



Effect of Offshore Oil Platform Structures on the Distribution Patterns of Commercially Important Benthic Crustaceans, with Emphasis on the Rock Crab

Final Technical Summary

Final Study Report



**U.S. Department of the Interior
Minerals Management Service
Pacific OCS Region**

Effect of Offshore Oil Platform Structures on the Distribution Patterns of Commercially Important Benthic Crustaceans, with Emphasis on the Rock Crab

Final Technical Summary

Final Technical Report

Authors

**H. Mark Page
Jenifer Dugan
Principal Investigators**

Prepared under MMS Cooperative
Agreement No. 14-35-0001-30758, Task # 12391
by
Coastal Marine Institute
Marine Science Institute
University of California
Santa Barbara, CA 93106

Disclaimer

This report has been reviewed by the Pacific Outer Continental Shelf Region, Minerals Management Service, U.S. Department of the Interior and approved for publication. The opinions, findings, conclusions, or recommendations in this report are those of the author, and do not necessarily reflect the views and policies of the Minerals Management Service. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use. This report has not been edited for conformity with Minerals Management Service editorial standards.

Availability of Report

Extra copies of the report may be obtained from:

U.S. Dept. of the Interior
Minerals Management Service
Pacific OCS Region
770 Paseo Camarillo
Camarillo, CA 93010
phone: 805-389-7621

Suggested Citation

The suggested citation for this report is:

Page, H.M. and J. Dugan. Effect of Offshore Oil Platform Structures on the Distribution Patterns of Commercially Important Benthic Crustaceans, with Emphasis on the Rock Crab. MMS OCS Study 99-0018. Coastal Research Center, Marine Science Institute, University of California, Santa Barbara, California. MMS Cooperative Agreement Number 14-35-0001-30758. 26 pages.

Table of Contents

FINAL TECHNICAL SUMMARY	1
FINAL TECHNICAL REPORT	7
Introduction	7
Materials and Methods	9
Study Site	9
Invertebrate Community and Faunal Litterfall	10
Species, Size, and Relative Abundance of Crabs: Benthos	10
Recruitment of Crabs to the Platform	11
Species, Size, Density, and Growth of Crabs: Platform Structure	11
Statistical Analyses	12
Results	12
Platform Invertebrate Community and Faunal Litterfall to the Benthos	12
Distribution and Abundance of Crabs: Benthos	12
Population Characteristics of Crabs: Benthos	15
Recruitment of Crabs to the Platform	16
Distribution and Abundance of <i>C. antennarius</i> : Platform Structure	17
Population Characteristics and Growth of <i>C. antennarius</i> : Platform Structure	18
Discussion	18
References	24

ACKNOWLEDGEMENTS

Thanks also to numerous divers and laboratory assistants, including but not limited to C. Culver, R. Fink, J. Flattery, M. Meeker, M. Newnham, N. Quinn, and K Schmitt. G. Olivera (Mobil), J. MacDonald (Mobil, Venoco), and T. Martinez, (Venoco) and the crew of the "Smith Tide" facilitated access to Platform Holly. M. Love supplied the videotape taken by the Delta submersible of the bottom beneath the platform. P. Freeman, C. Graham, T. Luna, and C. Smith, and the Santa Barbara Fishermen's Association reported the capture of tagged crabs.

FINAL TECHNICAL SUMMARY

STUDY TITLE: Coastal Marine Institute, Task 12391: Effect of Offshore Oil Platform Structures on the Distribution Patterns of Commercially Important Benthic Crustaceans, With Emphasis on the Rock Crab

REPORT TITLE: Effect of Offshore Oil Platform Structures on the Distribution Patterns of Commercially Important Benthic Crustaceans, With Emphasis on the Rock Crab

CONTRACT NUMBER: 14-35-0001-30758

SPONSORING OCS REGION: Pacific

APPLICABLE PLANNING AREA: Southern California

FISCAL YEAR(S) OF PROJECT FUNDING: FY95, FY96

COMPLETION DATE OF THE REPORT: January 1999

COST(S): FY 95 - \$20,850, FY 96 - \$9,000

CUMULATIVE PROJECT COST: \$29,850

PROJECT MANAGERS: H. Mark Page, Jenifer Dugan

AFFILIATION: Marine Science Institute, University of California, Santa Barbara

ADDRESS: Marine Science Institute, University of California, Santa Barbara, CA 93106

PRINCIPAL INVESTIGATORS: H. Mark Page, Jenifer Dugan

KEY WORDS: Santa Barbara Channel, oil platform, crabs, Cancridae, Majidae, benthos, soft-bottom, mussels, mussel mound

BACKGROUND: Offshore oil platforms act as artificial reefs which provide habitat for mussels, encrusting bivalves, sea anemones and other invertebrates. These structures are also sites of aggregation and/or production of sport and commercially important fish species. Studies of artificial reefs, in general, have centered on whether they attract or produce sport and commercially important fishes. We tested elements of a conceptual model describing possible interactions between offshore platforms and commercially important crab stocks based on ideas developed for fish populations and fishery refugia.

We hypothesized that the distribution and abundance of highly mobile, commercially important crab species fit into one of four scenarios: 1) "recruitment/emigration" scenario - a platform provides recruitment habitat and individuals that recruit to the platform emigrate at some point to the surrounding environment, contributing to the regional production of a species. This scenario is similar to a hypothesis reviewed in Bohnsack (1989) that describes production of new biomass. 2) "recruitment/resident" scenario - platform provides recruitment habitat, but individuals remain in the vicinity of the structure, forming a resident population; 3) "attraction" scenario - individuals that recruited elsewhere are attracted to and aggregate at the platform; and 4) "visitor" scenario - individuals that recruited elsewhere occur temporarily at the platform without aggregation.

OBJECTIVES: 1) Test whether commercially important crab species occurred in higher densities beneath a platform compared to adjacent soft bottom; 2) characterize spatial and temporal patterns of crab recruitment to a platform, including the importance of the platform invertebrate community as potential habitat and source of food for crabs; and 3) evaluate our data in the context of the four scenarios described above that reflect different combinations of recruitment, and of distribution and abundance of mobile species around oil platforms.

DESCRIPTION: This study was conducted ~3 km offshore of Goleta, California ($34^{\circ}25'N$; $119^{\circ}52'W$), in the Santa Barbara Channel at and in the vicinity of Platform Holly (Mobil, Venoco). To characterize the invertebrate community as potential habitat and source of food for crabs, community thickness was determined monthly on randomly selected conductor pipes at four depths (6, 12, 18, 24 m) from August 1995 through August 1996. From October 1995 through August 1996, faunal litterfall from conductor pipes to the benthos was measured monthly using traps. The traps, consisting of 38 cm internal diameter plastic circular hoops with attached 1.4 mm mesh bags, were suspended at a depth of 18 m between pairs of pipes. Wet biomass of the contents of the traps was determined using a spring scale after draining the sample of excess water. Displacement volume was measured for some samples by water displacement in a calibrated bucket.

Baited traps were used to evaluate the effect of location (beneath the platform versus soft bottom) and time-of-year on the abundance of adult crabs. From July 1995 through August 1997 traps were deployed monthly beneath the platform and retrieved after a 22 to 24 hour soak time. From October 1995 through May 1997 traps were deployed on soft bottom every two months ~200 m east, south, and west of the platform. Crabs in the traps were identified to species and sex, measured, and the presence of eggs recorded. Trapping results are expressed as catch per unit effort (CPUE).

Video recordings taken from a manned submersible (Delta) on October 29, 1996 provided qualitative information on bottom topography and semi-quantitative information on the abundance of adult cancrid and majid crabs on the bottom. Crabs in the video within an ~2 m wide swath along each of the four sides of the structure were counted and identified to genus or species where possible.

To assess potential movement of crabs between the platform and surrounding benthic habitats, all cancrid crabs >95 mm were tagged ~1 cm from the right margin of the epimeral suture with individually labeled yellow T-bar anchor tags (Floy FD-94) and released at the site of capture.

We deployed recruitment cages (12 x 30 cm cylinders, 12 mm mesh vexar) to measure spatial and temporal variation in the recruitment of crabs to the platform. We filled each cage with 5 kg of mussel community at depths of 12, 18, 24, and 64 m from March 1996 to September 1997. We retrieved the cages bimonthly and the mussel community was removed and searched. Crabs within the cages were identified to species and sex (where possible), and measured. Crabs also were sampled on conductor pipes at three depths (12, 18, 24 m) using SCUBA every other month from October 1995 to November 1996 and monthly from

December 1996 to July 1997. Two divers searched a 0.82 x 2.46 m (2 m^2) area crabs removed by hand. In addition, crabs concealed within the mussel community at 12 m were sampled by removing 5-10 kg of mussels at each station into 1.4 mm mesh bags. Crabs in the samples were identified to species and sex (where possible) and measured. Crab density was standardized to 5 kg wet weight of mussel community, or to area (m^2). To measure the growth rate of *C. antennarius* at the platform, crabs were enclosed in cages filled with mussel community. The cages were attached to the platform at a depth of ~9 m and the crabs measured monthly.

The effects of independent variables (e.g., depth, time, location) on the dependent variables (e.g., invertebrate community thickness, CPUE) were evaluated using analysis of variance (ANOVA). Tests for differences in the relative abundance of crab species between depths of 9 and 64 m were made using a paired t-test by sampling date. A Chi-square test was used to test for significant deviations from a predicted proportion of 0.50 male individuals for each species.

SIGNIFICANT CONCLUSIONS: Three species of *Cancer* (*Cancer antennarius*, *C. anthonyi*, *C. productus*) and the majid crab, *Loxorhynchus grandis*, were caught in traps deployed on the bottom. None of the crab species clearly fit the recruitment/emigration scenario. Although *Cancer antennarius* recruits to the platform, emigration of this species from the platform appears limited. There was no evidence of large scale movement of this crab from the platform into the surrounding soft bottom habitat and a behavioral preference for hard substrate may preclude such movement. *C. anthonyi* most closely fits the attraction scenario with movement between the platform and surrounding habitat. The attraction of primarily female *C. anthonyi* to the platform during the winter and spring months, may involve seasonal changes in habitat use related to reproduction; behavior that has not been invoked previously to explain patterns of aggregation around artificial structures. The distribution and abundance of *C. productus* and *L. grandis* most closely fit the visitor scenario. *C. productus* is present in low densities throughout the year while *L. grandis* is present seasonally. Our results, in the context of these scenarios, reflect interspecific differences in patterns of abundance, recruitment, and behavior, and illustrate the need to consider the responses of individual species to artificial structures such as oil platforms.

STUDY RESULTS: The invertebrate community on platform conductor pipes varied in thickness with depth and time. Thickness was greatest over time at a depth of 12 m (11.0 to 18.1 cm) and least at depths of 18 and 24 m (3.3 to 7.5 cm). Rates of faunal litterfall to the benthos varied over time, ranging from 0.08 to 2.60 kg wet weight•trap⁻¹•week⁻¹. Dislodged clumps of *M. galloprovincialis* formed 92.8% of this material.

Video recordings from the submersible showed that the topography of mud soft bottom beneath the platform is covered by a mound of mussel shells and other debris with an estimated height of 3 to 4 m. The mound was highest towards the west and north side of the platform. Mud substratum was visible on the east side of the platform.

The mean CPUE of *Cancer antennarius* over time was much higher beneath the platform (1.0 to 7.5 crabs•trap⁻¹) than on surrounding soft bottom (0 to 0.7 crabs•trap⁻¹). The mean CPUE

of *C. anthonyi* was also higher at the platform (0 to 16.7 crabs•trap⁻¹) than at the soft bottom stations (0 to 3.0 crabs•trap⁻¹). No effect of location on CPUE was found for *C. productus* and *Loxorhynchus grandis*. A strong effect of time on CPUE was found for *C. anthonyi* and *L. grandis*. For *C. anthonyi*, there was a pattern of generally higher values during the winter and spring (January-May, ≥3.0 crabs•trap⁻¹) compared with summer and fall (June-November, ≤2.0 crabs•trap⁻¹). *L. grandis* were present only during the fall and winter months. There was no relationship between the monthly mean CPUE of *C. antennarius*, *C. anthonyi*, *C. productus*, or *L. grandis* beneath the platform and monthly faunal litterfall rates measured at the conductor pipes.

The number of cancrid crabs in the video recordings ranged from 0.5 crab•10 m⁻² (east, west, and south transects) to 2 crabs•10 m⁻² along the north transect. Values for *L. grandis* were variable, ranging from ~0.2 crab•10 m⁻² along the east and south transects to 2 crabs•10 m⁻² along the west and north transects.

Seven hundred eighty cancrid crabs were tagged in this study (368 *C. antennarius*, 347 *C. anthonyi*, and 65 *C. productus*). Recapture rates were low for all species at the platform (*C. antennarius*- 1.4%, *C. anthonyi*-0.9%, *C. productus*-3.1%). No tagged individuals were recaptured at the soft bottom stations. 10 tagged *C. anthonyi* were caught in traps set by local fishermen at distances of up to 8 km from the platform and up to 1.5 years after initial tagging. No tagged individuals of the other species were reported by fishermen.

All *Cancer* individuals captured in traps on the bottom were adults. At the platform, the proportion of male crabs (number of male crabs/total number of trapped crabs) of *C. antennarius* (0.34), *C. anthonyi* (0.13) and of *C. productus* (0.10) differed significantly from 0.50. At the soft bottom stations, the proportion of male crabs was not significantly different from 0.50 for *C. antennarius* and *C. productus* or biased towards male crabs for *C. anthonyi* (0.76). A trend of more male than female *L. grandis* were trapped at both platform (0.89) and soft bottom (0.85) locations.

Only 1.8% (n=169) and 8.3% (n=12) of female *C. antennarius* were ovigerous beneath the platform and on the structure, respectively. The percent of female *C. anthonyi* that were ovigerous ranged from 0% in Summer and Fall to 28 and 37%, respectively in Winter 1996, and Spring 1997 and was positively correlated with the CPUE of females beneath the platform (excluding the outlying mean value of 15.3 crabs/trap in November 1995).

Only *C. antennarius* recruited onto the platform. Recruitment was clearly seasonal; crabs ≤10 mm CW were most abundant during late Spring and Summer. In the recruitment cages, there were no differences in the densities of crabs ≤10 mm CW with depth. In addition, only *C. antennarius* were observed in visual surveys on the platform. There was no effect of time or depth (12, 18 and 24 m) on crab density which, for grouped data, averaged 0.8 crab•m⁻². If data from mussel community samples and visual surveys are combined, the density of crabs was dramatically higher at 12 m than at 18 or 24 m during late Spring and early Summer due to crab recruitment. The rate of growth of *C. antennarius* in cages at the platform was two to three times faster than rates reported previously for this species.

STUDY PRODUCTS:

Presentations:

Page, H., J. Dugan, D. Dugan, and J. Richards. 1997. Commercially important crabs and offshore oil and gas platforms. Platform Decommissioning Workshop, MMS/California State Lands Commission, Ventura, California. (poster).

Page, H. M., J. Dugan, D. Dugan, and J. Richards. 1997. Distribution of rock and sheep crabs in relation to an offshore platform. Annual meeting of the Western Society of Naturalists, Monterey, California.

Publications:

Page, H. M., J. E. Dugan, D. Dugan, and J. Richards. Effects of an offshore oil platform on the distribution and abundance of commercially important crab species. *Marine Ecology Progress Series*. In press.

Dugan, D. S. *An investigation of the population structure and growth rate of the brown rock crab, Cancer antennarius, on an offshore oil platform*", Masters Thesis, California State Polytechnic University, San Luis Obispo. In preparation.

Dugan, D. S. J. E. Dugan, and H. M. Page. Population structure and growth rate of the brown rock crab, *Cancer antennarius*, on an offshore oil platform. *Target-Fishery Bulletin*. In preparation.

FINAL STUDY REPORT

INTRODUCTION

Artificial structures can dramatically alter the species composition, distribution, and abundance of local invertebrate and fish fauna. Typically located on soft mud or sand bottom, artificial structures provide hard attachment sites for sessile invertebrates and may attract and aggregate mobile invertebrates and fishes (e.g., Wolfson *et al.* 1979, Davis *et al.* 1982, Bohnsack 1989, Love *et al.* 1994, Herrnkind *et al.* 1997). Observations of aggregations of fishes around artificial reefs and oil platforms, in particular, have fueled the "production versus attraction" controversy. Do these structures enhance the recruitment, growth, and/or survival of individuals or do they simply attract and concentrate individuals from surrounding habitat (e.g., Reggio 1989, Bohnsack *et al.* 1997, Carr and Hixon 1997, Herrnkind *et al.* 1997, Lindberg 1997)?

Offshore oil and gas platforms are among the largest artificial structures in the marine environment. It has been proposed in the "rigs to reef" concept that obsolete oil and gas structures can serve as artificial reefs (Reggio 1987). Obsolete structures are cropped or toppled in place or towed and submerged in a different location, providing hard substrata in a typically soft bottom environment. However, the "rigs to reef" concept is controversial. While sport fishermen typically support the concept because of the apparent aggregation of fishes around these structures, many commercial fishermen prefer platform removal due to the potential of fouling gear and loss of access (MMS/State Lands Commission 1994). Part of the controversy exists because of a lack of information on the mechanisms by which active oil platforms, *de facto* artificial reefs, affect the distribution and abundance of sport and commercially important species.

Three species of commercially important cancrid crabs (*Cancer antennarius*, *C. anthonyi*, *C. productus*), and the majid crab, *Loxorhynchus grandis*, are fished in the vicinity of platforms offshore of southern California (USA). Platforms may affect the distribution and abundance of these large, mobile crustaceans through the alteration of physical habitat and local infaunal and epifaunal benthic communities. Support members, conductor pipes, and attached invertebrate community on platforms may provide potential habitat and/or food for crabs. The attached invertebrate community is often many centimeters thick on platforms along the central and south coast of California; many of the species (e.g., *Mytilus californianus*, *M. galloprovincialis*, *Pollicipes polymerus*) are also components of rocky and pier piling intertidal and subtidal communities (Bascom *et al.* 1976, Stimpson 1977, Wolfson *et al.* 1979, Page 1986, Page and Hubbard 1987).

Food availability and habitat heterogeneity beneath a platform may also attract crabs. Clumps of mussel community, dislodged from the platform structure, fall to the bottom as "faunal litterfall". Over time, faunal litterfall creates a "shell mound" extending in height several meters off the original bottom (reviewed in MBC 1987). The shell mound provides hard attachment sites, microhabitats, and food for an assemblage of invertebrate species typically not present on soft bottom. For example, Wolfson *et al.* (1979) reported unusually high densities of echinoderms (e.g., *Pisaster* spp., *Patiria miniata*) beneath platform Eva, 3 km

offshore of Huntington Beach, southern California ($33^{\circ}40'N$, $118^{\circ}93'W$) feeding on mussels dislodged from the structure.

Based on our preliminary observations and on ideas developed for the potential effects of artificial reefs on fish populations (Bohnsack and Sutherland 1985, Bohnsack 1989), we hypothesized that the distribution and abundance of highly mobile, commercially important crab species may fit into one of four scenarios (**Figure 1**). In the "recruitment/emigration" scenario, a platform provides recruitment habitat and individuals that recruit to the platform emigrate at some point to the surrounding environment, contributing to the regional production of a species. There may be no way of knowing whether the recruitment of these individuals would have occurred elsewhere, but this scenario is closest to the production of new biomass hypothesis reviewed in Bohnsack (1989). In the "recruitment/resident" scenario, the platform also provides recruitment habitat, but individuals remain in the vicinity of the structure, forming a resident population. In the "attraction" scenario, individuals that recruited elsewhere are attracted to and aggregate at the platform. The attraction scenario could also lead to increased regional production through, for example, the increased growth rate and/or survival of individuals while at the structure. This pattern may occur seasonally or throughout the year. Finally, in the "visitor" scenario, individuals that recruited elsewhere occur temporarily at the platform without aggregation; these individuals may also be present seasonally or throughout the year .

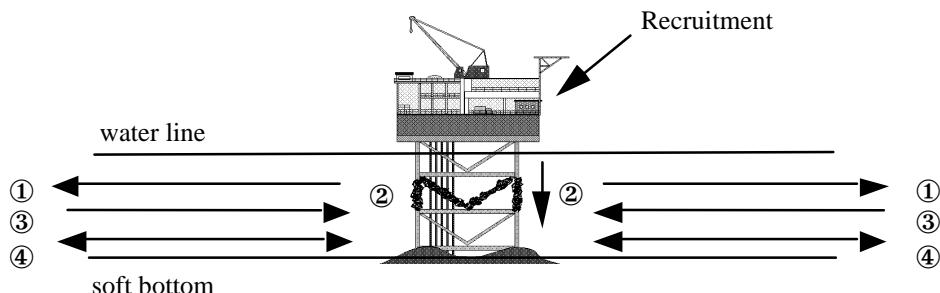


Figure 1. Diagram illustrating four possible distribution and abundance scenarios for large mobile crab species relative to an offshore oil platform. 1) "recruitment/emigration"-recruitment to platform; emigration from platform, 2) "recruitment/resident"-recruitment to platform; resident population, 3) "attraction"-attraction of individuals that recruited elsewhere, 4) "visitor"-individuals that recruited elsewhere occur temporarily at the platform without aggregation.

The objectives of our study, emphasizing commercially important crab species, were to: 1) test whether crabs occurred in higher densities beneath a platform compared to adjacent soft bottom, 2) characterize spatial and temporal patterns of crab recruitment to a platform, including the importance of the platform invertebrate community as potential habitat and source of food for crabs, and 3) evaluate our data in the context of the four scenarios described above that reflect different combinations of recruitment, and of distribution and abundance of mobile species around oil platforms.

MATERIALS AND METHODS

Study Site

This study was conducted ~3 km offshore of Goleta, California ($34^{\circ}25'N$; $119^{\circ}52'W$), in the Santa Barbara Channel at and in the vicinity of the oil and natural gas platform "Holly" (Mobil, Venoco: **Figure 2**). The platform is 19 x 36 m at the water line. Bottom depth at the platform is ~66 m.

Support members and conductor pipes are covered intertidally and subtidally by a community of sessile and semi-mobile invertebrates. On Platform Holly, mussels contributed most to community biomass to a depth of ~12 m while barnacles (e.g. *Megabalanus californicus*, *Balanus aquila*), encrusting bivalves (e.g. *Chama arcana*, *Crassadoma gigantea*), and anemones (*Metridium senile*), were more abundant deeper. *Mytilus galloprovincialis*, comprised nearly 100% of the mussels at depths shallower than ~6 m while large clumps of *M. californianus* were present between 9 m and 12 m. Thirty conductor pipes (each 160 cm in diameter) arranged in three rows of 10 pipes one meter apart provided replicate surfaces for measurements of invertebrate community thickness and the sampling of crabs on the structure.

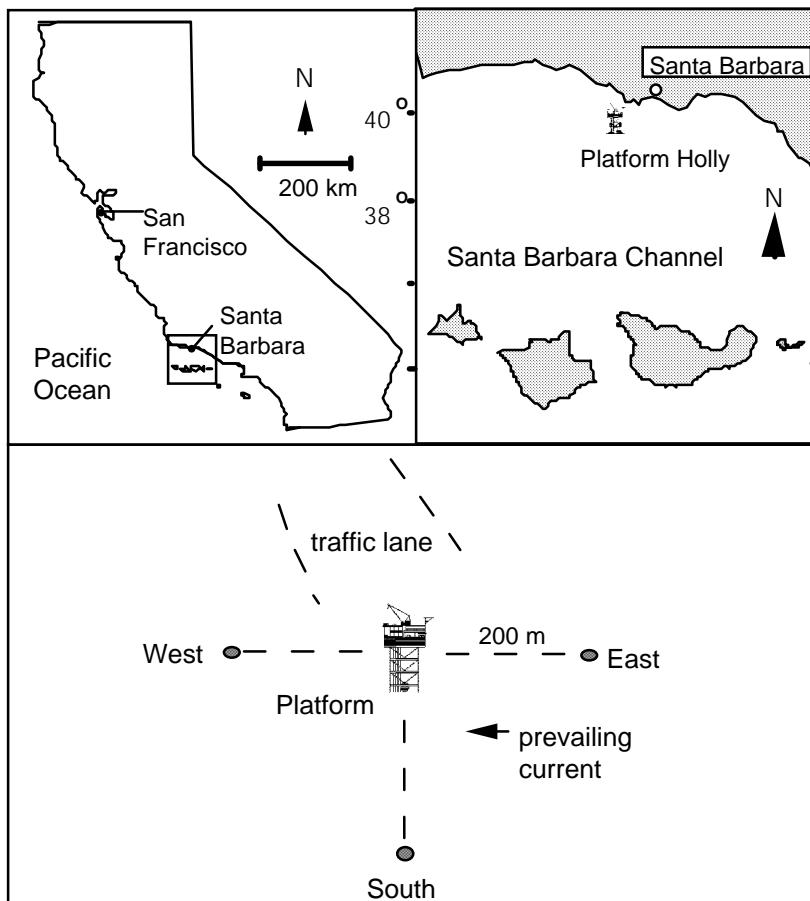


Figure 2. Map showing the location of the oil and natural gas platform study site in the Santa Barbara Channel and the arrangement of sampling stations around the platform.

Invertebrate Community and Faunal Litterfall

To characterize the invertebrate community as potential crab habitat, we determined community thickness on randomly selected conductor pipes ($n=4$) monthly at four depths (6, 12, 18, 24 m) from August 1995 through August 1996. Measurements of circumference were converted to estimates of radius ($r=C/2\pi$). Invertebrate community thickness was calculated as the difference between the radius of a conductor pipe with and without the attached invertebrates.

To estimate rates of faunal litterfall from conductor pipes to the benthos, traps ($n=3$) were suspended between pairs of pipes at a depth of 18 m and retrieved monthly from October 1995 through August 1996. The traps consisted of 38 cm internal diameter (area= 0.113 m^2) plastic circular hoops with attached 1.4 mm mesh bags. Since faunal litterfall consisted primarily of mussels and associated epifauna by weight (e.g., attached barnacles, anemones), the contents of the bags were sorted by mussel species (*Mytilus californianus* or *M. galloprovincialis*). Wet biomass of each mussel species and associated epifauna was determined using a spring scale after draining the sample of excess water. Displacement volume was measured for some samples by water displacement in a calibrated bucket.

Video recordings taken from a manned submersible (Delta) on October 29, 1996 provided qualitative information on bottom topography. The video recordings were taken along the north, south, east, and west outer margins of the structure.

Species, Size, and Relative Abundance of Crabs: Benthos

Baited traps (Fathom Plus) were used to evaluate the effect of location (immediately beneath the platform versus soft bottom) and time-of-year on the abundance of adult crabs. The traps were baited with a total of 1.4 kg of coarsely chopped mackerel (*Scomber japonicus*) enclosed in two vexar mesh containers (mesh size= ~5 mm). Traps were deployed monthly beneath the platform from July 1995 through August 1997 ($n=4$ traps) and retrieved after a 22 to 24 hour soak time. Because of prevailing westerly currents, traps were deployed along the west side of the platform to prevent entanglement in the structure. Traps were deployed on soft bottom every two months ~200 m east, south, and west of the platform from October 1995 through May 1997 ($n=3$ traps at each location: **Figure 2**). Depth of the bottom at these stations ranged from ~60 to 64 m. The crewboat transportation corridor along the north side of the platform precluded deployment of traps at this location.

Crabs in the traps were identified to species and sex, measured, and the presence of eggs recorded. For cancrid crabs, carapace width (CW) was measured as the distance to the nearest 1 mm between the outermost anterolateral teeth. For majid crabs, carapace length (CL) was measured to the nearest 1 mm from the notch in the rostrum to the posterior end of the carapace. Trapping results are expressed as catch per unit effort (CPUE).

Video recordings taken from the submersible also provided semi-quantitative information on the abundance of adult cancrid and majid crabs on the bottom. Crabs in the video within an ~2 m wide swath along each of the four sides of the structure were counted and identified to genus or species where possible.

To assess potential movement of crabs between the platform and surrounding benthic habitats, all cancrid crabs >95 mm were tagged ~1 cm from the right margin of the epimeral suture with individually labeled yellow T-bar anchor tags (Floy FD-94) and released at the site of capture.

Recruitment of Crabs to the Platform

To measure spatial and temporal variation in the recruitment of crabs to the platform, we deployed recruitment cages (12 x 30 cm cylinders of 12 mm mesh vexar) filled with 5 kg of mussel community typically found at a depth of 12 m (*M. californianus*, *M. galloprovincialis* and associated organisms) from March 1996 to September 1997. Prior to deployment, the mussel community was carefully searched and all crabs removed. The recruitment cages were attached to conductor pipes at depths of 12, 18, and 24 m, and deployed on the bottom (64 m) (n=3 to 4 at each depth). Cages were retrieved bimonthly and the mussel community removed and searched. Crabs within the cages were identified to species and sex (where possible), and measured.

Species, Size, Density, and Growth of Crabs: Platform Structure

To further examine temporal variation in the recruitment and size structure of crabs on the platform, crabs were sampled on at least four conductor pipes at three depths (12, 18, 24 m) using SCUBA every other month from October 1995 to November 1996 and monthly from December 1996 to July 1997. Conductor pipe sites were selected randomly at each depth. On the conductor pipes, a two divers searched a 0.82 x 2.46 m (2 m²) area and removed crabs by hand.

Crabs concealed within the mussel community at a depth of 12 m were sampled by removing 5-10 kg of mussels at each station into 1.4 mm mesh bags. The wet weight of *Mytilus californianus* and *M. galloprovincialis* and associated fauna was determined in the laboratory as above. Crabs in the samples were identified to species and sex (where possible) and measured. Crab density was standardized to 5 kg wet weight of mussel community, or to area (m²) using data on the volume of the mussel sample (m³) divided by the thickness of the attached community (m).

Crabs were also sampled on horizontal and diagonal support members between depths of 9 m and 18 m in February 1995, December and May 1996 and August 1997. Divers carefully searched support members and removed crabs by hand.

To compare the relative abundance of larger crabs (>80 mm CW) on the platform with the bottom, three Fathom Plus traps were deployed on horizontal members, among the conductor pipes at a depth of 9 m on seven dates from November 1995 to June 1997.

In addition, the growth rate of *Cancer antennarius* on the platform was estimated by enclosing crabs individually in cages. The cages (typically 38 x 14 cm, mesh size=~5 mm) were filled with mussel community found at a depth of 9 m which provided both habitat and food for the crabs. Cages were attached to the structure at a depth of ~ 9 m and checked monthly at which time the crabs were measured (CW) and the mussel community replaced. Enclosing crabs in

cages with unlimited food (clumps of mussel community) was not anticipated to artificially enhance growth since food is abundant on the platform.

Statistical Analyses

All statistical analyses were done using Systat 5.2 (Wilkinson *et al.* 1992). The effects of independent variables (i.e., depth, location, and/or time) on the dependent variables (i.e., thickness of the invertebrate community, faunal litterfall rates, and crab abundance) were evaluated using repeated measures analysis of variance (ANOVA). This statistic was appropriate since our study was restricted to one platform. Tests for differences in the relative abundance of crab species between depths of 9 and 64 m were made using a paired t-test by sampling date. Comparisons of individual mean size between locations were made for each crab species with unpaired t-tests. Data were log transformed ($x' = \log_{10}(x+1)$) prior to analysis to correct for heteroscedasticity (Zar 1984). A Chi-square test was used to test for significant deviations from a predicted proportion of 0.50 male individuals for each species.

RESULTS

Platform Invertebrate Community and Faunal Litterfall to the Benthos

The invertebrate community on platform conductor pipes varied in thickness with depth and time (depth, $P<0.001$, $F=34.91$, $df=2$; time, $P<0.05$, $F=2.32$, $df=12$, Two-way ANOVA). Thickness was greatest over time at a depth of 12 m (11.0 ± 1.8 to 18.1 ± 1.3 cm, $x\pm1SE$) and least at depths of 18 and 24 m (3.3 ± 0.4 to 7.5 ± 0.9 cm: **Figure 3a**). The increase in mean thickness over time at 6 m, from 6.3 ± 1.2 in August 1995 to 15.3 ± 0.4 cm in August 1996 reflects the recolonization of conductor pipes by mussels (primarily *M. galloprovincialis*) following a maintenance cleaning at this depth during Summer 1995.

Rates of faunal litterfall to the benthos varied significantly over time ($P<0.05$, $F=2.77$, $df=9$, One-way ANOVA), ranging from 0.08 ± 0.03 to 2.60 ± 0.81 kg wet weight•trap $^{-1}$ •week $^{-1}$ ($x\pm1SE$: **Figure 3b**). Overall, dislodged clumps of *M. galloprovincialis* formed $92.8\pm3.3\%$ ($n=28$) of this material. The wet weight and displacement volume of mussel clumps were highly correlated and described by the following relationship: $v=0.74w-0.04$, $r^2=0.98$, $n=30$, where v =volume ($\times 10^3$ cm 3) and w =wet weight (kg).

Video recordings from the submersible showed that the topography of mud soft bottom beneath the platform is covered by a mound of mussel shells and other debris with an estimated height of 3 to 4 m. The mound was highest towards the west and north side of the platform. Mud substratum was visible on the east side of the platform.

Distribution and Abundance of Crabs: Benthos

Three species of *Cancer* (*Cancer antennarius*, *C. anthonyi*, *C. productus*) and the majid crab, *Loxorhynchus grandis*, were caught in traps deployed on the bottom. There were no significant differences among soft bottom stations in CPUE with location or time ($P>0.1$, Two-way ANOVA) and these data were pooled for each species in subsequent analyses ($n=9$ stations). There was a strong effect of location (platform versus soft bottom) on CPUE for *C.*

antennarius and *C. anthonyi* ($P<0.001$, Two-way ANOVA: **Table 1**). The mean CPUE of *C. antennarius* over time was much higher beneath the platform (1.0 ± 0.4 to 7.5 ± 2.7 crabs•trap $^{-1}$, $\bar{x}\pm1SE$) than on surrounding soft bottom (0 to 0.7 ± 0.2 crabs•trap $^{-1}$: **Figure 4a**). The mean CPUE of *C. anthonyi* was also higher at the platform (0 to 16.7 ± 1.9 crabs•trap $^{-1}$) than at the soft bottom stations (0 to 3.0 ± 0.5 crabs•trap $^{-1}$: **Figure 4b**). No effect of location on CPUE was found for *C. productus* and *L. grandis* (**Table 1**, **Figure 4c, d**).

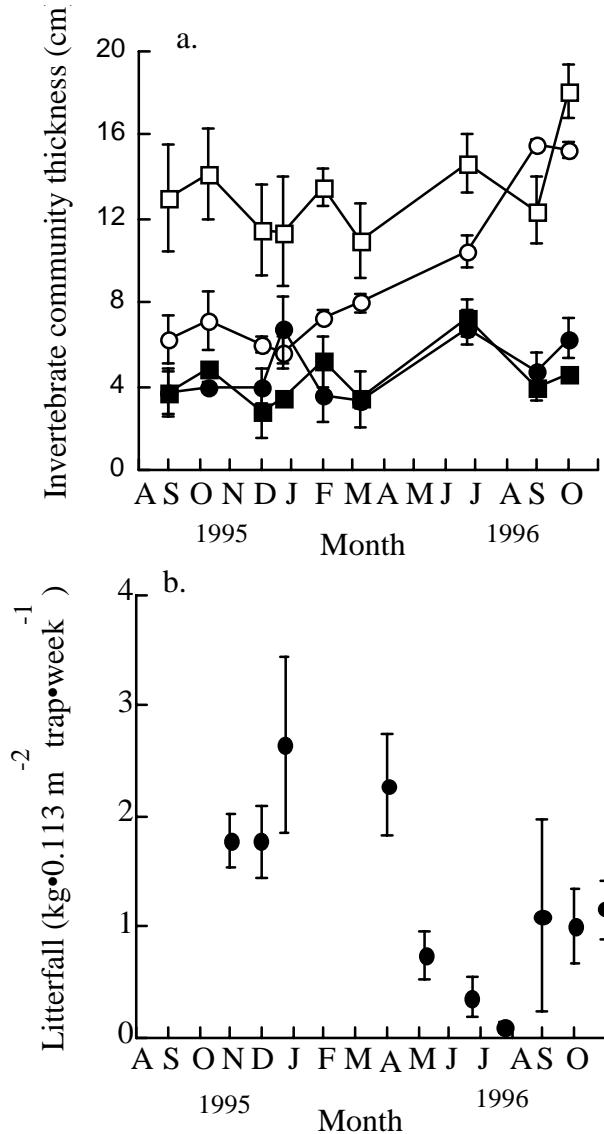


Figure 3. a) Thickness of the invertebrate community at depths of 6 m (○), 12 m (□), 18 m (●), and 24 m (■). n=4 to 6 conductor pipes, and b) faunal litterfall over time measured at a depth of 18 m, n=3 faunal litterfall traps, $x=\pm1 SE$.

Video recordings showed a patchy distribution of crabs on the mussel mound. The density of cancrid crabs ranged from 0.5 crab• $10 m^{-2}$ (east, west, and south transects) to 2 crabs• $10 m^{-2}$ along the north transect. Densities of *Loxorhynchus grandis* ranged from ~0.2 crab• $10 m^{-2}$ along the east and south transects to 2 crabs• $10 m^{-2}$ along the west and north transects.

A strong effect of time on CPUE ($P<0.01$) was found for *Cancer antennarius* and *Loxorhynchus grandis* (Table 1, Figure 4). For *C. antennarius*, there was a pattern of generally higher values during the winter and spring (January-May, $\geq 3.0 \text{ crabs} \cdot \text{trap}^{-1}$) compared with summer and fall (June-November, $\leq 2.0 \text{ crabs} \cdot \text{trap}^{-1}$). *L. grandis* were present only during the fall and winter months.

There was no correlation between the monthly mean CPUE of *Cancer antennarius*, *C. anthonyi*, *C. productus*, or *Loxorhynchus grandis* beneath the platform and monthly faunal litterfall rates measured at the conductor pipes ($r<0.4$, $df=7$).

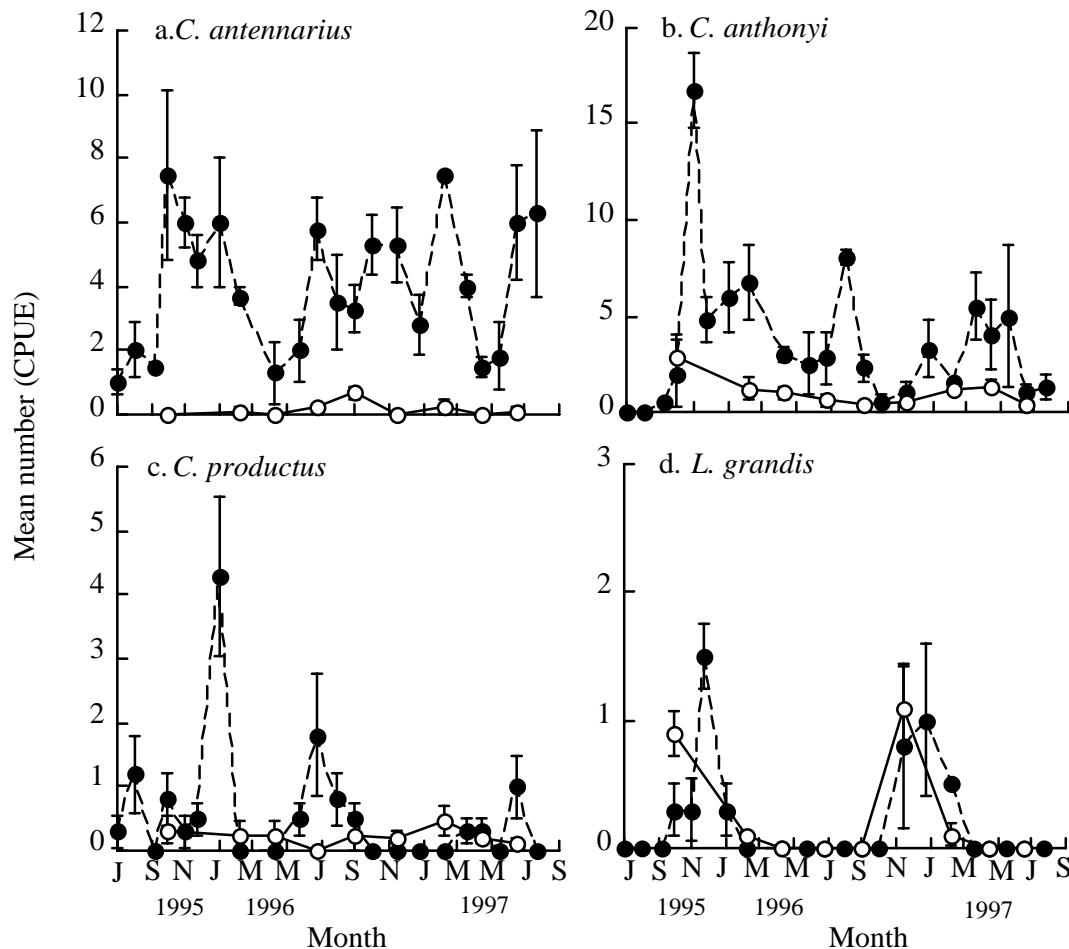


Figure 4. Spatial and temporal patterns in the abundance (express as CPUE) of, *Cancer antennarius*, *C. anthonyi*, *C. productus*, and *Loxorhynchus grandis* beneath Platform Holly and on adjacent soft bottom. Locations: Platform Holly (●), grouped soft bottom stations (○). $n=3$ to 4 traps at Holly, $n=9$ at each soft bottom stations, $x\pm 1\text{SE}$. Note differences among figures in scale of y-axis.

Seven hundred eighty cancrid crabs were tagged in this study (368 *C. antennarius*, 347 *C. anthonyi*, and 65 *C. productus*). Recapture rates were low for all species at the platform (*C. antennarius*- 1.4%, *C. anthonyi*-0.9%, *C. productus*-3.1%). No tagged individuals were recaptured at the soft bottom stations. However, by November 1997, 10 tagged *C. anthonyi* were caught in traps set by local fishermen at distances of up to 8 km from the platform and up to 1.5 years after initial tagging. No tagged individuals of the other species were reported

by fishermen. The low recapture rate of tagged individuals of all crab species is likely related to the large size of the crab populations associated with Platform Holly. Tagged *C. antennarius* survived for >6 months in flowing seawater in the University of California Marine Laboratory indicating that the tag-related mortality was very low.

Table 1. Results of repeated measures Two-way ANOVA evaluating the effect of location and time (platform versus soft bottom) on the abundance (CPUE) of *Cancer* spp. and of *Loxorhynchus grandis*. Data log₁₀(x+1) transformed prior to analysis.

Species	Location		Time		Location x Time	
	F	P	F	P	F	P
<i>C. antennarius</i>	98.33	<0.001	1.89	0.07	3.09	<0.01
<i>C. anthonyi</i>	27.13	<0.001	2.87	<0.01	4.54	<0.001
<i>C. productus</i>	0.76	>0.1	1.99	0.06	1.62	>0.1
<i>L. grandis</i>	0.12	>0.1	3.69	0.001	0.91	>0.1

Population Characteristics of Crabs: Benthos

All *Cancer* individuals captured in traps on the bottom exceeded the minimum size of maturity (*C. antennarius*-73 mm CW, Carroll 1982; *C. anthonyi*-89 mm CW, Anderson and Ford 1976; *C. productus*-70 mm CW, Orensanz and Gallucci 1988) and can be considered adults. The mean size of *C. antennarius* and *C. productus* captured in traps did not differ with sex or between platform and soft bottom locations (**Table 2**). The mean size of male *C. anthonyi* was significantly larger than that of female individuals at both platform (P<0.001, t=10.10, df=254, Student's t-test) and soft bottom locations (P<0.01, t=2.78, df=63). Female *C. anthonyi* were larger at soft bottom stations than beneath the platform (P=0.05, t=1.97, df=240).

At the platform, the proportion of male crabs (number of male crabs/total number of trapped crabs) of *Cancer antennarius* (0.34), *C. anthonyi* (0.13) and of *C. productus* (0.10) differed significantly from 0.50 (**Table 2**). In contrast, at the soft bottom stations, the proportion of male crabs was not significantly different from 0.50 for *C. antennarius* and *C. productus* or biased towards male crabs for *C. anthonyi* (0.76: **Table 2**). Although not significantly different from 0.5, a trend of more male than female *Loxorhynchus grandis* were trapped at both platform (0.89) and soft bottom (0.85) locations.

Very few *Cancer antennarius* (≥80 mm CL) were ovigerous. Overall, only 1.8% (n=169) and 8.3% (n=12) of female *C. antennarius* were ovigerous beneath the platform and on the structure, respectively. Data for *C. anthonyi* were grouped by quarter (Winter=December-February, Spring=March-May, Summer=June-August, Fall=September-November) to increase statistical power for analysis. The percent of female *C. anthonyi* that were ovigerous ranged from 0% in summer and Fall to 28 and 37%, respectively in Winter 1996, and Spring 1997. Percentage of female crabs ovigerous was positively correlated (P<0.05, r=0.83, df=6) with the CPUE of females beneath the platform, if the outlying mean value of 15.3 crabs/trap in November 1995 was excluded from the analysis.

Table 2. Population characteristics of *Cancer* spp. and *Loxorhynchus grandis*. (x_m) mean size of male crabs, carapace width for *Cancer* spp., carapace length for *L. grandis*, (x_f) mean size of female crabs, sample sizes in parentheses, ($n_m/(n_m+n_f)$) proportion of male crabs in the samples, Significance levels for Chi-square test against a theoretical proportion of 0.50 male crabs * $P<0.05$, *** $P<0.001$

Species	Platform	Location	
			Soft bottom
<i>Cancer antennarius</i>			
x_m	102±15 (110)	111±14 (16)	
x_f	103±14 (216)	104±8 (7)	
$n_m/(n_m+n_f)$	0.34***	0.70	
<i>Cancer anthonyi</i>			
x_m	143±20 (33)	136±18 (63)	
x_f	115±15 (220)	121±12 (20)	
$n_m/(n_m+n_f)$	0.13***	0.76*	
<i>Cancer productus</i>			
x_m	161±26 (5)	175±18 (8)	
x_f	151±18 (45)	150±21 (11)	
$n_m/(n_m+n_f)$	0.10***	0.42	
<i>Loxorhynchus grandis</i>			
x_m	176±16 (16)	169±16 (17)	
x_f	150 (2)	172±22 (3)	
$n_m/(n_m+n_f)$	0.89	0.85	

Recruitment of Crabs to the Platform

Of the four crab species on the benthos, only *Cancer antennarius* recruited on the platform (**Figure 5**). Recruitment was clearly seasonal; crabs ≤10 mm CW were most abundant during late spring and summer. In the recruitment cages, there were no differences in the densities of crabs ≤10 mm CW among depths of 12, 18, and 24 m ($P>0.05$, One-way ANOVA) and the data were grouped. Densities of *C. antennarius* ≤10 mm CW were generally <0.5 crabs•5 kg mussels⁻¹, but reached 11.0±5.0 and 7.1±2.8 crabs•5 kg mussels⁻¹ in June 1996 and May 1997, respectively. In the mussel community samples, densities of *C. antennarius* ≤10 mm CW were also generally <0.5 crabs•5 kg mussels⁻¹, except in June 1996 and June 1997 when values of 3.0±2.2 and 2.7±1.8 crabs•5 kg mussels⁻¹ were recorded.

Small *C. antennarius* were also found in recruitment cages deployed on the bottom. Mean number of crabs ≤10 mm CW ranged from lows of 0 to 1.7±0.9 crabs•5 kg mussels⁻¹ August 1996 through January 1997 (n=3-4 cages), to a high of 11.5 (n=2 cages) in late March 1997.

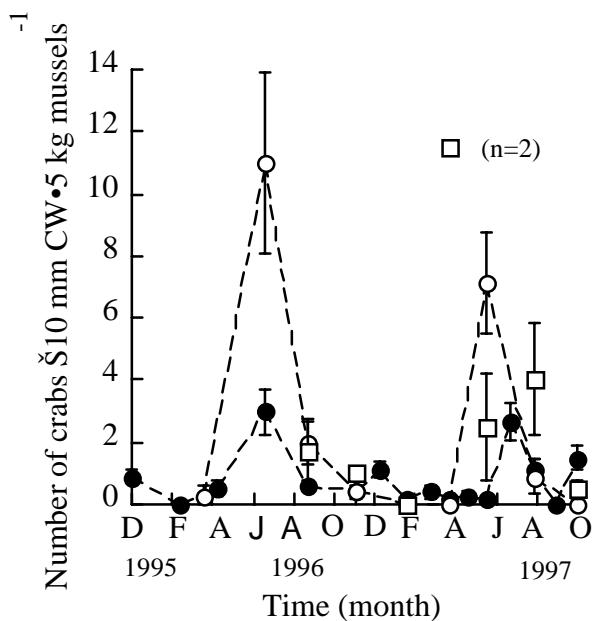


Figure 5. Mean number of *Cancer antennarius* ≤ 10 mm CW in mussel community samples from a depth of 12 m (●) and from caged mussels deployed at depths of 12, 18, and 24 m (○) and 66 m (□). n=3 to 6 samples or cages, $x \pm 1\text{SE}$.

Distribution and Abundance of *Cancer antennarius*: Platform Structure

Of the four crab species, only *C. antennarius* were observed in visual surveys on the platform. *Cancer antennarius* ≤ 10 mm CW were hidden within the mussel community and rarely observed in those surveys. The density of crabs observed in the open and collected during visual surveys ranged from 0 to 4 crabs•m $^{-2}$. There was no effect of time or depth (12, 18 and 24 m) on crab density which, for grouped data, averaged 0.8 ± 0.1 crab•m $^{-2}$ ($x \pm 1\text{SE}$, n=153 quadrats).

However, if data from mussel community samples and visual surveys are combined, the density of crabs was dramatically higher at 12 m than at 18 or 24 m during late spring and early summer due to crab recruitment. For example, the density of *C. antennarius* ranged from low mean values of 1 crab•m $^{-2}$ on 18 February 1996 and 9 crabs•m $^{-2}$ on 18 January 1997 to high values of 134 crabs•m $^{-2}$ on 25 May 1996, and 183 crabs•m $^{-2}$ on 21 June 1997.

Trapping data suggested that adult *C. antennarius* were less abundant on the structure than on the bottom. Mean CPUE values of adult *C. antennarius* ranged from 0 to 0.7 ± 0.5 crabs•trap $^{-1}$ at a depth of 6 m compared with from 2.0 ± 1.9 to 6.0 ± 1.6 crabs•trap $^{-1}$ on the bottom ($P < 0.001$, $t = 7.76$, df=20, Paired t-test: **Figure 6**).

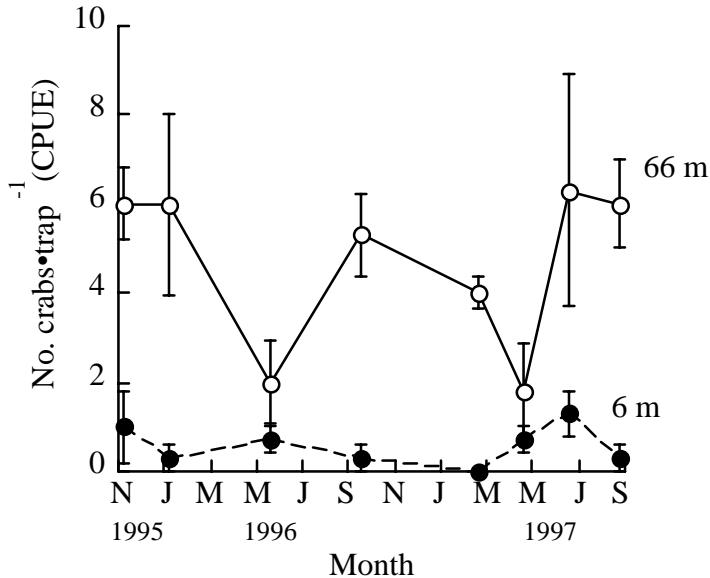


Figure 6. Comparison of the relative abundance (as CPUE) of *Cancer antennarius* (>80 mm) trapped among the conductor pipes on the structure (6 m) and on the bottom (66 m). n=3 to 4 traps at each location, x±1SE.

Population Characteristics and Growth of *Cancer antennarius*: Platform Structure

Approximately 90% of *C. antennarius* in the mussel community samples from 12 m (n=137) were ≤20 mm CW (Figure 7). Although a distinct period of recruitment into mussel clumps was evident, there were no temporal changes in the size distribution of *C. antennarius* >20 mm CW visually sampled on the structure that might reflect individual growth within this cohort, and the data were grouped across time (Figure 7). Most *C. antennarius* individuals on the structure ranged between ~30 to 70 mm CW. The proportion of male crabs collected during visual surveys (0.56, n=615) was not significantly different from 0.50 (P>0.1, Chi-square test).

The molt increment and interval of *C. antennarius* were positively correlated with size and did not differ between male and female crabs (Figure 8a, b). The calculated growth rate of *C. antennarius* in the cages attached to the structure was 2 to 3x faster than the rate reported previously for this species by Carroll (1982) (Figure 8c).

DISCUSSION

Two of the four crab species, *Cancer antennarius* and *C. anthonyi*, occurred in higher densities at the platform compared to surrounding soft bottom. The platform structure, associated invertebrate community, and the altered benthos beneath the platform could attract crabs through the provision of: 1) food; 2) recruitment habitat; 3) the preferred habitat of adults (habitat selection); and/or 4) increased shelter from predation. These possible mechanisms of attraction are discussed below.

Both *Cancer* species could be attracted to the platform by food provided by the mussel community, *Mytilus californianus* and *M. galloprovincialis*, found from the surface to depths of <12 to 15 m and, through faunal litterfall, on the bottom. Physical disturbance is an

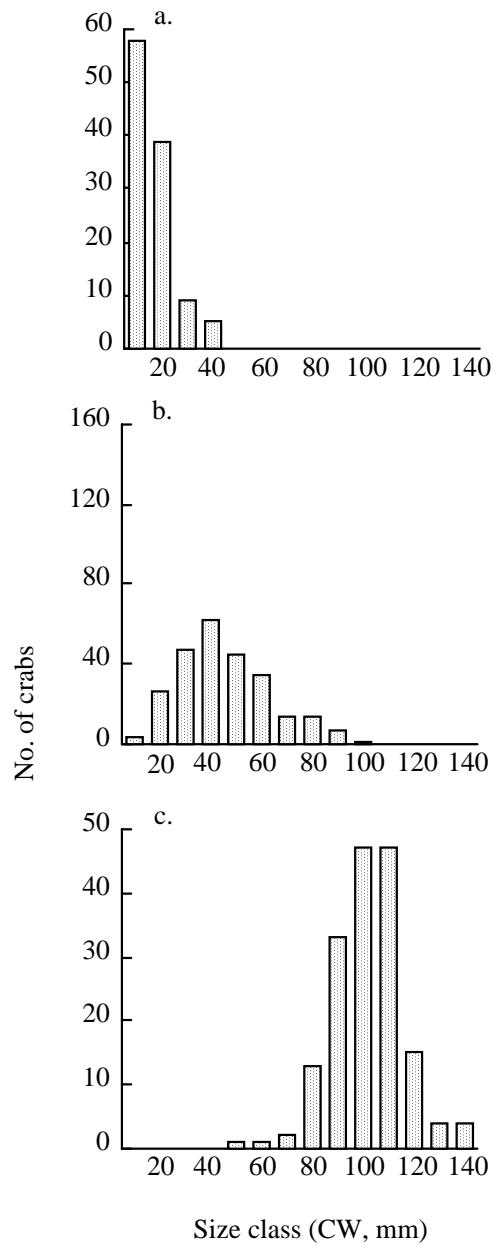


Figure 7. Size frequency distribution of *Cancer antennarius* a) within the mussel community and b) collected during visual surveys of conductor pipes and support members.

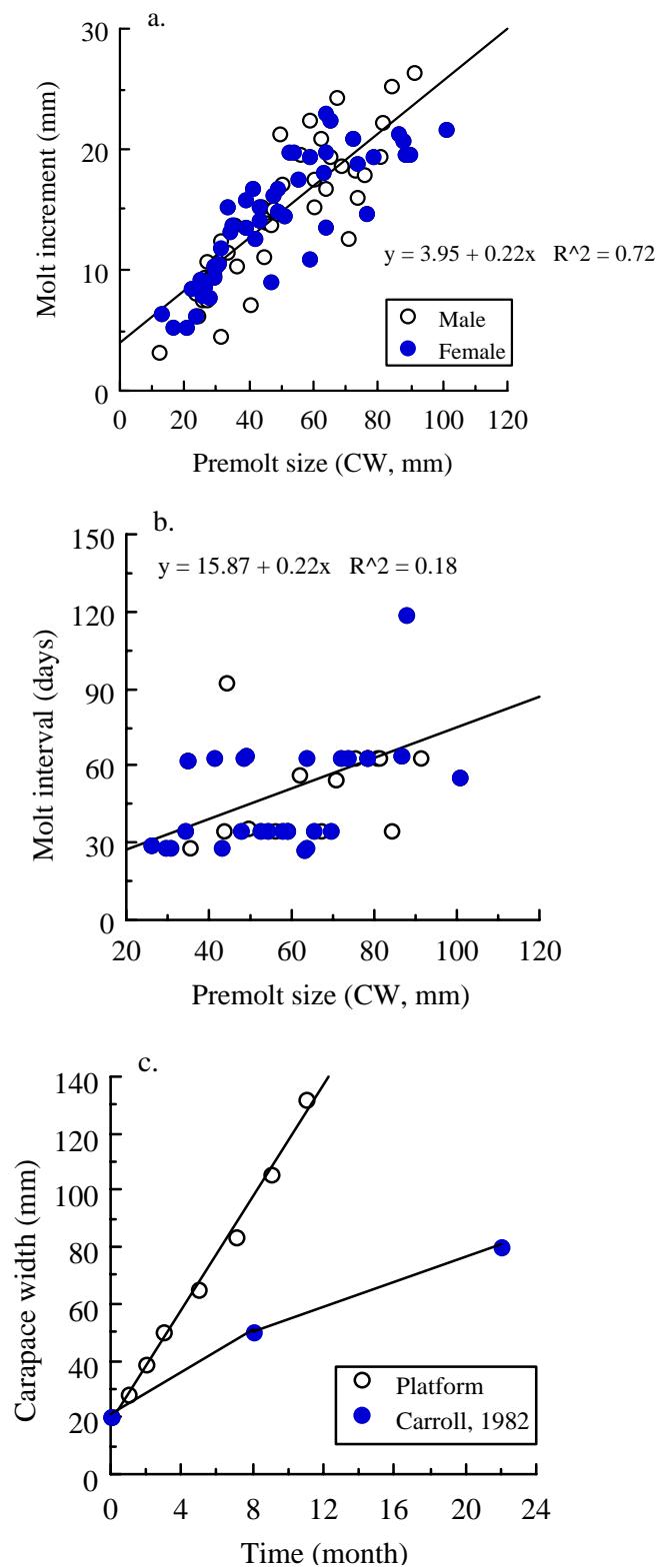


Figure 8. a) Molt increment and b) intermolt interval for *Cancer antennarius* in cages at Platform Holly, and c) constructed growth curves for *C. antennarius* at Holly and Diablo Canyon (from Carroll 1982). Lines in (c) fitted by eye.

important process that structures mussel communities in the Santa Barbara Channel. *M. californianus* has a thicker shell and reaches a much larger size than *Mytilus galloprovincialis* and is the superior competitor for primary space. However, *M. galloprovincialis* has a much higher recruitment rate and more rapid growth than *M. californianus*. Waves dislodge clumps of mussels containing both species, creating patches of open space that are rapidly colonized by *M. galloprovincialis*. Species composition shifts over time, as *M. californianus* recruit into these clumps and outcompete *M. galloprovincialis* for space (Harger 1972ab). At Platform Holly, disturbance from storm events and platform maintenance facilitated the recruitment and growth of *M. galloprovincialis* and this species was the principal biomass component of faunal litterfall. This species also has relatively weak byssal threads and is more easily dislodged by wave action than is *M. californianus* (Harger 1972ab). Faunal litterfall has greatly modified the benthic habitat beneath the platform, creating a high relief mound qualitatively similar to that reported at other platforms offshore of California (Wolfson *et al.* 1979).

Faunal litterfall is continuous though temporally variable. Using mean values ranging from 121 to 2644 g•0.113 m⁻² (**Figure 2b**), we estimate that the mussel community attached to the 30 conductor pipes contributed from 47 to 1031 kg mussels•week⁻¹ to the bottom. Since the area of the conductor pipes represents only a fraction of the total submerged surface area of the platform, rates of faunal litterfall from the entire structure would be considerably higher.

Food is abundant on the platform and faunal litterfall, though temporally variable, is continuous to the bottom. The growth of crabs should be rapid if food is abundant. Growth rates of *Cancer antennarius* on the structure were considerably higher (2 to 3x) than rates projected for this species in the rocky subtidal of Diablo Cove, California (Carroll 1982), supporting these conclusions.

However, only *Cancer antennarius* recruited to the platform. Recruitment contributed to elevated densities of small individuals of this species during the late winter and spring months. The timing of peak recruitment (late spring and early summer) is similar to that reported for this species elsewhere in southern California (Winn 1985). The presence of the smallest juvenile *C. antennarius* within mussel clumps is consistent with reports that this species recruits preferentially onto hard substrata (Winn 1985). This species is also reported to recruit preferentially in shallow water and late stage rock crab larvae (*Cancer* spp.) have been noted near the surface (Shanks 1986). There was no effect of depth (12, 18, 24, 66 m) on the density of *C. antennarius* ≤10 mm CW in recruitment cages. However, crabs could have recruited in shallow water, dropped to the bottom indirectly in association with faunal litterfall, and moved into the cages.

Recruitment cannot explain the higher densities of *Cancer anthonyi* at the platform compared to soft bottom. *C. anthonyi* megalopae have a preference for soft substrata (Winn 1985) and we hypothesize that individuals of this species recruits onto sand or mud bottom in shallow water and move into deeper water as they grow larger. Such an ontogenetic shift in habitat use exists for other *Cancer* species. For example, young-of-the year *C. magister* occur in high densities in intertidal beds of eelgrass and patches of bivalve shell fragments and move into deeper water as they grow (Stevens and Armstrong 1985, Armstrong and Gunderson 1985).

A preference for hard substrata and/or structurally complex habitats may also explain, in part, the dramatically higher densities of adult *Cancer antennarius* at the platform compared to surrounding soft bottom. Habitat use is reported to differ between adult *Cancer antennarius* and *C. anthonyi*. Winn (1985) reported that *C. antennarius* adults have a behavioral preference for hard substrata that includes rocky shores, subtidal reefs, and the interface between hard and soft bottom habitats. In contrast, *C. anthonyi* adults are reported to occur primarily on silty sand to mud substrata. This species also occurs at the interface between rocky and soft bottom habitats (Carroll and Winn 1989) and was an important component on and around experimental artificial reefs in Santa Monica Bay (Turner *et al.* 1969). The recapture of *C. anthonyi*, tagged at the platform, at a distance of several kilometers by fisherman, supports the view that this species moves between the platform and surrounding soft bottom habitat.

Two lines of evidence suggest a link between the attraction of adult *Cancer anthonyi* to the platform and the reproductive cycle of this species. First, the sex ratio of *C. anthonyi* beneath the platform was highly skewed towards female crabs (87% female), compared to the sex ratio of this species from the surrounding soft bottom (24% female). Second, peak abundance of this crab beneath the platform coincided with the peak in the percentage of ovigerous females (excluding the outlying data from November 1995).

Sex-specific differences in movement and habitat use also have been reported for other species of *Cancer*. Ovigerous *C. irroratus* are found in water <30 m deep although the distribution of this species extends from 9 to 274 m (Musick and McEachran 1972). *C. magister* is present in estuaries and along the open coast, but ovigerous females are found primarily along open coast (Armstrong and Gunderson 1985). Ovigerous *C. magister* are also reported to burrow deeply into sediments possibly as protection against predation (O'Clair and Freese 1985). Similarly, seasonal changes in the preferred habitat of female *C. anthonyi* may enhance the survival of these individuals especially when ovigerous. The greater abundance of *C. anthonyi* beneath the platform during the winter and early spring compared with summer and fall months, suggests that female crabs move seasonally between the platform and surrounding areas.

Refuges from predation could be provided by the attached invertebrate community and mussel mound. Nevertheless, small *Cancer antennarius* (<35 mm CW) are susceptible to predation by fishes (e.g., *Scorpaenichthys marmoratus*), conspecifics, and other invertebrates (e.g., *Octopus* spp.) and we hypothesize that predation on juvenile crabs strongly influences the density and size distribution of crabs on the structure. This view is supported by three lines of evidence. First, our observations of an abrupt decline in crab density at a sizes of >20 mm CW. Second, recruitment cohorts failed to affect the size distribution of crabs on the structure over time through individual growth; a pattern that reflects the decline in density of newly recruited crabs. Finally, densities of crabs ≤10 mm CW were dramatically higher in recruitment cages, protected from large predators, than in uncaged mussels. In contrast, large crabs (>100 mm) are less vulnerable to predation by fish and invertebrates (Carroll and Winn 1989) and from humans since commercial and sport fishing activity is prohibited in the vicinity of the structure.

Two crab species, *Cancer productus* and *Loxorhynchus grandis*, were caught much less frequently than were *C. antennarius* and *C. anthonyi*. Not much is known about the

abundance of these crabs. In general, *C. productus* is more abundant in northern California while *C. antennarius* and *C. anthonyi* are more abundant in southern and central California (Carroll and Winn 1989, Parker 1992). *C. productus* may prefer hard substrata (Parker 1992), but this species did not recruit or aggregate at the platform. Overall, 90% of the *C. productus* individuals trapped beneath the platform were females, compared with 58% of the crabs on soft bottom, suggesting that the behavioral patterns of female crabs of this species are similar to those of *C. anthonyi*.

Loxorhynchus grandis individuals were present at the platform and soft bottom stations only during the late fall and early winter. Most individuals (85-89%) were male. This species undergoes seasonal movements and male *L. grandis* are reported to move offshore (to depths of 50 to 60 m) in fall and winter and onshore in early spring (Culver and Kuris 1992). Female crabs may also undertake offshore movements, but to shallower depths. Both sexes migrate onshore in early spring and piles of adult female crabs surrounded by male crabs are observed at depths of 7-10 m in spring and summer. In general, larger crab species are highly mobile, capable of moving distances of several kilometers during seasonal migrations (e.g., review by Rebach 1983, Rodin 1989, Stone and O'Clair 1989). In addition, seasonal differences in the distribution of male and female crabs are common. For example, female *Paralithodes camtschatica* are less mobile and have a narrower depth distribution than male crabs, occurring in water <50 m deep during the summer and moving to deeper sites in the winter (Rodin 1989).

We hypothesized that four scenarios, describing different combinations of recruitment, could explain patterns of distribution and abundance of commercially important crabs around oil platforms (**Figure 1**). However, none of the crab species clearly fit the recruitment/emigration scenario. Although *Cancer antennarius* recruits to the platform, emigration of this species from the platform appears limited. There was no evidence of large scale movement of this crab from the platform into the surrounding soft bottom habitat and a behavioral preference for hard substrate may preclude such movement. In contrast, *C. anthonyi* most closely fits the attraction scenario with movement between the platform and surrounding habitat. The presence of primarily female *C. anthonyi* around the platform during the winter and spring months, may involve seasonal changes in habitat use related to reproduction; behavior that has not been invoked previously to explain the attraction of mobile species to artificial structures. Finally, the distribution and abundance of *C. productus* and *L. grandis* most closely fit the visitor scenario. *C. productus* is present in low densities throughout the year while *L. grandis* is present seasonally. Our results, in the context of these scenarios, reflect interspecific differences in patterns of abundance, recruitment, and behavior, and illustrate the need to consider the responses of individual species to artificial structures such as oil platforms.

REFERENCES

- Anderson, W.F. and R.F. Ford. 1976. Early development, growth and survival of the yellow crab *Cancer anthonyi* Rathbun (Decapoda, Brachyura) in the laboratory. *Aquaculture*. **7**:267-279.
- Armstrong, D.A. and D.R. Gunderson. 1985. The role of estuaries in Dungeness Crab early life history: A case study in Grays Harbor, Washington. In: *Proceedings of the symposium on Dungeness crab biology and management*. Alaska Sea Grant Report No.1 85-3, Anchorage, p. 145-170.
- Bascom, W.A., J. Mearns, and M.D. Moore. 1976. A biological survey of oil platforms in the Santa Barbara Channel. *J. Petroleum Tech.* **28**:1280-1284.
- Bohnsack, J.A. 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preference? *Bull. Mar. Sci.* **44**:631-645.
- Bohnsack, J.A. and D.L. Sutherland. 1985. Artificial reef research: a review with recommendations for future priorities. *Bull. Mar. Sci.* **37**:11-39.
- Bohnsack, J.A., A.M. Ecklund and A.M. Szmant. 1997. Artificial reef research: is there more than the attraction-production issue? *Fisheries*. **22**:14-16.
- Carr M.H. and M.A. Hixon. 1997. Artificial reefs: the importance of comparisons with natural reefs. *Fisheries*. **22**:28-33.
- Carroll, J.C. 1982. Seasonal abundance, size composition and growth of rock crab, *Cancer antennarius* Stimpson, off central California. *J. Crust Biol.* **2**:549-561.
- Carroll, J.C. and R.N. Winn. 1989. Species Profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest)--Brown Rock Crab, Red Rock Crab, and Yellow Crab. In: *US Army Corps of Engineers Report*. No. TR EL-82-4, U. S. Fish and Wildlife Service Biological Report. 82 (11.117).
- Culver, C.S. and A.M. Kuris. 1992. Sheep crab. In: Leet, W.S., C.M. Dewees and C.W. Haugen (eds). *California's living marine resources and their utilization*. California Sea Grant, Sea Grant Extension Publication UCSGEP-92-12, p. 20-22.
- Davis, N.G., R. VanBlaricom and P.K. Dayton. 1982. Man-made structures: effects on adjacent benthic communities. *Mar. Biol.* **70**:295-303.
- Harger, J.R.E. 1972a. Competitive coexistence: maintenance of interacting associations of the sea mussels *Mytilus edulis* and *Mytilus californianus*. *Veliger*. **14**:387-410.
- Harger, J.R.E. 1972b. Competitive coexistence among intertidal invertebrates. *Amer. Sci.* **60**:600-607.
- Herrnkind, W.F., M.J. Butler IV and J.H. Hunt. 1997. Can artificial habitats that mimic natural structures enhance recruitment of Caribbean spiny lobster? *Fisheries*. **22**:24-27.
- Lindberg, W.J. 1997. Can science resolve the attraction-production issue? *Fisheries*. **22**:10-13.

- Love, M., J. Hyland, A. Ebeling, T. Herrlinger, A. Brooks and E. Imamura. 1994. A pilot study of the distribution and abundances of rockfishes in relation to natural environmental factors and an offshore oil and gas production platform off the coast of southern California. *Bull. Mar. Sci.* **55**:1062-1085.
- MBC Applied Environmental Sciences. 1987. *Ecology of oil/gas platforms offshore California*. U.S. Dept Interior, OCS Study/MMS. 86-0094.
- MMS/California State Lands Commission. 1994. Abandonment and removal of offshore oil and gas facilities: education and information transfer. *Workshop Proceedings*. University of California, Santa Barbara.
- Musick, T.A. and J.D. McEachra. 1972. Autumn and winter occurrence of decapod crustaceans in Chesapeake Bight, U. S. A. *Crustaceana*. **22**:190-200.
- O'Clair, C.E. and L. Freese. 1985. Responses of Dungeness crabs, *Cancer magister*, exposed to bark debris from benthic deposits at log transfer facilities: survival, feeding, and reproduction. In: *Proceedings of the Symposium on Dungeness Crab Biology and Management*. Anchorage, Alaska Sea Grant Report No.1 85-3, p. 227-229.
- Orensanz, J.M. and V.F. Gallucci. 1988. Comparative study of postlarval life-history schedules in four sympatric species of *Cancer* (Decapoda: Brachyura: Cancridae). *J. Crust Biol.* **8**:187-220.
- Page, H.M. 1986. Differences in population structure and growth rate of the stalked barnacle *Pollicipes polymerus* between a rocky headland and an offshore oil platform. *Mar. Ecol. Prog. Ser.* **29**:157-164.
- Page, H.M. and D.M. Hubbard. 1987. Temporal and spatial patterns of growth in mussels *Mytilus edulis* on an offshore platform: relationships to water temperature and food availability. *J. Exp. Mar. Biol. Ecol.* **111**:159-179.
- Parker, D. 1992. Rock Crabs. In: Leet, W.S., C.M. Dewees and C.W. Haugen (eds). *California's living marine resources and their utilization*. California Sea Grant, Sea Grant Extension Publication. Univ. Calif., San Diego, UCSGEP-92-12, p. 18-20.
- Rebach, S. 1983. Orientation and migration in Crustacea. In: Rebach, S. and D.W. Dunham (eds). *Studies in adaptation. The behavior of higher Crustacea*. John Wiley & Sons. New York, p. 217-264.
- Reggio, V.C. 1987. Rigs-to-reefs. *Fisheries*. **12**:2-7.
- Reggio, V.C. 1989. Petroleum structures as artificial reefs: a compendium. In: *Fourth International Conference on Artificial Habitats for Fisheries*. Rigs-to-Reefs Special Session. Miami, Florida, OCS Study/MMS 89-0021.
- Rodin, V.E. 1989. Population biology of the King Crab *Paralithodes camtschatica* Tilesius in the North Pacific Ocean. In: *Proceedings of the International Symposium on King and Tanner Crabs*. Alaska Sea Grant College Prog. Rept. No. 90-04. Anchorage, Alaska, p. 133-144.

- Shanks, A.L. 1986. Vertical migration and cross-shelf dispersal of larval *Cancer* spp. and *Randallia ornata* (Crustacea: Brachyura) off the coast of southern California. *Mar. Biol.* **92**:189-199.
- Stevens, B.G. and D.A. Armstrong. 1985. Ecology, growth, and population dynamics of juvenile Dungeness crab, *Cancer magister* Dana, in Grays Harbor, Washington, 1980-1981. In: *Proceedings of the symposium on Dungeness crab biology and management*. Alaska Sea Grant Report No.1 85-3. Anchorage, Alaska, p. 119-134.
- Stimpson, R.A. 1977. The biology of two offshore oil platforms. *Inst. Mar. Res. Univ. Calif.*, San Diego, IMR Ref. 76-13.
- Stone, R.P. and C.E. O'Clair. 1989. Seasonal migration of primiparous and multiparous female red king crabs (*Paralithodes camtschatica*). In: *Proceedings of the International Symposium on King and Tanner Crabs*. Alaska Sea Grant College Prog Rept. No. 90-04. Anchorage, Alaska, p. 189-191.
- Turner, C.H., E.E. Ebert and R.R. Given. 1969. Man-made reef ecology. Calif. Dept. of Fish and Game, *Fish. Bull.* 146.
- Wilkinson, L., M. Hill and E. Vang. 1992. *SYSTAT: statistics*, version 5.2 edition. SYSTAT, Inc. Evanston, IL.
- Winn, R.N. 1985. *Comparative ecology of three Cancrid crab species (Cancer anthonyi, C. antennarius and C. productus) in marine subtidal habitats in southern California*. Ph.D. Dissertation. University of Southern California.
- Wolfson, A., G. VanBlaricom, N. Davis and G.S. Lewbel. 1979. The marine life of an offshore oil platform. *Mar. Ecol. Prog. Ser.* **1**:81-89.
- Zar, J. 1984. *Biostatistical analysis*. Prentice-Hall. Englewood Cliffs, New Jersey.



The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.



The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The **MMS Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.