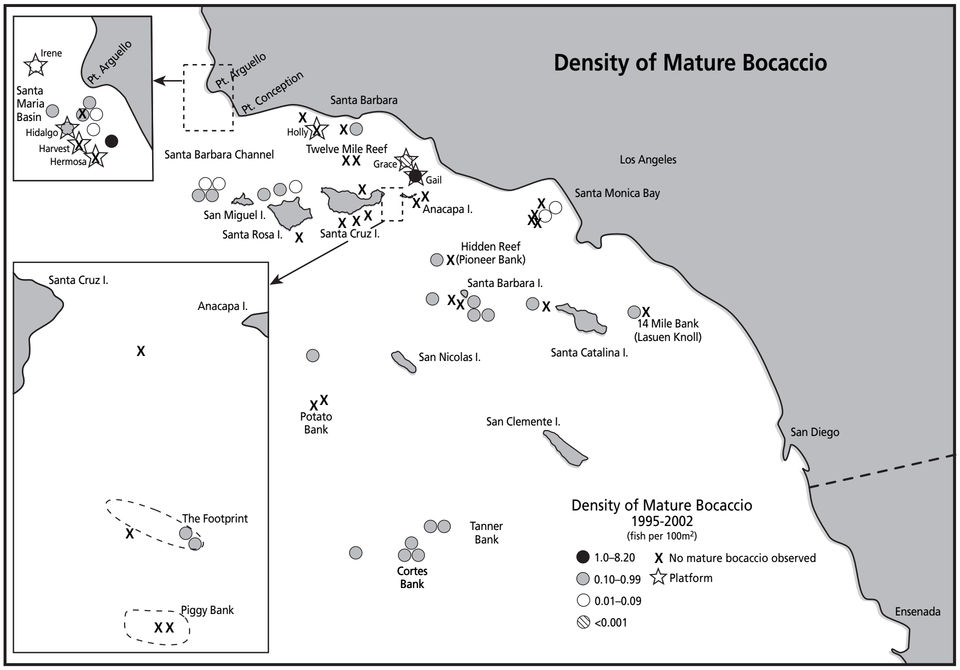

Figure 2. Densities of mature bocaccio at seven platforms and 63 natural reefs in the southern California Bight and off central California, 1995-2002. Included are sites that were classified as "rocky high relief", "rocky low relief", or "boulders" and in depths of 60 m or more.

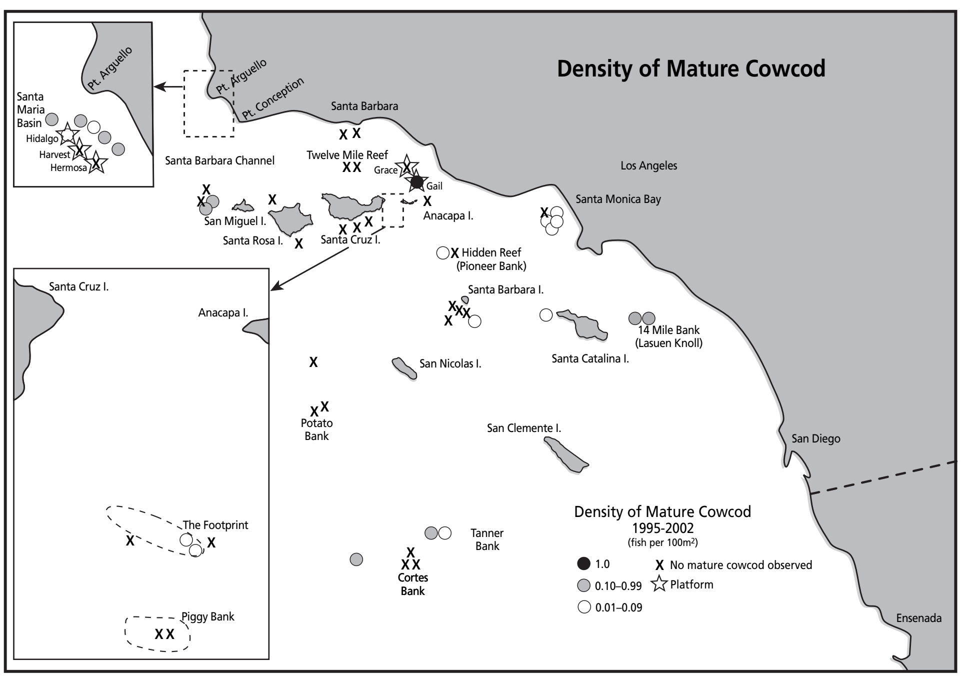

Figure 3. Densities of mature cowcod at five platforms and 52 natural reefs in the southern California Bight and off central California, 1995-2002. Included are sites that were classified as "rocky high relief", "rocky low relief", or "boulders" and in depths of 80 m or more.

surveyed natural reefs with appropriate habitat had adult cowcod on them. Platforms had nearly identical ratios as at natural reefs, as 57% (4 out of 7) had adult bocaccio and 40% (2 out of 5) had adult cowcod.

Densities of mature bocaccio and cowcod were highly variable among survey sites, but were generally very low at both natural reefs and platform habitats (Figs. 2 and 3). The mean density on natural reefs for bocaccio and cowcod was 0.15 per 100 m^2 (SE 0.03) and 0.04 per 100 m^2 (SE 0.01) respectively. Higher densities of mature fishes on natural reefs tended to occur in more remote areas (Figs. 2 and 3). The mean density around platforms for bocaccio and cowcod was higher, 1.25 per 100 m^2 (SE 1.16) and 0.21 per 100 m^2 (SE 0.19), respectively. While densities were much lower on reefs than on natural reefs at most sizes, relative numbers of medium-size fish tended to be higher on reefs than on platforms (Fig. 4).

For both species, the larger average adult size at platform habitat proportionally increased the potential larval production at platforms compared to natural reefs, especially for bocaccio (Fig. 5). Mean (±1SE) larval production (no. eggs/m^2) at platform sites was 2883 (2597) for bocaccio and 743 (676) for cowcod, while mean production for natural outcrop sites was much less, 254 (58) for bocaccio and 132 (34) for cowcod.

Of particular interest, Platform Gail had by far the highest densities of mature bocaccio (8.17 per 100 m^2 compared to 1.46 for the highest density on a natural reef) and cowcod (1.00 per 100 m^2 compared to a maximum of 0.23 for natural reefs) of any natural or human-made habitat in this study (Figs. 2 and 3). Platform Gail also had the highest potential larval production values, topping out at 18,397 eggs/m^2 for bocaccio and 3440 eggs/m^2 for cowcod (Fig. 5). This means that if Platform Gail (whose footprint is 0.5337 ha) were removed during decommissioning it would be the equivalent of removing 12.57 ha of average-producing natural habitat in southern California for cowcod, or equivalent to removing 29.24 ha of average-producing natural habitat in southern California for bocaccio.

Discussion

Our study provides the first published evidence, based on direct underwater observations, for intense depletion of both adult bocaccio and cowcod on many natural structures in southern California (previous evidence came from fishery-dependent data, e.g., Love et al., 1998 and Butler et al., 2003; and larval or juvenile surveys, e.g., Love, et al., 1998; Moser et al., 2000; Butler et al., 2003). It is likely that these low densities were due both to overfishing and to poor larval and pelagic juvenile survivorship (Love et al., 2002; Love et al., 2003). With the exception of Platforms Gail and Hidalgo, densities were also low for adults of both species at platforms.

Platform Gail harbored unusually high densities of adult bocaccio and cowcod. The high densities of both species at Platform Gail are likely due to its status as a de facto marine protected area (Schroeder and Love, 2002), a bottom depth that is commonly occupied by adult bocaccio and cowcod, and the presence of a bottom crossbeam that provides a sheltering area for both species (Fig. 1). It is probable that the adult bocaccio and cowcod living at Platform Gail were derived from young-of-the-year (YOY) that had recruited from the plankton to that platform's jacket, shell mound, or pipeline. During nine years of surveys, we have on several occasions observed relatively high densities of YOY bocaccio recruiting to the midwaters of Platform Gail and YOY cowcod to its shell mound and pipeline (Love et al., 2003; Love and York, in press). In addition, our research indicates that both species not only have recruited as YOYs to the jacket or surrounding structures, these year classes also have remained at the platform over succeeding years (Love et al., 2003; Love, unpubl. data).

The densities of bocaccio and cowcod we observed at Platform Gail were not only far higher than those of any other platform or natural reef in southern California, they were higher than four of five deeper-water sites surveyed in Soquel Canyon in central California and were surpassed only by an outcrop that likely has never been fished (Yoklavich et al., 2000). This natural refuge provides a comparison from deeper waters

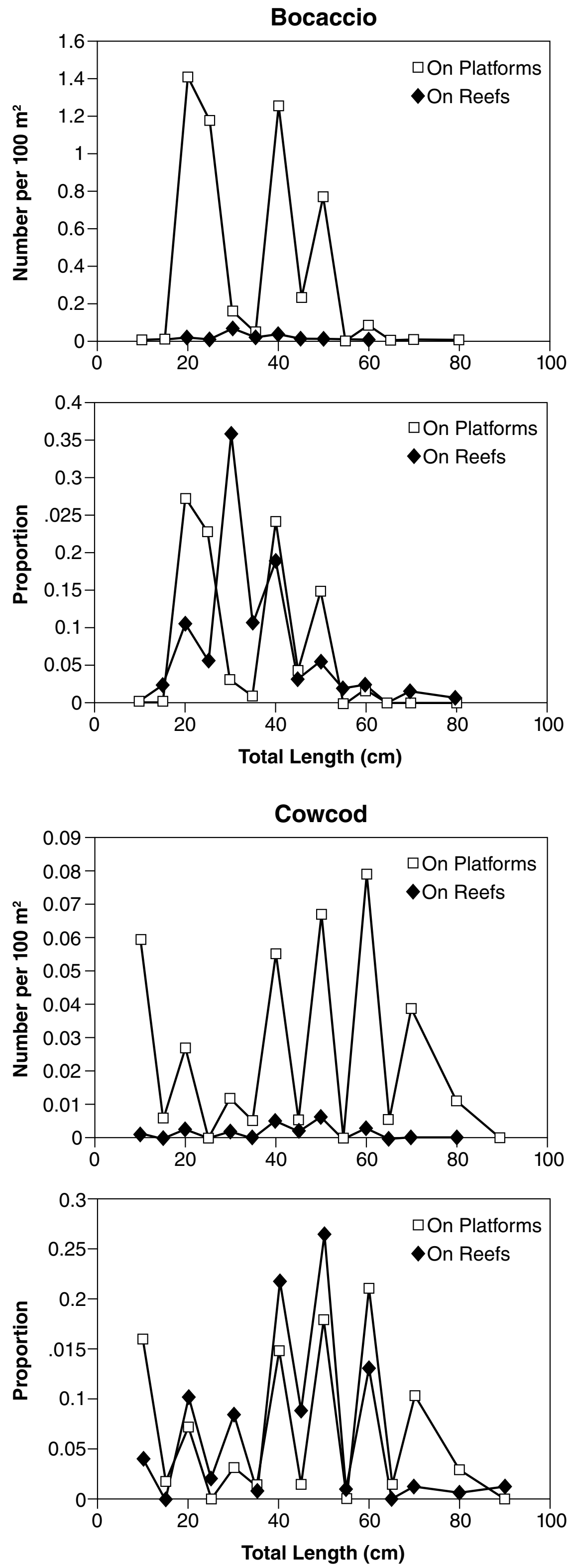

Figure 4. Average densities by size of bocaccio and cowcod observed at natural reefs and platforms. Data from all dives in suitable habitat and all fish sizes are included.

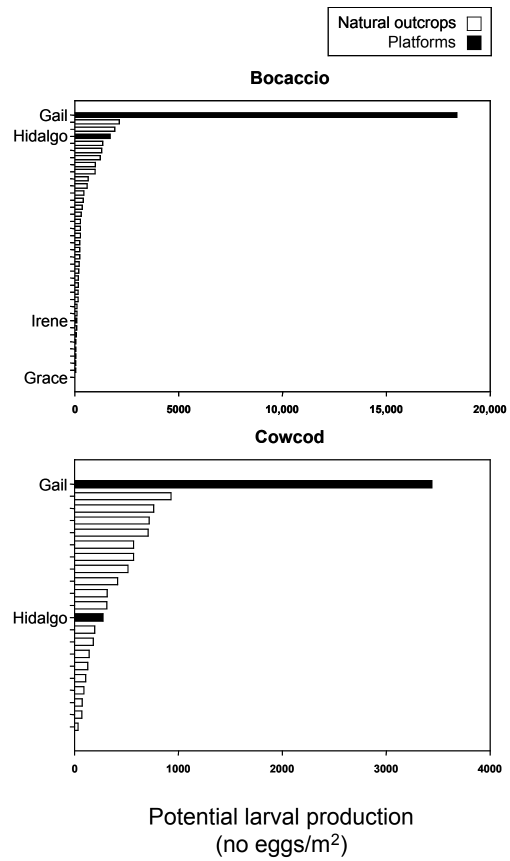

Figure 5. Comparison of potential larval production (no. eggs/m^2) of sites that had at least one mature bocaccio (40 natural reefs and four platforms) or one mature cowcod (25 natural reefs and two platforms). Bars representing platforms are darkened. Platforms in the appropriate depth range that did not harbor mature cowcod included Grace, Harvest, Hermosa, and for bocaccio, Harvest, Hermosa and Holly.

off central California, as most of the abundant species at the Soquel Submarine Canyon site (e.g., bocaccio, cowcod, lingcod, greenspotted, and greenblotched rockfishes) are also those most characteristic of the jacket bottom at Platform Gail (Love et al., 2003). Yoklavich et al. (2000) make the point that the Soquel Canyon site may be an important site for larval production, noting that "These areas appear to function as a natural harvest refugium, potentially contributing new recruits to adjacent fished areas" through larval export. The high densities and relatively large size of fishes at Platform Gail translate into substantially higher potential larval export per unit area for that platform than for any other site surveyed in our study.

On a regional basis, how important is larval bocaccio and cowcod production at Platform Gail? First, from our research submersible surveys it is clear that there is little larval production from bocaccio and cowcod that live on natural outcrops in the Santa Barbara Channel. With the exception of the carbonate feature Twelve Mile Reef (Fig. 2), located in the center of the Santa Barbara Channel, much of the sea floor in the Channel (at depths frequented by adult bocaccio and cowcod) is composed of soft substrata (G. Cochrane, United States Geological Survey, pers. comm.). The Twelve Mile Reef was at one time the major Santa Barbara Channel fishing ground for a number of rockfish species, including both cowcod and bocaccio (M. Kronman, Santa Barbara Harbor Department, pers. comm.; M. Love, unpubl. data). However, during our surveys we observed no adult bocaccio and cowcod on that outcrop. Other, and smaller, Santa Barbara Channel features (Fig. 2) also harbored few or no adults of these species.

Rockfish larvae may be partially retained in the east Santa Barbara Channel, where Platform Gail is sited, through oceanographic fronts and eddies (Nishimoto, 2000). Under certain conditions, larvae generated within the Santa Barbara Channel may also be entrained in seasonal gyres located in the western Channel (Nishimoto and Washburn, 2002). Thus local sources of larvae may be critical to the maintenance of Santa Barbara Channel rockfish populations and Platform Gail, apparently one of the major producers of bocaccio and cowcod larvae in the Channel, may be quite important. It is interesting to note that some of the highest densities of YOY bocaccio we have observed anywhere in our studies were found at platforms Gilda and Grace, which are located within a few kilometers of Platform Gail (M. Love, unpubl. data). Thus, there is a possibility that these young fishes were generated as larvae at the latter structure.

While platform fish assemblages vary with platform bottom depth, it is clear that many of the platforms off southern California, regardless of bottom depth, act as de facto marine reserves. At these platforms, fish species in addition to bocaccio and cowcod have also responded to protection from fishing as densities of other economically important species (e. g., brown, *Sebastes auriculatus*, copper, *Sebastes caurinus*, flag, *S. rubrivinctus*, greenblotched, *S. rosenblatti*, and greenspotted, *S. chlorostictus*, rockfishes, and lingcod, *Ophiodon elongatus*) are higher at platforms than at most or all southern California natural reefs (Schroeder and Love, 2002; Love et al., 2003). It is likely that larval production of these species, per unit area, will also be higher at platforms than at most natural habitats. Thus, the potential importance of platforms as marine refugia may be large given the generally very low densities of adults of a number of rockfish species on natural reefs in southern California. If future platform decommissioning involves retaining some of the platform jacket in place, it important to note that the high fish densities we observed would only be maintained if the platforms remained protected from fishing.

Clearly, southern and central California platforms vary widely in size, bottom depth, and fish assemblages. For instance, of the platforms we surveyed, Platform Gail, and to a lesser extent, Hidalgo, were unique in having high densities of mature bocaccio and cowcod. Given these variables, it would be premature to judge the importance of all of these structures as fish habitat. In addition, all of our surveys were conducted in the fall and we do not know whether adult cowcod and bocaccio remain at any of these structures throughout the year, although the interannual persistence of high densities of large bocaccio and cowcod at Platform Gail lends credence to this hypothesis. However, it is clear from our analysis that platforms can be important habitat for adult fishes, particularly of species that have been heavily exploited. Given the high densities of adults of many species of economically important rockfishes and lingcod around platforms and the low densities of these same species on many or most natural reefs in southern California, it is quite possible that some platforms are of regional significance as sources of larval production and export for some species. The extent of this significance should play an important role in determining the preferred option of future decommissioning activities (removal or leave-in-place) once oil and gas production ceases.

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Task 2: 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

Milton S. Love, Edward Brothers, Donna M. Schroeder, William H. Lenarz

Abstract

Some decommissioning alternatives regarding the fate of offshore oil platforms include leaving some or all of the platform structure on the seabed as an artificial reef. Questions surrounding the utility of such structures as productive fish habitat have not been resolved. Despite the high numbers of fishes that can reside around offshore platforms, little is known about the comparative ecological performance between natural and artificial habitats, where higher growth, reproduction or survival rates would be beneficial to regional fish populations. To address this need, we analyzed the otolith microstructure of 187 young-of-the-year (YOY) blue rockfish (*Sebastes mystinus*) to compare mean daily growth rate and birth date distribution among three platforms and three natural reefs in the Santa Barbara Channel region. Paired natural and platform sample sites were selected to include a range of oceanographic conditions present in the region. We found a significant though modest lunar pattern in birth dates where blue rockfish produced (or successfully recruited) fewer larvae in the week following the full moon. Channel-wide patterns of birth date distribution were present. Sites located in the west channel region included a range of birth dates (January through March) whereas those in the east channel were limited to January and February. Mean growth rates were significantly different across sites (ANOVA, $F = 71, 96$, $df = 5, 180$, $P \leq 0.01$). At the one site pair where comparisons were valid, YOY rockfish growth rates were significantly higher at the platform habitat. 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.

Introduction

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).

Platform midwaters (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 (Love et al., 2003; Carr 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., in press). 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 fishes living around artificial and natural habitats (as measured by fish growth, survival, and reproduction) is a major determinant of that habitat's importance (Carr and Hixon, 1997; 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 daily growth rates of these young fishes.

Methods

Sample Collections

During the fall of 1999, YOY blue rockfish were collected by pole spear at three platforms and three 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), Platform Holly and Naples Reef (in the same water mass and located with 8 km of each other) and Platform Gilda and Anacapa Island (in different water masses and within 16 km of each other). Collections were made during one day at each site.

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 um followed by 1 um). Microincrements were counted with the aid of a video microscope (to about 1500x 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/day) 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 ANOVA's to test the hypotheses that mean birthdate (day of the year), age, standard length, and growth did not vary among sites. ANOVA's are robust to minor deviations from the assumption that observations are normally distributed. We compared the results of the ANOVA's using untransformed data with ANOVA's using log-transformed data and the F values were very close. We chose to use untransformed data for the analyses. We used Scheffé's Post Hoc Test to contrast means of the six sites.

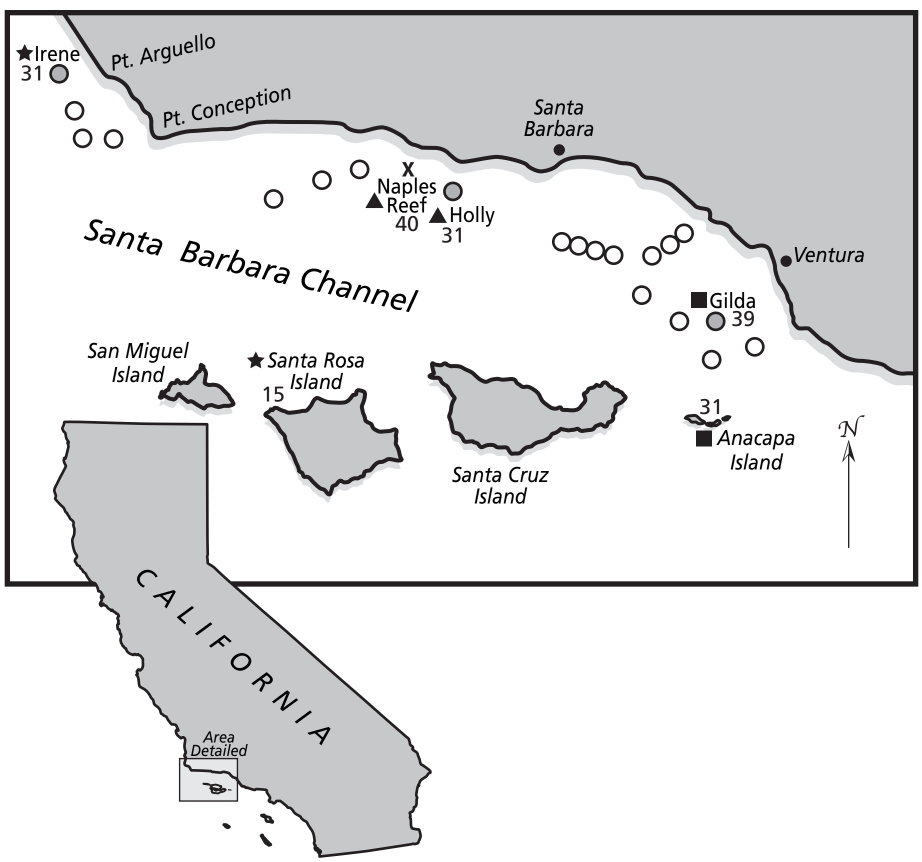

Figure 1. Location and number of young-of-the-year blue rockfish collected at six sites in southern and central California, September-November 1999. Platform and natural reef comparison pairs are noted by stars, triangles, and squares.

Results

We collected a total of 187 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 15 September and 23 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 6.7-11.1 cm and mean lengths of fish sampled at each site ranged from 8.1 to 10.0 cm (Fig. 2, Table 1). The ANOVA showed that lengths were significantly different among sites ($F = 31.69$, $df = 5,180$, $P \leq 0.01$). Scheffé's contrasts were significant for the site pairs Platform Holly – Naples Reef and Platform Gilda – Anacapa Island (Table 2). Mean lengths were not statistically different at the site pair Platform Irene – Santa Rosa Island (Table 2). Young-of-the-year blue rockfish ranged in age from 199 to 316 days and mean ages of fish at each site varied between 215 to 301 days (Table 1, Fig. 3). Mean ages were statistically different between almost all sites (one-way ANOVA, $F = 205.60$, $df = 5,180$, $P \leq 0.01$, 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 ($F = 22.20$, $df = 5,180$, $P \leq 0.01$), 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 2). In both instances mean birth dates were within four days of each other (Table 1). Patterns of birth dates were very similar at Platform Irene and Santa Rosa Island; parturition in March was only observed in fish inhabiting these two sites (Fig. 4). Mean birth dates were 18 days apart for fish at Platform Gilda and Anacapa Island (Scheffé's Test $P < 0.05$, Table 2).

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 is 39.

Site	n	Date of Sample	Mean Date of Birth	Mean Age (days)	Mean Length (SL cm)	Mean Growth (mm/day)
Platform Irene	31	16-Nov-99	18Feb(5Jan-16Mar)	270(245-315)	8.6(7.4-10.5)	0.32(0.27-0.39)
Santa Rosa I.	15	16-Nov-99	14Feb(10Jan-21Mar)	275 (240-310)	8.5(6.7-9.5)	0.31(0.27-0.36)
Platform Holly	31	15-Oct-99	26Jan(9Jan-19Feb)	262(238-279)	10.0(8.7-11.1)	0.38(0.33-0.46)
Naples Reef	40	25-Sep-99	30Jan(3Jan-16Feb)	240(221-265)	8.6(7.5-9.7)	0.36(0.33-0.40)
Platform Gilda	39	15-Sep-99	12Feb(13Jan-28Feb)	215(199-245)	8.1(6.9-10.3)	0.38(0.33-0.44)
Anacapa I.	31	23-Nov-99	25Jan(11Jan-18Feb)	301(278-316)	9.0(7.9-9.4)	0.30(0.28-0.33)

There was some indication that the timing of larval release was related to moon phase (Rayleigh's Test, Table 3, Fig. 5). While at most sites parturition dates were statistically uniform over a lunar cycle, when data was pooled it appeared that few larvae were extruded during the week following the full moon.

Calculated mean daily growth rates of individuals ranged from 0.27 to 0.46 mm/day and mean growth rates at each site varied between 0.30 and 0.38 mm/day (Table 1, Fig. 6). Mean growth rates were statistically different among most sites (ANOVA, $F = 71.96$, $df = 5,180$, $P \leq 0.01$). Growth rates were significantly different between fish living at Platform Holly and Naples Reef and those living at Platform Gilda and Anacapa Island (Table 2). In both instances, 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).

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

Mean Length (mm, SL)

	Naples Reef	**Platform Gilda**	**Platform Irene**	**Platform Holly**	**Anacapa Island**
Platform Gilda	0.51				
Platform Irene	-0.03	-0.54			
Platform Holly	-1.46**	-1.97**	-1.43**		
Anacapa Island	-0.37	-0.88**	-0.34	1.09**	
Santa Rosa Island	0.07	-0.44	0.10	1.53**	0.44

Mean Age (days)

	Naples Reef	**Platform Gilda**	**Platform Irene**	**Platform Holly**	**Anacapa Island**
Platform Gilda	23.33**				
Platform Irene	-32.44**	-55.77**			
Platform Holly	-24.05**	-47.38**	8.39		
Anacapa Island	-63.15**	-86.48**	-30.71**	-39.10**	
Santa Rosa Island	-36.85**	-60.18**	-4.41	-12.80	26.30**

Mean Birth Date (day of year)

	Naples Reef	**Platform Gilda**	**Platform Irene**	**Platform Holly**	**Anacapa Island**
Platform Gilda	-13.33**				
Platform Irene	-19.56**	-6.23			
Platform Holly	4.05	17.38**	23.61**		
Anacapa Island	4.15	17.48**	23.71**	0.10	
Santa Rosa Island	-15.15**	-1.82	4.41	-19.20**	-19.30**

Mean Growth Rate (mm/day)

	Naples Reef	**Platform Gilda**	**Platform Irene**	**Platform Holly**	**Anacapa Island**
Platform Gilda	-0.015				
Platform Irene	0.042**	0.057**			
Platform Holly	-0.023*	-0.008	-0.065**		
Anacapa Island	0.064**	0.078**	0.022*	0.086**	
Santa Rosa Island	0.052**	0.067**	0.010	-0.074**	-0.012

We wished to make an overall comparison of growth rates of blue rockfish combining all platform data and comparing that to all natural reef data. However, because fish at Platform Gilda and Anacapa Island were sampled two months apart and because growth rates may decline later in the season (thus complicating inter-site comparisons), in these comparisons we did not include data from these two sites. We combined the growth rates of fish from Platform Irene and Holly and compared the mean growth rate with that of fish living at Naples Reef and Santa Rosa Island. Blue rockfish living at the platforms grew 0.016mm/day more quickly (Scheffé's Test, $P<0.05$).

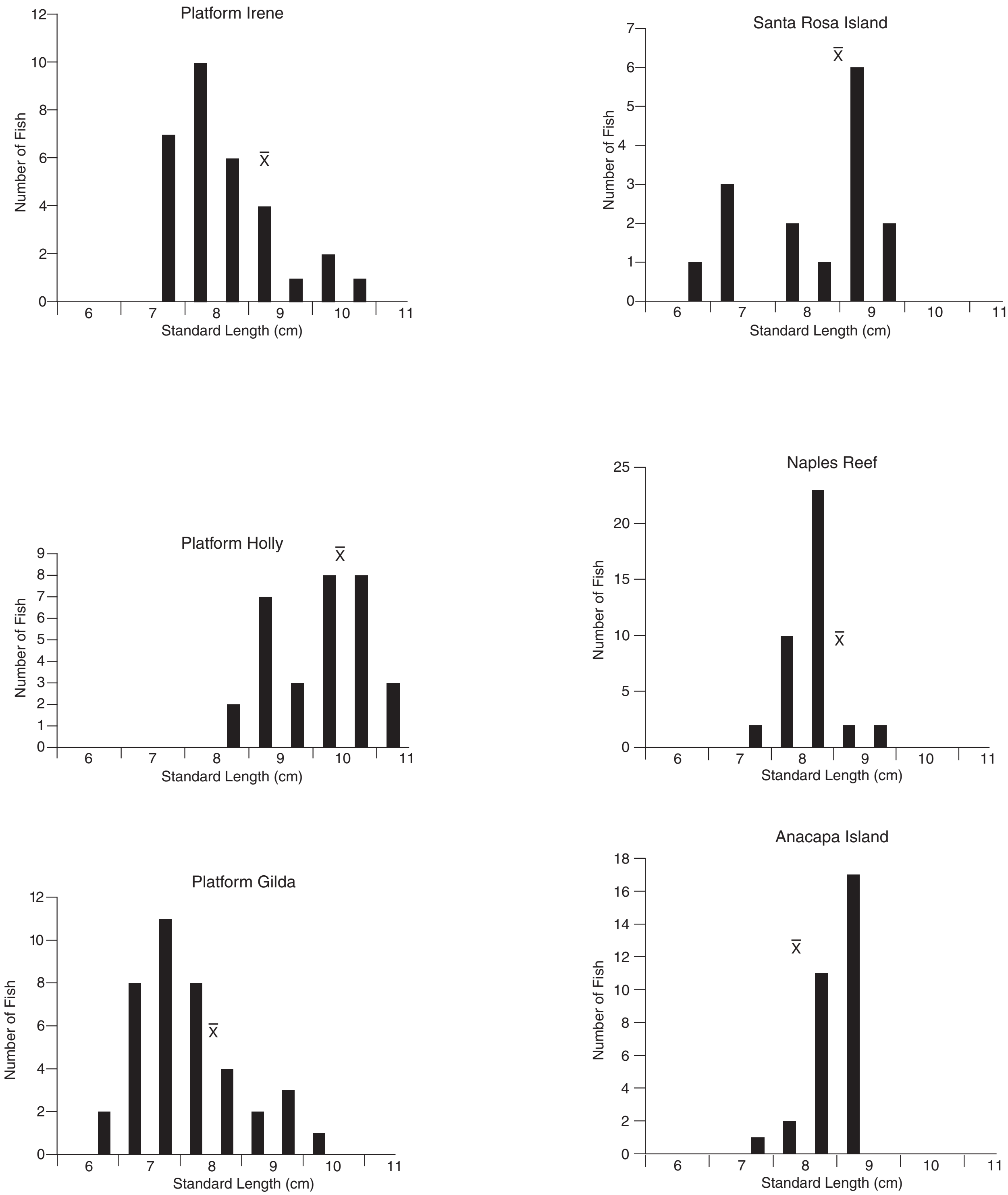

Figure 2. Size distribution of young-of-the-year blue rockfish collected at six sites in southern and central California, September-November 1999.

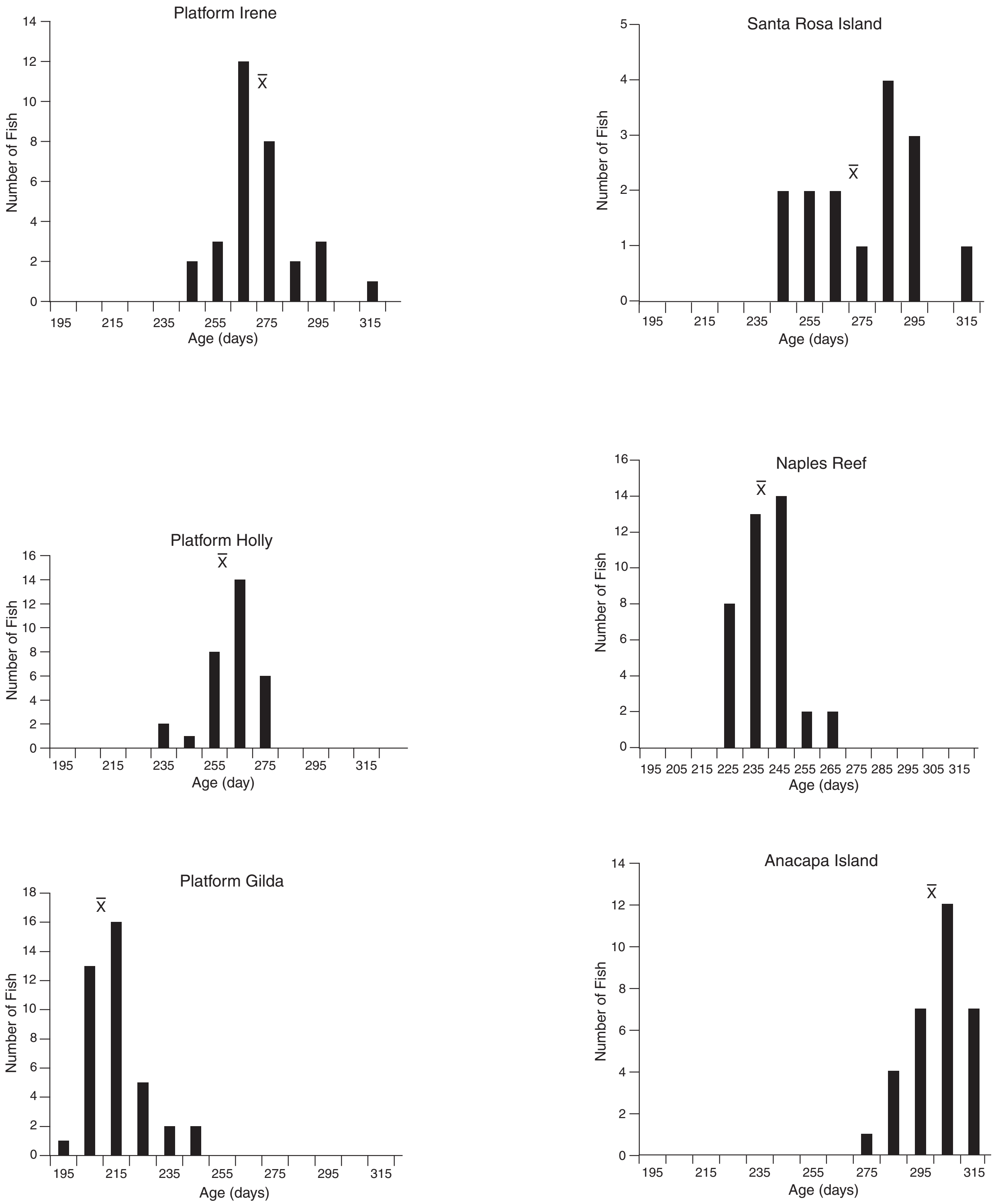

Figure 3. Age distribution of young-of-the-year blue rockfish collected at six sites in southern and central California, September-November 1999.

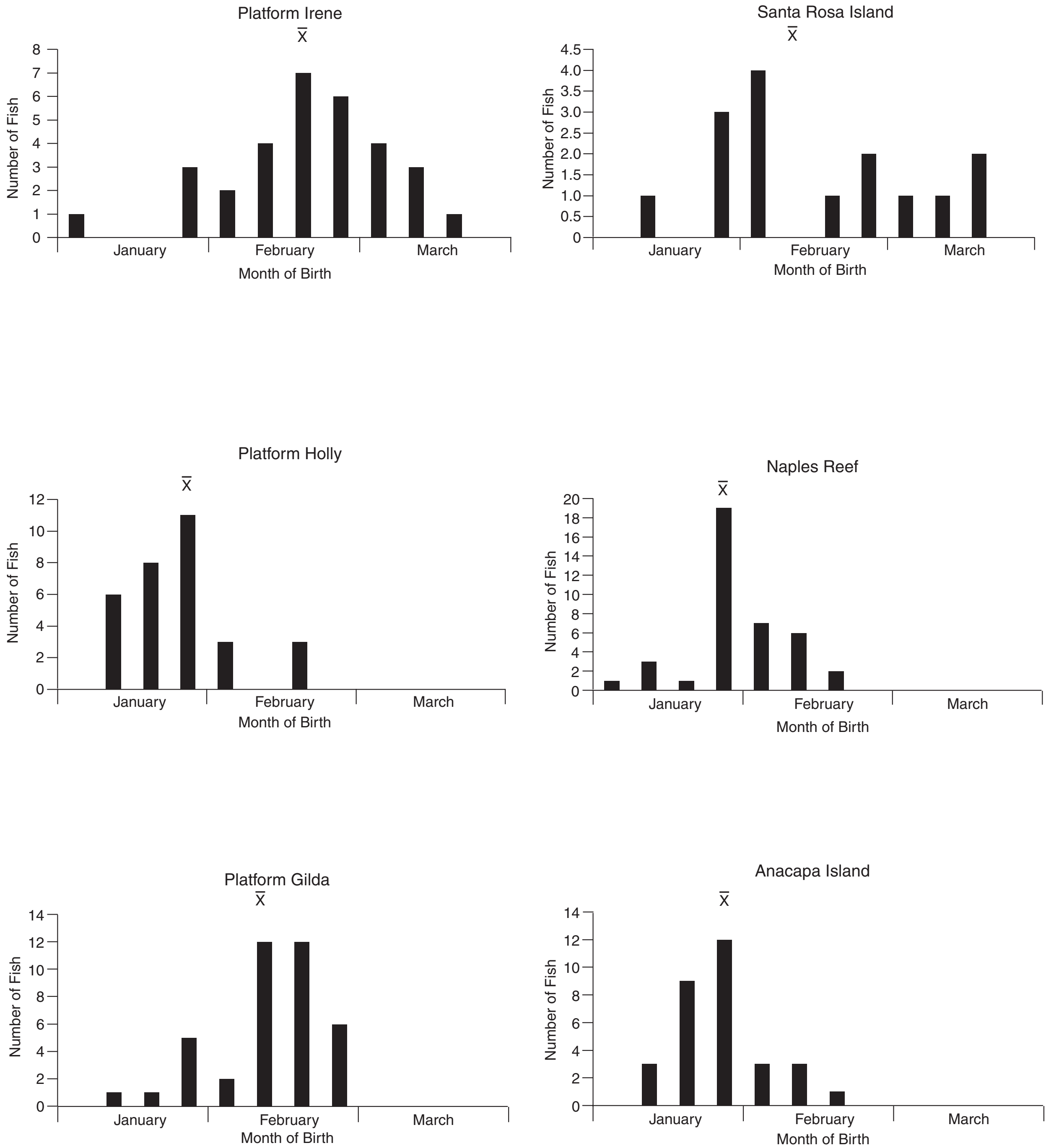

Figure 4. Parturition date distribution of young-of-the-year blue rockfish collected at six sites in southern and central California, September-November 1999.

Table 3. Statistics of Rayleigh's test (Z) for distributions of parturition dates for blue rockfish in 1999.

Site	**Z**	**Significance Level**
Platform Irene	0.61	ns
Santa Rosa I.	1.60	ns
Platform Holly	2.51	ns
Naples Reef	2.97	ns
Platform Gilda	4.77	0.01
Anacapa I.	1.07	ns
Pooled Data	3.51	0.05

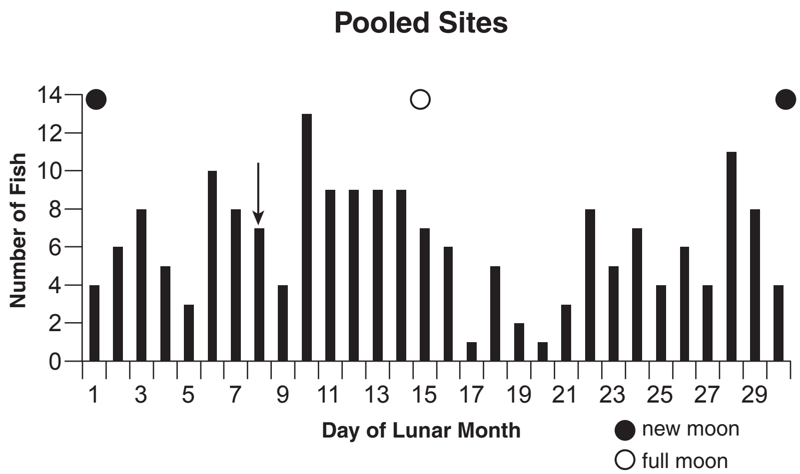

Figure 5. Distribution of parturition over the lunar month, as back-calculated from otoliths of young-of-the-year blue rockfish. Three lunar cycles are pooled. Arrow indicates the mean lunar day of parturition. New moon (filled circle) was set as the first day, full moon (open circle) as the 15th day.

Discussion

For blue rockfish, we identified a number of patterns in growth and birth date distribution across the sampling region.

First, we observed a significant, albeit subtle, lunar pattern in blue rockfish birth dates. In 1999, blue rockfish appeared to produce fewer larvae in the week following the full moon. Because parturition has not been observed in 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 in the third lunar quarter 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 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.

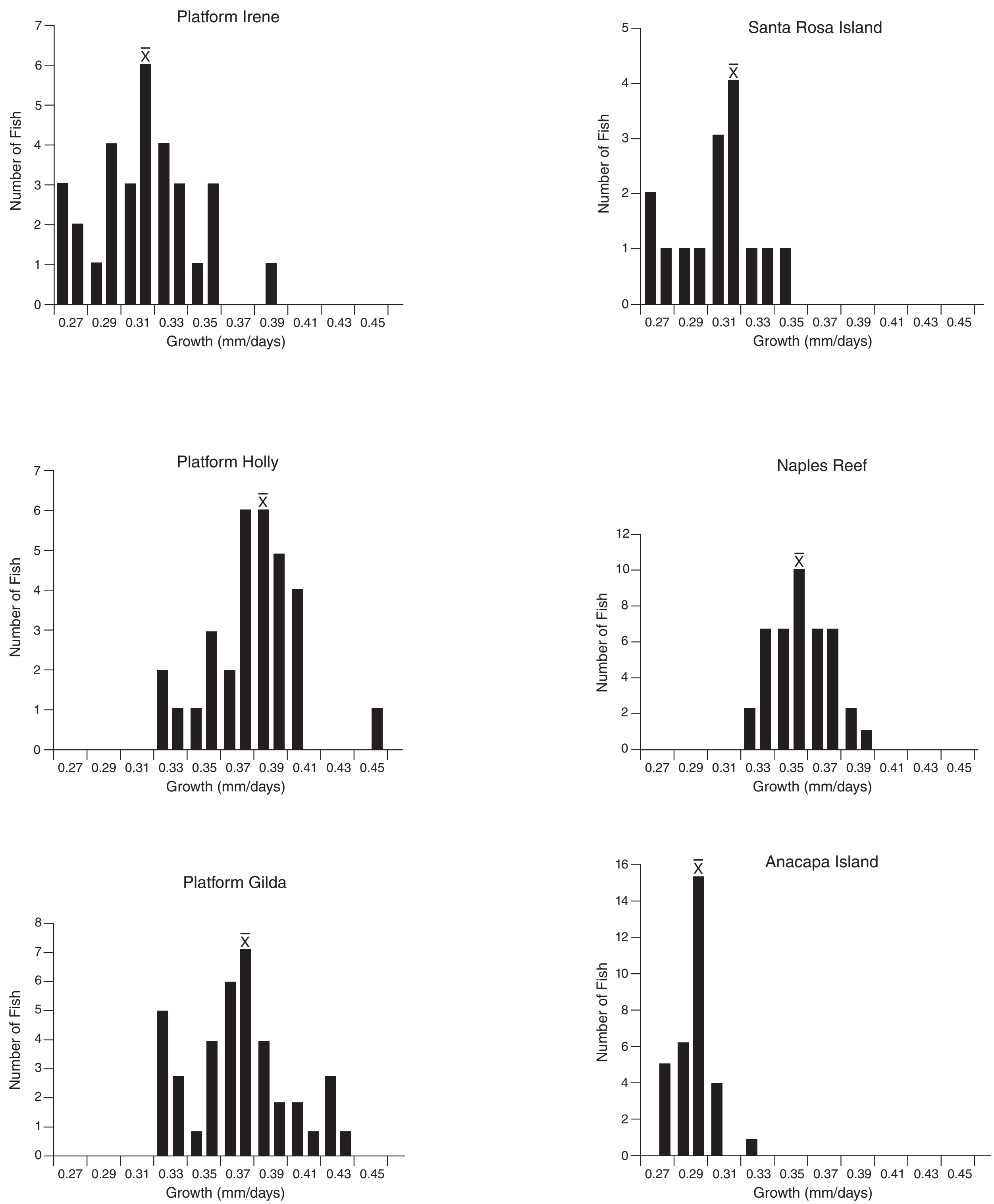

Figure 6. Distribution of growth rates of young-of-the-year blue rockfish collected at six sites in southern and central California, September-November 1999.

There is some evidence that the YOY blue rockfish living at Platform Irene and Santa Rosa Island and those living at Platform Holly and Naples Reef either came from similar source populations or had larvae and pelagic juveniles that had experienced similar pelagic environmental conditions. Evidence is strongest for fish living at Platform Irene and Santa Rosa Island. Fish at these two sites had statistically identical mean birth dates (Platform Irene, 18 February; Santa Rosa Island, 14 February) and mean lengths (Platform Irene, 8.6 mm; Santa Rosa Island, 8.5 mm), and they were the only sites harboring fish that had been born in March (Tables 1, 2; Figure 4). Fish at Platform Holly and Naples Reef had non-significantly different birth dates (Platform Holly, 25 January; Naples Reef, 30 January). Interestingly, Platform Gilda and Anacapa Island, although relatively near each other, harbored blue rockfish YOYs that were quite dissimilar in all measured variables (Tables 1, 2; Figures 2-4). Platform Irene and Santa Rosa Island are often strongly bathed by the California Current and it is likely that in 1999 larvae produced off central California were carried southwards to both platform and island. The source populations for the other sites are more problematic. For instance, while we have little data on current patterns in the eastern Santa Barbara Channel (site of Platform Gilda and Anacapa Island) in 1999, research on the source populations of 2004 YOY bocaccio living around Platform Gilda implies that pelagic juveniles were brought to that site on currents flowing from several directions (M. Nishimoto et al., 2005).

The growth rates of YOY blue rockfish in our studies (with mean per site ranging from 0.30 to 0.38 mm/day) 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/day in field studies and 0.27 mm/day 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 extrusion to post settlement. In that study, growth rates were 0.17 mm/day in greenstriped rockfish (*Sebastes elongatus* Ayres, 1859), 0.25 mm/day in cowcod (*Sebastes levis* (Eigenmann and Eigenmann, 1889)), and 0.32 mm/day 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/day, Kacher and Amara 2005; gray snapper, *Lutjanus griseus* (Linnaeus, 1758), 0.62-0.88 mm/day, Denit and Sponaugle, 2004; greater amberjack, *Seriola dumerili* (Risso, 1810), 1.65-2.00 mm/day, Wells and Rooker 2002; blue marlin, *Makaira nigricans* Lacepede, 1802, 16.6 mm/day).

The two-month disparity in collection dates among locations complicated our comparing the growth rates of fish from Platform Gilda and Anacapa Island and from comparing growth rates among all sites. Nevertheless, it is clear that there is 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 (Gaines and Roughgarden, 1987; Singer, 1985) and zooplankton density may be greater around Platform Holly than over Naples Reef. The 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 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 those 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 on foraging activities rather than predator avoidance.

While such environmental factors as hypoxia, salinity, and the varied nutritional values of prey can influence growth rates of the early life stages of marine fishes (Lee et al., 1994; McNatt and Rice, 2004; Wuenschel et al., 2004), in ocean waters temperature and food availability are usually the most important parameters (Boehlert and Yoklavich, 1983; Denit and Sponaugle, 2004; Kurita et al., 2004; Bacon et al., 2005). In black rockfish (*Sebastes melanops* Girard, 1856), a species closely related to blue rockfish, water temperature was perhaps the major factor affecting growth rates (Boehlert and Yoklavich, 1983). We did not see a clear temperature effect on growth rate in our study. This was particularly apparent when comparing growth rates of fish living at Platform Irene, Santa Rosa and Anacapa islands. All of the fish from these sites were taken in November (thus we measured growth over the same period) and growth rates were not significantly different. However, these sites reside in two different oceanographic regimes; Platform Irene and Santa Rosa Island are in the cold California Current and Anacapa Island in the warmer waters of the southern California Bight. In 1999, from July (when blue rockfish begin to settle out of the plankton) to November (when the fish were captured), mean temperatures off Point Arguello (near Platform Irene) were about 3° colder (13.8°C, s.d. 1.1°C) than near Anacapa Island (17.0°C, s.d. 0.8°C) (data from Point Arguello, Arguello Mid-Shelf Mooring, 34.5202, -120.6970; Anacapa Island data from the Anacapa Mid-Shelf Mooring, 34.0542, -119.3035, B. Emery, University of California, Santa Barbara, pers. comm.). Thus water temperature, at least as experienced by the fish our samples, may not have been the major factor in growth rates. Another possibility is that while temperature was important, differences in food availability may have been sufficiently large that they swamped any temperature effect.

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 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. (in press) 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). Our current study supports previous research implying that at least some platforms may benefit regional fish populations.

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Task 3: Comparative Predation Rate on Painted Greenling Between Natural Habitat and an Offshore Oil Platform

Donna M. Schroeder and Milton S. Love

Abstract

Off southern California, decisions regarding decommissioning of offshore oil platforms will rely in part on the ecological performance of platforms as juvenile fish habitat. Here we use a tethering experiment to determine the relative risk of predation for a small benthic fish, the painted greenling (*Oxylebius pictus*), between a natural reef and an oil platform. We found that juvenile painted greenling at the natural reef suffered a predation rate more than 2.5 times greater than platform juveniles. Platform habitat had lower painted greenling density ($t = -3.941$, $p = 0.017$) and lower piscivore density ($t = -3.965$, $p = 0.017$), but there was no significant difference among habitats in the ratio of predators to prey (Mann-Whitney $U = 3.00$, $p = 0.513$). The number of predator species was greater at the natural reef (7 reef species vs 1 platform species), which suggests that relative predation risk among habitat types may be governed by the habitat-specific suite of predators. Decommissioning decisions can alter platform fish assemblages, including the piscivore assemblage. Thus, the ecological performance of platform structure as juvenile fish habitat should be considered a dynamic property that will be impacted by the decommissioning process.

Introduction

In decommissioning offshore oil platforms, options that leave some or all of the platform structure on the seabed ("rigs-to-reefs") engender a great deal of controversy (Schroeder and Love 2004). Assessment of the quality of platform habitat bears greatly upon decommissioning decisions, because such information aids in understanding the ecological role of platforms at a regional scale. Thus, measuring the comparative ecological performance (i.e., a species' reproduction, growth and survivorship rates) between natural and platform habitats has been identified as a priority research area by marine scientists and resource managers (Manago and Williams 1998, Holbrook et al. 2000).

For example, in certain years, many offshore platforms host large numbers of juvenile fishes (Schroeder et al. 2000, Love et al. in press). These observations might imply that, for these species, platforms are high quality habitat. However, the ultimate fate of these juveniles remains unclear. Specifically, it is unknown whether these fish may suffer higher rates of mortality than they would at natural habitats.

In this study, we estimate the relative predation rate of a juvenile fish between natural habitat and an offshore oil platform. We used a tethering technique because, despite inherent artifacts of a tethering approach (Peterson and Black 1994, Halpin 2000), the technique is useful to evaluate relative differences in predation rate at small scales (Aronson et al. 2001). Further, tethering is a more direct approach than other field techniques, such as visual surveys or tag and recapture, where changes in fish abundance may be due to a combination of immigration and mortality rates. To provide insight in explaining potential differences in predation rate, we also compared densities of painted greenling and piscivores between habitat types. Studies that investigate comparative ecological performance among natural and artificial habitats are useful in fisheries management and restoration ecology, where use of artificial reefs plays an increasingly important role (Powers et al. 2003).

Methods

We conducted the study at two sites located in the Santa Barbara Channel off southern California. Platform Holly (34.3897 N, 119.9055 W) is located in 64 m of water, and 2.9 km offshore of the mainland. The subsurface platform structure (called the jacket) is supported by steel tubular legs anchored in the seafloor. Steel horizontal, diagonal, and oblique crossbeams extend both around the perimeter of the jacket and reach inside and across the platform. We conducted our study at Platform Holly on the shallowest (9 m) horizontal crossbeams. In depths less than 10 m, the platform structure is annually cleaned of sessile organisms. At the time of the study, the substrate was encrusted with a dead "turf" matrix (old byssal threads, decaying holdfasts, etc), red algae, bryozoans, and a number of small mussels. Naples Reef (34.4222 N, 119.9523 W) is located approximately 1 km offshore the mainland coast, with a depth range of 6.5 to 18 m. Here sedimentary rock outcrops form a series of ridges and pinnacles that frequently exceed a meter or more in height, and provide numerous caves and crevices for shelter-seeking fishes. We conducted our study in a high relief area at 10 m depth. In certain years, giant kelp, *Macrocystis pyrifera*, forms extensive stands on the reef.

Our model organism, the painted greenling, *Oxylebius pictus* (Hexagrammidae), is a small reef fish common to offshore platforms and kelp beds off California. We employed a tethering approach to compare relative predation rates on juvenile painted greenling between a natural and an artificial (platform) habitat. This benthic fish lacks a swim bladder, and its most frequently observed daytime behavior is to simply rest on the bottom, making tethering a suitable experimental technique.

The tethering apparatus consisted of two 30 m horizontal lines secured to the rock or platform substrate. Two lines were used for ease of deployment, and were laid end-to-end to simulate a continuous line. To these lines we attached ten 0.5 m monofilament tethers ("2 lb" test) spaced approximately 5 m apart, with a swivel at the origin and a small, 0.6 cm hook at the terminus.

Scuba divers used hand nets to collect juveniles between 6 and 9 cm total length. After capture, divers attached the fish to the monofilament line by inserting the small hook into the dorsal musculature just posterior of the soft dorsal fin. Painted greenling were then placed into a small underwater holding chamber for approximately ten to thirty minutes so that the fish could acclimate and all fish could be released at the same time. All sets occurred between 1000 and 1400 hrs. After a one hour time period, divers enumerated the number of fish losses and released the remaining fish back into the field. We deployed 5 sets of ten tethers at each site. Tethering trials were conducted between November 15 and December 10, 2003.

To detect potential tethering artifacts that may occur with this experimental protocol, we installed an underwater video system on Naples Reef to observe the activity of a tethered painted greenling and its interactions with other organisms during a one hour set that was distinct from the experimental sets.

We tested the hypothesis of no difference in mean fish losses between platform and natural habitat using a two-tailed *t*-test (n=5). Fish losses were recorded as the proportion of fish remaining after each set. Prior to statistical analysis, we arcsine transformed the data to improve normality.

We used scuba to visually survey the fish assemblages at Platform Holly and Naples Reef. At each habitat type, density (individuals per hectare), mean size (total length) and species composition of reef fishes were estimated in shallow portions of platforms (0 to 9 m depth) and natural reefs (7 to 15 m). We performed three surveys during the Fall of 2003. All divers performing visual counts had completed previous training in size estimation. In each platform survey, scuba divers swam a pattern which incorporated all four corner legs as well as major horizontal crossbeams and portions inside the platform jacket. Natural reef surveys consisted of divers recording observations along eight haphazardly placed 30 m length x 2 m width x 2 m height belt transects. We tested the hypothesis of no difference in mean painted greenling density (no. fish/1000m^3), mean predator density (no. fish/1000m^3), and mean ratio of predators to painted greenling density, between platform and natural habitat using two-tailed *t*-tests (n=3). For each fish assemblage, we determined the proportion of potential predators by referring to Quast (1968), who enumerated the percent occurrence of perciform fishes in gut contents of kelp bed fishes.

Results

Experiments employing tethering techniques must include a thorough assessment of any treatment artifacts, particularly those relating to fish behavior. Diver observations and video tape at the natural reef revealed that after tethered painted greenling were released from the underwater holding chamber they either directly settled down on the substrate, or swam to the end of the tether, stopped, and then either settle to the bottom or swam to the nearest shelter (typically a patch of red algae or large cobbles). Fish did not exhibit sustained struggling behavior or other apparent distress signs that might have attracted predators. At the platform, diver observations recorded that tethered greenling behaved much in the same way as those on the natural reef, except that there were fewer refuges for the fish, and most remained exposed. Currents were stronger at Platform Holly than at Naples Reef, and tethered fish generally swam in the downstream direction.

During the videotaped session at Naples Reef, we observed three predator strikes on two different painted greenling. One kelp bass, *Paralabrax clathratus*, made two strikes (one successful) on an untethered painted greenling (which was positioned near the tethered fish), and one sheephead, *Semicossyphus pulcher*, made one successful strike on the tethered fish. Based on this video tape record and diver observations, we assumed that fish losses are able to approximate the relative predation rate between habitat types.

Relative predation rate on painted greenling was significantly higher at Naples Reef than at Platform Holly (Fig. 1). Naples Reef also had higher painted greenling density (t = -3.941, p = 0.017) and higher predator density (all species combined, t = -3.965, p = 0.017; Fig. 1). The number of predator species was much greater at Naples Reef than at Platform Holly (Table 1). In the test comparing the mean ratio of predators to prey between habitats, unequal variances required the use of a nonparametric test; there was no significant difference between means (Mann-Whitney U = 3.00, p = 0.513; Fig. 1).

Table 1. Mean (1SE) density (no. fish/1000 m3) of each predator species between habitat types.

Common name	**Scientific name**	**Naples Reef**	**Platform Holly**
Lingcod	*Ophiodon elongatus*	0.3 (0.3)	–
Kelp bass	*Paralabrax clathratus*	5.7 (1.9)	–
Barred sand bass	*Paralabrax nebulifer*	0.3 (0.3)	–
Cabezon	*Scorpaenichthys marmoratus*	0.3 (0.3)	3.0 (2.5)
Kelp rockfish	*Sebastes atrovirens*	1.7 (0.9)	–
Gopher rockfish	*Sebastes carnatus*	0.7 (0.3)	–
Sheephead	*Semicossyphus pulcher*	20.0 (2.5)	–

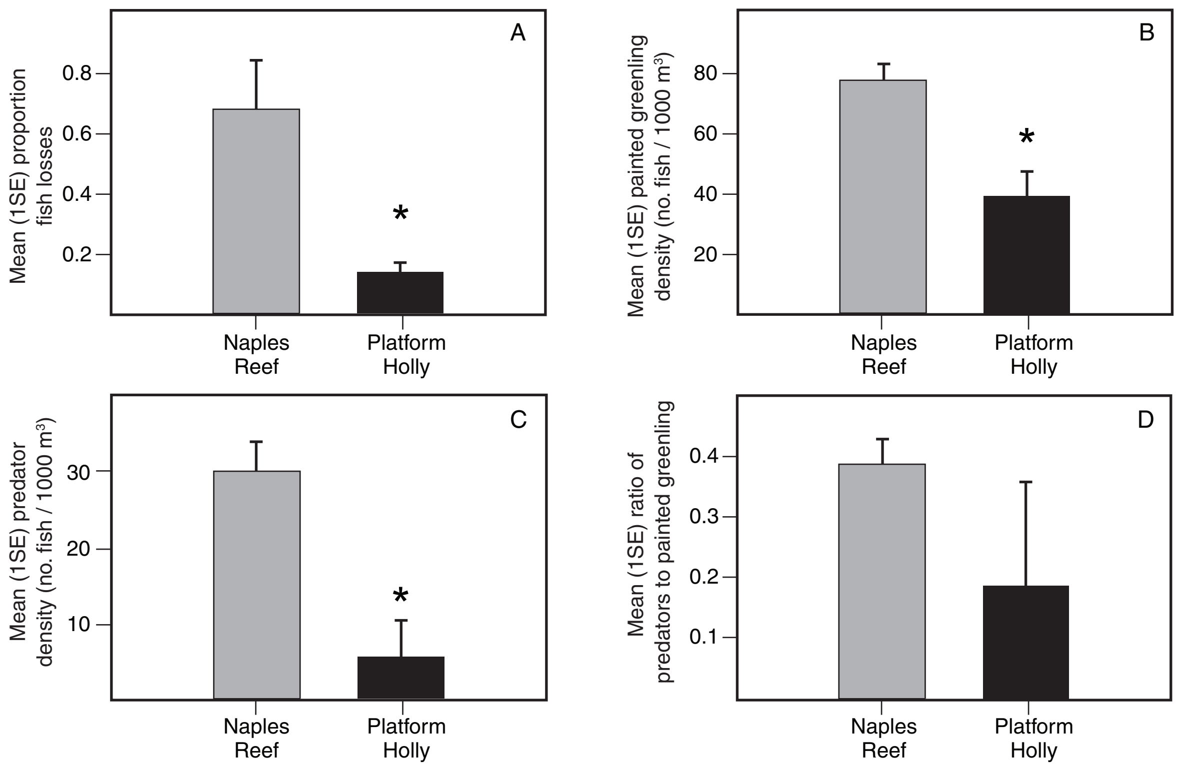

Fig. 1. Comparison of (A) mean proportion of fish losses (representing relative predation risk; n = 5), (B) painted greenling density (n = 3), (C) predator density (n = 3), and (D) predator to prey ratio (n = 3), between Naples Reef and Platform Holly. Significance levels of $p < 0.05$ are indicated by asterisks.

Discussion

The tethering experiment shows that juvenile painted greenling residing at Naples Reef experienced a relative predation rate more than 2.5 times greater than the estimated rate experienced by juveniles residing at Platform Holly. How can we interpret this result to actual differences in predation among habitat types? It is important to note that experimental predation rates are generally not equivalent to natural predation rates; the later tends to be much lower (Linehan et al. 2001). Next, we consider whether common difficulties in using tethering as an experimental approach could negate the general result of higher predation on juveniles at the natural reef.

Differences in the escape response between tethered and untethered prey could limit generality of experimental conclusions. For example, some studies found that highly mobile prey made poor experimental subjects because, when tethered, they behaved in a manner that attracted predators (e.g., Zimmer-Faust et al. 1994). Painted greenling are benthic fish and tethering did not produce obvious anomalous behavior. When tethering trials were terminated, remaining fish were observed quiescent on the bottom much like free-ranging fish. Further, the video tape record of an untethered fish being eaten by a piscivore before a nearby tethered fish supports the supposition that behavior was not dramatically altered in this experiment.

Another criticism of tethering is that the technique promotes predation by novel species. In particular, tethered fish may be more susceptible to predation by aggressive invertebrates such as crabs (Curran and Able 1998, Linehan et al 2001, Adams et al. 2004). Page et al. (1998) show that Platform Holly hosts large densities rock crabs (*Cancer* spp.). If these crabs preyed upon tethered painted greenling, it would not have changed the conclusion of a lower relative predation rate at Platform Holly compared to Naples Reef.

An implicit assumption of tethering experiments is that second-order interactions do not affect results (Peterson and Black, 1994, Halpin 2000). That is, any artifact of tethering prey is equivalent across treatments. Problems arise if there is an interaction between habitat and the degree to which a tethering artifact is expressed. For instance, Adams et al. (2004) show that tethered prey often became entangled in seagrass (further restricting prey movement and increasing risk) but not in other habitat types. In this study, fish may have more easily broken free from their tethers at Platform Holly than at Naples Reef due to higher current flow and presence of sharp-edged mussel shells which could increase the chance of line abrasion. Escaped fish would be recorded as fish losses and artificially enhance estimates of predation rate. But if either of these interactions occurred, it would have not altered the general conclusion of a higher relative predation rate at Naples Reef.

A number of studies show that mortality rates of juvenile reef fishes are higher when predatory fishes are abundant (Connell 1996, Beets 1997, Stewart and Jones 2001, Webster 2002, but see also Nakamura and Sano 2004). Connell (1997) experimentally demonstrated that tethered juvenile fishes on small artificial reefs, where there are few predators, also had higher survivorship rates than juveniles on natural reefs. Caution must be used in interpreting these results as a large number of predators does not necessarily translate into higher mortality; there must be an increase in encounter, strike or success rate (Holling 1959). A higher risk of predation at Naples Reef corresponded to a higher predator density, and a higher number of predator species. However, the ratio of predator to juvenile painted greenling were not different between habitats (although statistical power was weak). This result suggests that the relative predation risk among habitat types may depend in part upon the habitat-specific suite of predators. Fish assemblages (including piscivore density) show a great deal of variability among platforms and decommissioning decisions can affect these assemblages (Schroeder and Love 2004). Thus, the ecological performance of platform structure as juvenile fish habitat should be considered a dynamic property that will be impacted by the decommissioning process.

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