MMS OCS Study
MMS 2007-007

MEGABENTHIC INVERTEBRATES ON SHELL MOUNDS UNDER OIL AND GAS PLATFORMS OFF CALIFORNIA

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

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MEGABENTHIC INVERTEBRATES ON SHELL MOUNDS UNDER OIL AND GAS PLATFORMS OFF CALIFORNIA

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TECHNICAL SUMMARY

Study Title: Benthic Invertebrate Communities on Shell Mounds Surrounding Oil and Gas Platforms in the Santa Barbara Channel and Santa Maria Basin
Report Title: Megabenthic Invertebrates on Shell Mounds Under Oil and Gas Platforms off California
Contract Number: 1435-MO-08-AR-12693
Sponsoring OCS Region: Pacific
Applicable Planning Area: Central and Southern California
Fiscal Years of Project Funding: FY2004-FY2006
Completion Date of Report: September 2008
Principal Investigators: Jeffrey H. R. Goddard & Milton S. Love
Key Words: Oil platforms, OCS platforms, shell mounds, California, decommissioning, platform decommissioning, video transects, megabenthic invertebrates, structure-forming invertebrates, non-native species, community composition, asteroid echinoderms, spawning aggregations, food subsidy, sea stars, *Asterina miniata*, *Metridium farcimen*, *Pleurobranchaea californica*, *Pisaster*, *Stylasterias forreri*, *Watersipora subtorquata*.

Background and Objectives:

Twenty-seven oil and gas platforms are located off the California coast, in waters up to 365 m deep. When a platform becomes uneconomical to operate for its original use, it faces decommissioning, a complex process involving state and federal agencies and requiring extensive environmental review. During their working lives, platforms accumulate a wealth of benthic and pelagic biota, which may include economically important species, species of conservation importance, and even non-native species. Therefore, the environmental review required by decommissioning must consider the ecological impacts on the region of altering or removing each platform and its associated biota as called for by the various decommissioning options. The latter range from complete removal of a platform, to partial removal, to toppling, and finally, no removal.

The fishes associated with platforms off California have been extensively studied and documented, and the platforms have been found to provide important habitat for the juveniles and adults of many species, including some overexploited, economically valuable species of rockfish. Although there has long been interest in the platforms as sites of aquaculture of bivalves such as mussels and rock scallops (with at least one commercial venture), interest in the benthic invertebrate biota associated with the platforms has generally lagged behind that of the fishes. This has changed recently, owing to (1) an increasing recognition of the functional significance - beyond the usual predator/prey relationships - of many sessile invertebrates of the types found on the platforms to fishes, and (2) because the platforms support a large biomass of sessile species, some of which might provide sustainable sources of marine natural products difficult or ecologically harmful to obtain in significant quantities from natural reefs.

Shell mounds are a unique biogenic feature of offshore oil platforms. Formed by the wave- or maintenance-induced dislodgement of mussels, barnacles and other fouling organisms growing on the upper reaches of the platforms, these mounds cover large circular or oval areas around the base of each platform, rise more than 5 meters in height, and provide islands of hard, calcareous substrate for organisms in an otherwise mostly soft bottom habitat. The fishes associated with

shell mounds have been quantitatively investigated and described, as part of the comprehensive studies of platform fishes. A few studies have examined invertebrate communities on shallow water (<50 meters deep) shell mounds. These have reported unusually high densities of sea stars, which prey largely on the shelled and other fouling organisms falling from the shallow water portions of the platforms. However, relatively little is known about the invertebrate communities on mussel mounds under platforms in deeper waters, including those on the Pacific outer continental shelf (Pacific OCS). Even less is known about the ecological importance of these invertebrates to the associated fish assemblages and as potentially important spawning sites and sources of larvae for distant and more widespread populations. Thus, the overall goals of this study were to identify and quantify the invertebrate fauna on deepwater shell mounds, compare important elements of the fauna to those found on neighboring soft sediments and natural reefs, and investigate elements of their potential ecological and conservation importance.

Description:
We investigated the invertebrate fauna on deepwater shell mounds and their ecological importance through four tasks.

Task One:
Identify megabenthic invertebrates on shell mounds associated with OCS platforms off California and determine their densities and depth distribution.

Task Two:
Compare shell mound invertebrate species richness and community composition among platforms, and test for differences in community structure by year, depth, geographic location, and age of platform.

Task Three:
Investigate the relationship between the density of large, structure-forming invertebrates and fishes commonly associated with shell mounds.

Task Four:
Compare sea star densities on shell mounds with those on natural reefs.

Significant Results
Task 1: In this study we utilized archived videotapes of transects conducted between 1997 and 2005 on the shell mounds under 15 platforms, in waters 49 to 365 m deep, in the Santa Maria Basin, Santa Barbara Channel, and San Pedro Bay. We counted all recognizable invertebrates in quadrats randomly selected from these transects.

Asteroid echinoderms, or sea stars, the large sea anemone, *Metridium*, the large side-gilled slug *Pleurobranchaea californica*, and rock crabs *Cancer* spp. dominated the deepwater shell mound megafauna, accounting for more than 90 % of the total number of individuals counted. In addition, spot prawns, *Pandalus platyceros* and the sea urchin *Allocentrotus fragilis* were abundant at a few shell mounds, and large masses (> 50 cm high) of one non-mytilid, non-native species, the foliose bryozoan *Watersipora subtorquata*, was observed under Platform Gilda. Ophiuroids, whose density was estimated qualitatively, were also abundant on some shell mounds. Like neighboring soft sediment communities, echinoderms were the most abundant megabenthic taxon on the shell mounds. However in contrast to the numerical dominance of echinoid echinoderms on the soft sediments, sea stars comprised 77 % of the total number of organisms counted on the shell mounds.

Excluding ophiuroids, the sea star *Asterina miniata* attained the highest densities, reaching nearly 10 individuals per m^2 under Platform Elly and averaging 4.1 per m^2 on the seven shell mounds occurring in less than 100 m of water. This species had a wide depth distribution, but was most abundant above 100 m.

Except for the ophiuroids and *Metridium*, both of which are suspension feeders, the dominant taxa were all carnivorous or omnivorous predators or scavengers, dependent primarily on the food subsidy of mussels and other fouling organisms growing on the upper reaches of each platform. As demonstrated previously for shallow water shell mounds, once this subsidy is cut off (e.g., by any of decommissioning options resulting in no platform structure in shallow water), the shell mounds will become increasingly covered by sediments, and their community composition will shift toward a higher proportion of omnivorous, suspension and deposit feeding species.

The white-plumed anemone *Metridium farcimen* was the only large, structure-forming, sessile invertebrate prevalent on the shell mounds. It occurred on shell hash and artificial substrates on all shell mounds but reached its highest densities (> 0.3 per m^2) on the shell mounds in greater than 90 m of water. Other structure forming, sessile invertebrates included vase and foliose sponges, gorgonians and crinoids (feather stars), each of which occurred at low density (< 0.03 per m^2) on only a few shell mounds each. Where they occurred, sponges and crinoids were prevalent on shell hash, while gorgonians were restricted to rock, platform structures, and platform debris, possibly indicating avoidance of settlement by the larvae of this taxon on the relatively small, calcareous components of the shell matrix. Brittle stars were dense (> 40 per m^2) on four shell mounds, but their relatively small size and slender arms (which are retractable into the shell hash) do not contribute the same large-scale structure to the shell mounds as the above organisms. The clumps of the bryozoan *Watersipora* observed at Platform Gilda added three-dimensional structure to that shell mound, but almost certainly originated mostly, if not entirely, from the upper reaches of the platform. *Metridium* was orders of magnitude denser on the shell mounds than reported from natural reefs and banks, the sponges and crinoids orders of magnitude less dense, and gorgonians were either less or more dense on the shell mounds, depending on the natural reefs studied. Gorgonians, however, were not observed on shell hash, but only on rock and artificial hard substrata.

The relative lack of large sessile structure-forming taxa on the shell mounds other than *Metridium* may be due to avoidance by the larval stages of these species of settling on the relatively small, calcareous components of the shell hash, but might also result from high rates of predation on the post-metamorphic and juveniles stages by the abundant predatory sea stars. Regardless of the cause of their scarcity and low species richness, the lack of these structure-forming species - which typically shelter a wide variety of both sessile and mobile macro invertebrates and fishes - probably results in significantly reduced overall biodiversity on the shell mounds compared to natural reefs. These components of the shell mound benthic community could be enhanced in classic artificial reef style by the addition of hard substrata. Because they are suspension feeders not as dependent as the mobile species on the food subsidy of shellfish growing on the platforms, enhancement of the large, structure-forming organisms would occur on the shell mound regardless of the presence or absence of a standing platform, and indeed, on a large scale could be accomplished by the platform decommissioning option that calls for toppling entire platforms. Given the large dimensions but relatively simple design of the platform jackets (the legs and crossbeams supporting both the topside structures and oil

and gas conductors), huge amounts of artificial secondary structure and surface area could be added to toppled platforms, providing sites for settlement and growth of *Metridium* at all depths, gorgonians in at least shallow waters, and perhaps large sponges and crinoids and other taxa, such as black corals (Antipaththaria) in deeper waters. Separate from the growth of this biotic structure, the physically enhanced, toppled jackets would likely also provide many more spatial refuges for mobile invertebrates and fishes than exist on standing, unmodified platforms.

Task 2: For the seven platforms sampled at least five times each, depth appeared to be the most important variable explaining the total number of megabenthic invertebrate taxa observed on each shell mound, with the number of taxa increasing over the depth range (64 to 225 m) spanned by these platforms. The influence of geographic location was also noteworthy, with lower numbers of taxa tending to occur under shell mounds in San Pedro Bay than in either the Santa Maria Basin or Santa Barbara Channel.

Ordination of the species density data for all years at all platforms showed that each platform had a distinctive community composition, with the shell mound at Platform Hidalgo having the most temporally variable community composition. Of the three environmental factors examined, depth was found to be the most important determinate of community structure, a result consistent with previous studies on natural reefs in the region. Geographic location was also important in distinguishing between shell mound communities from the Santa Maria Basin and San Pedro Bay, at the western and eastern ends of the study region.

Task 3: Few taxa of large, structure-forming invertebrates were observed on the shell mounds, and consisted of (in order of overall density): the large anemone *Metridium*, clumps of the foliose bryozoan *Watersipora* (observed only under Platform Gilda), the crinoid echinoderm *Florometra*, sea pens, including *Ptilosarcus*, gorgonians, and vase and foliose sponges. Except for *Metridium*, which occurred on all shell mounds, each of these taxa occurred on only three or fewer shell mounds. Sea pens, primarily of the family Virgulariidae, were restricted to soft sediments, while the gorgonians were observed only on hard substrates including rock, pipelines or platform debris such as tires. Large *Metridium* were common on the shell matrix, pipelines and platform debris.

By comparing a similarity matrix based on the densities of 12 of the most abundant shell mound fishes with each of the possible matrices based on the densities of the four most common structure-forming invertebrates (plus ophiuroids, which added texture, if not structure, to some of the shell mounds), we found that fishes from shallower water shell mounds were most highly correlated with ophiuroids and gorgonians, and more highly correlated with gorgonians alone than ophiuroids alone. Fishes from deeper water shell mounds were most highly correlated with large *Metridium* and sea pens, and fairly highly correlated with large *Metridium* alone.

Guided by the above general correlations, we found that the densities of painted greenling and four species of rockfish were correlated with the densities of particular structure-forming invertebrates. Both painted greenling and vermilion rockfish were significantly correlated with gorgonians, probably reflecting the association of all three species with rocky substrata, rather than a direct relationship between the fish and gorgonians themselves.

The density of greenblotched rockfish was correlated with the density of sea pens and the sea urchin *Allocentrotus*, both of which are typically associated with soft sediments, but were observed in this study in mixed shell mound/soft sediment habitat. The young of these rockfish may utilize the structure provided by sea pens and *Allocentrotus*, perhaps as spatial refuges from predation or as feeding sites.

The density of pinkrose rockfish was correlated with the density of sea pens, and greenstriped rockfish were significantly correlated with the density of large *Metridium*, the most abundant structure-forming invertebrate on the shell mounds. While a functional relationship cannot necessarily be inferred from these correlations, they suggest that some fishes may be partitioning, as habitat, the few structure-forming invertebrates found on shell mounds.

Task 4: For this task we compared the density of sea stars on the shell mounds with those reported from rocky reefs at similar depths in the same region by the Biological California offshore Monitoring Program (CAMP). Asteroid echinoderms were at least an order of magnitude denser on the shell mounds, a result consistent with earlier studies on shell mounds in shallower waters.

Given the scarcity of hard bottom habitat on the outer continental shelf, and its relatively low densities of sea stars, the denser populations of sea stars found on deepwater shell mounds may be important to the region as spawning aggregations and sources of larvae, especially if the geographically more extensive, shallow water populations of the same species continue to be impacted by the microbial wasting disease first observed in the Santa Barbara Channel in the late 1990's. If the wasting disease is related to long-term warming trends in surface waters, deepwater shell mounds might provide a cold-water refuge from the disease. However, it should be emphasized that any lasting reproductive contribution by shell mound sea stars, whatever its magnitude, depends on the continued transfer of live mussels, barnacles, and other fouling organisms – the prey of most of the sea stars – from the upper reaches of the platforms to the shell mounds. Any platform decommissioning option resulting in the loss of platform structure in shallow water would cut this food subsidy, eventually resulting in significantly reduced densities and reproductive output by the predatory sea stars.

An additional possible, but largely unexplored, consequence of high asteroid density on the shell mounds might be an increased susceptibility to disease outbreaks, should the shell mound populations become exposed to infectious agents. Depending on the vectors and agents involved, this may be less likely on deeper shell mounds compared to shallow ones. One species of particular concern is the ciliate *Orchitophyra stellarum* a parasitic castrator introduced from the north Atlantic Ocean. This parasite apparently has a wide range of host and has been found in *Pisaster ochraceus* from British Columbia.

STUDY PRODUCTS

This report.

MEGABENTHIC INVERTEBRATES ON DEEPWATER SHELL MOUNDS ASSOCIATED WITH OCS PLATFORMS OFF CALIFORNIA

EXECUTIVE SUMMARY

Information needed

Twenty-seven oil and gas platforms are located off the California coast, in waters up to 365 m deep. When a platform becomes uneconomical to operate for its original use, it faces decommissioning, a complex process involving state and federal agencies and requiring extensive environmental review. During their working lives, platforms accumulate a wealth of benthic and pelagic biota, becoming *de facto* artificial reefs. Species associated with the platforms may include economically important species, species of conservation importance, and even non-native species. Therefore, the environmental review required by decommissioning must consider the ecological impacts on the region of altering or removing each platform and its associated biota, as called for by the various decommissioning options. These options, which are summarized and discussed in OCS Study MMS 2003-032, range from complete removal of a platform, to partial removal, to toppling, and finally, no removal.

The fishes associated with OCS platforms off California have been extensively studied and documented by OCS Studies MMS 99-0015 and 2003-032, and the platforms have been found to provide important habitat for the juveniles and adults of many species, including some overexploited, economically valuable rockfishes. Although there has long been interest in the platforms as sites of aquaculture of bivalves such as mussels and rock scallops (with at least one commercial venture), interest in the benthic invertebrate biota associated with the OCS platforms has generally lagged behind that of the fishes. This has changed recently, owing to (1) an increasing recognition of the functional significance – beyond the usual predator/prey relationships – of many sessile invertebrates of the types found on the platforms to fishes, and (2) because the platforms support a large biomass of sessile species, some of which might provide sustainable sources of marine natural products difficult or harmful to obtain in significant quantities from natural habitats (MMS Environmental Studies Program: Advancing Marine Biotechnology: Use of OCS Platforms as Sustainable Sources of Marine Natural Products).

Shell mounds are a unique biogenic feature of offshore oil platforms. Formed by the wave- or maintenance-induced dislodgement of mussels, barnacles and other fouling organisms growing on the upper reaches of the platforms, these mounds cover large circular or oval areas around the base of each platform, rise more than 5 meters in height, and provide islands of hard, calcareous substrate for organisms in an otherwise mostly soft bottom habitat (Sea Surveyor Inc. 2003).

As part of comprehensive studies of fishes on platforms and natural reefs in the Pacific OCS region (summarized in OCS Study MMS 2003-032), the fishes associated with mussel mounds have been quantitatively investigated and described by researchers from the University of California at Santa Barbara. These studies have found that the shell mound fish assemblages are diverse and similar to those of the platform bottoms, but tend to be dominated by small fishes (mainly rockfishes), compared to the older juveniles and adults associated with the platform

bottoms.

A few studies have examined invertebrate communities on shallow water (<50 meters deep) shell mounds. These have reported unusually high densities of sea stars, which prey largely on the shelled and other fouling organisms falling from the shallow water portions of the platforms. One important study from the shallow water shell mounds demonstrated that when this food subsidy is cut off by removal of the overlying platform, the invertebrate community on the shell mound shifts from one dominated by predatory and scavenging species to one dominated by omnivorous, suspension and deposit feeding species.

Relatively little is known about the invertebrate communities on mussel mounds under Pacific OCS platforms in deepwater. Even less is known about the ecological importance of these invertebrates to the associated fish assemblages and as potentially important spawning sites and sources of larvae and new recruits for distant and more widespread populations of invertebrates. Thus, the overall goals of this study were to identify and quantify the invertebrate fauna on deepwater shell mounds, compare important elements of the fauna to those found on neighboring soft sediments and natural reefs, and investigate elements of their potential ecological and conservation importance.

Research Summary

Task One. Identify megabenthic invertebrates on shell mounds associated with OCS platforms off California and determine their densities and depth distribution

In this study we utilized archived videotapes of transects conducted between 1997 and 2005 on the shell mounds under 15 OCS platforms, in waters 49 to 365 m deep, in the Santa Maria Basin, Santa Barbara Channel, and San Pedro Bay, off central and southern California. We counted all recognizable invertebrates in quadrats randomly selected from these video transects.

Asteroid echinoderms, or sea stars, the large sea anemone, *Metridium*, the large side-gilled slug *Pleurobranchaea californica*, and rock crabs *Cancer* spp. dominated the deepwater shell mound megafauna, accounting for more than 90 % of the total number of individuals counted. In addition, spot prawns, *Pandalus platyceros* and the sea urchin *Allocentrotus fragilis* were abundant at a few shell mounds, and large masses (> 50 cm high) of one non-mytilid, non-native species, the foliose bryozoan *Watersipora subtorquata*, was observed under Platform Gilda. Ophiuroids (brittle stars), whose density was estimated qualitatively, were also abundant on some shell mounds. In contrast to the numerical dominance of echinoid echinoderms on neighboring soft sediments, sea stars comprised 77 % of the total number of organisms counted on the shell mounds.

Excluding ophiuroids, the sea star *Asterina miniata* attained the highest densities, reaching nearly 10 individuals per m^2 under Platform Elly and averaging 4.1 per m^2 on the seven shell mounds occurring in less than 100 m of water. This species had a wide depth distribution, but was most abundant above 100 m.

Except for the ophiuroids and *Metridium*, both of which are suspension feeders, the dominant taxa were all carnivorous or omnivorous predators or scavengers, dependent primarily on the food subsidy of mussels and other fouling organisms growing on the upper reaches of each platform.

The white-plumed anemone *Metridium farcimen* was the only large, structure-forming, sessile

invertebrate prevalent on the shell mounds. It occurred on shell hash and artificial substrates on all shell mounds but reached its highest densities on the shell mounds in greater than 90 m of water. Other structure-forming, sessile invertebrates included vase and foliose sponges, gorgonians and feather stars (crinoids), each of which occurred at low density on only a few shell mounds each. Where they occurred, sponges and crinoids were prevalent on shell hash, while gorgonians were restricted to rock, platform structures, and platform debris. Brittle stars were dense (> 40 per m^2) on four shell mounds, but do not contribute the same large-scale structure to the shell mounds as the above organisms. *Metridium* was orders of magnitude denser on the shell mounds than reported from natural reefs and banks, the sponges and crinoids orders of magnitude less dense, and gorgonians were either less or more dense on the shell mounds, depending on the natural reefs studied. No gorgonians, however, were observed on shell hash, only on rock and artificial hard substrata.

The relative lack of large sessile structure-forming taxa on the shell mounds other than *Metridium* may be due to avoidance by the larval stages of these species of settling on the relatively small, calcareous components of the shell hash, but might also result from high rates of predation on the post-metamorphic and juveniles stages by the abundant predatory sea stars. Regardless, the lack of these structure-forming species - which typically shelter a wide variety of both sessile and mobile macro invertebrates and fishes - probably results in significantly reduced overall biodiversity on the shell mounds compared to natural reefs. These components of the shell mound benthic community could be enhanced in classic artificial reef style by the addition of hard substrata. Because they are suspension feeders not as dependent as the mobile species on the food subsidy of shellfish growing on the platforms, this enhancement would occur on the shell mound regardless of the presence or absence of a standing platform, and indeed, on a large scale could be accomplished by the platform decommissioning option that calls for toppling entire platforms. Given the large dimensions but relatively simple design of the platform jackets, huge amounts of artificial secondary structure and surface area could be added to toppled platforms, providing sites for settlement and growth of different structure-forming taxa at different depths. Separate from the growth of this biotic structure, the physically enhanced, toppled jackets would likely also provide many more spatial refuges for mobile invertebrates and fishes than exist on standing, unmodified platforms.

Task Two. Compare shell mound invertebrate species richness and community composition among platforms, and test for differences in community structure by year, depth, geographic location, and age of platform

For the seven platforms sampled in at least five years each, depth appeared to be the most important variable explaining the total number of megabenthic invertebrate taxa observed on each shell mound, with the number of taxa increasing over the depth range (64 to 225 m) spanned by these platforms. The influence of geographic location was also noteworthy, with lower numbers of taxa tending to occur under shell mounds in San Pedro Bay than in either the Santa Maria Basin or Santa Barbara Channel.

Ordination of the species density data for all years at all platforms showed that each platform had a distinctive community composition, with the shell mound at Platform Hidalgo having the most temporally variable community composition. Of the three environmental factors examined,

depth was found to be the most important determinate of community structure, a result consistent with previous studies on natural reefs in the region. Geographic location was also important in distinguishing between shell mound communities from the Santa Maria Basin and San Pedro Bay, at the western and eastern ends of the study region.

Task Three. Investigate the relationship between the density of large, structure-forming invertebrates and fishes commonly associated with shell mounds

Few types of large, structure-forming invertebrates were observed on the shell mounds, and consisted of (in order of overall density): the large anemone *Metridium*, clumps of the foliose bryozoan *Watersipora*, the crinoid echinoderm *Florometra*, sea pens, including *Ptilosarcus*, and rare gorgonians, and vase and foliose sponges. Sea pens, primarily of the family Virgulariidae, were restricted to soft sediments, while the gorgonians were observed only on hard substrates including rock, pipelines or tires. Large *Metridium* were common on shell hash, as well as pipelines and platform debris.

By comparing a similarity matrix based on the densities of 12 of the most abundant shell mound fishes with each of the possible matrices based on the densities of the four most common structure-forming invertebrates (plus ophiuroids, which added texture, if not structure, to some of the shell mounds), we found that fishes from shallower water shell mounds were most highly correlated with ophiuroids and gorgonians, and more highly correlated with gorgonians alone than ophiuroids alone. Fishes from deeper water shell mounds were most highly correlated with large *Metridium* and sea pens, and fairly highly correlated with large *Metridium* alone.

Guided by the above general correlations, we found that the densities of painted greenling and four species of rockfish were correlated with the densities of particular structure-forming invertebrates. Both painted greenling and vermilion rockfish were significantly correlated with gorgonians, probably reflecting the association of all three species with rocky substrata, rather than a direct relationship between the fish and gorgonians themselves.

The density of greenblotched rockfish was correlated with the density of sea pens and the sea urchin *Allocentrotus*, both of which are typically associated with soft sediments, but were observed in this study in mixed shell mound/soft sediment habitat. The young of these rockfish may utilize the structure provided by sea pens and *Allocentrotus*, perhaps as spatial refuges from predation or as feeding sites.

The density of pinkrose rockfish was correlated with the density of sea pens, and greenstriped rockfish were significantly correlated with the density of large *Metridium*, the most abundant structure-forming invertebrate on the shell mounds. While a functional relationship cannot necessarily be inferred from these correlations, they suggest that some fishes may be partitioning, as habitat, the few structure-forming invertebrates found on shell mounds.

Task Four. Compare sea star densities on shell mounds with those on natural reefs

For this task we compared the density of sea stars on the shell mounds with those reported from rocky reefs at similar depths in the same region by the Biological California offshore Monitoring Program (CAMP). Asteroid echinoderms were at least an order of magnitude denser

on the shell mounds, a result consistent with earlier studies on shallow water shell mounds.

Given the scarcity of hard bottom habitat on the outer continental shelf, and its relatively low densities of sea stars, the denser populations of sea stars found on deepwater shell mounds may be important to the region as spawning aggregations and sources of larvae, especially if the geographically more extensive, shallow water populations of the same species continue to be impacted by the microbial wasting disease first observed in the Santa Barbara Channel in the late 1990's. If the wasting disease is related to long-term warming trends in surface waters, deepwater shell mounds might provide a cold-water refuge from the disease. However, it should be emphasized that any lasting reproductive contribution by shell mound sea stars, whatever its magnitude, depends on the continued transfer of live mussels, barnacles, and other fouling organisms – the prey of most of the sea stars – from the upper reaches of the platforms to the shell mounds. Any platform decommissioning option resulting in the loss of platform structure in shallow water would cut this food subsidy, eventually resulting in significantly reduced densities and reproductive output by the predatory sea stars.

An additional possible, but largely unexplored, consequence of high asteroid density on the shell mounds might be an increased susceptibility to disease outbreaks, should the shell mound populations become exposed to infectious agents. One species of particular concern is the ciliate *Orchitophyra stellarum* a parasitic castrator introduced from the north Atlantic Ocean.

Conclusions and Recommendations

In contrast to natural reefs, shell mounds in both shallow and deepwater are dominated by predatory and scavenging taxa, especially asteroid echinoderms, and except for the anemone *Metridium farcimen*, large structure-forming invertebrates are scarce. Asteroids are at least an order of magnitude more abundant on shell mounds than on reefs at similar depths and are largely dependent on the food subsidy of mussels and other fouling organisms growing on the upper reaches of the platforms. Therefore, only those decommissioning options retaining platform structure in shallow water will result in the continued dominance of this taxon. As free-spawning organisms with limited migratory ability as adults, the high densities of sea stars on the deepwater shell mounds may be important as spawning aggregations, especially if shallow water populations continue to be impacted by disease outbreaks associated with long-term ocean warming. However, the magnitude of the reproductive contribution by shell mound asteroids is unknown, and their unusually high densities could also render them more susceptible to disease outbreaks, should infectious agents reach them.

Limited evidence obtained in this study suggests that a few shell mound fishes may be partitioning habitats created by those few structure-forming invertebrates found on or intermingled with the shell mounds. However, the overall paucity of structure-forming invertebrate taxa on the shell mounds compared to natural reefs likely suppresses their habitat value to many other fishes and invertebrates. If decisions are ultimately made to retain part or all of the platforms as artificial reefs, we recommend adding large, non-calcareous, hard substrata to the shell mounds in order to promote the settlement and growth of more structure-forming invertebrates. This would enhance biodiversity on the shell mounds regardless of the decisions made about the shallow water portions of the platforms, and indeed, could be accomplished on a large scale by toppling entire platforms and then using the legs and crossbeams for the attachment of extensive amounts of artificial secondary structure.

In California the non-native bryozoan *Watersipora subtorquata* had previously been known only from shallow waters, largely in bays and harbors. This species commonly reaches basketball size on hard substrata in calm water, and its occurrence both on and under platform Gilda presents new risks for spread to previously unavailable deepwater habitats, including ecologically valuable natural reefs. If the colonies of this species on the shell mound are determined to be viable and reproducing every effort should be made to eradicate this species from both the jacket and shell mound.

Based on this study, deeper shell mounds have more megabenthic invertebrate taxa than mounds in shallow water. Therefore, deeper shell mounds may be the most valuable in terms of their conservation potential as artificial reefs, especially since they stand in waters as yet relatively unaffected by long-term ocean warming.

Task 1: Identify megabenthic invertebrates on shell mounds associated with OCS platforms off California and determine their densities and depth distribution.

Rationale

   Shell mounds are a unique biogenic feature of offshore oil platforms in California. Formed by the dislodgement of mussels, barnacles, encrusting bivalves, and other fouling organisms growing on the upper reaches of the platforms, these mounds cover large circular or oval areas around the base of each platform, rise more than 5 meters in height, and provide islands of hard, calcareous substrate for organisms in an otherwise mostly soft bottom habitat (Page et al. 1999; Love et al. 2003; Sea Surveyor Inc. 2003). The fishes associated with mussel mounds under nine deepwater platforms have been quantitatively investigated and described (Love et al., 1999, 2003), and a few studies have examined invertebrate communities on shallow water (<50 meters deep) shell mounds (Wolfson et al. 1979; de Wit 1999, 2001; Page et al. 1999; Bomkamp et al. 2004). However, little is known about the megabenthic invertebrates (defined as > 1 cm and visible in photographs; Gage and Taylor, 1991) on mussel mounds in waters deeper than 50 meters, where most of the OCS platforms off California stand. Even less is known about the ecological importance of these invertebrates to the associated fish assemblages and as spawning sites and sources of larvae and new recruits for distant and more widespread populations.

   Knowledge of the epibenthic invertebrate communities on deepwater shell mounds, their relation to associated fishes, and their potential importance as sources of new recruits for declining shallow water populations of ecologically important sea stars, will expand our understanding of the ecological importance of offshore oil platforms as artificial reefs. Owing to the finite economic lifespans of oil and gas platforms, decisions eventually need to be made regarding their decommissioning. Ten alternatives, outlined and discussed by Love et al. (2003) and Schroeder and Love (2004), range from complete removal of a platform, to partial removal, to toppling, and finally, no removal. Safety, legal and ecological issues surround each alternative (Holbrook et al. 2000; Schroeder and Love 2004). Information on the shell mound invertebrate communities will allow for a more thorough evaluation of the ecological consequences of each decommissioning option.

Methods

   To identify megabenthic invertebrates on shell mounds and quantify their density, we used DVD recordings of Hi-8 mm videotapes of belt transects conducted on the shell mounds using the submersible *Delta*. These video transects were conducted in the fall, from 1997 to 2005, as part of surveys of fishes associated with the 15 OCS platforms (Figure 1, Table 1). As described in Love et al. (1999, 2003), these videos were made using an externally mounted camera as the *Delta* moved at a speed of about 0.5 kt approximately one meter above the bottom during daylight hours. An observer verbally annotated all tapes with observations primarily of fish, but also occasionally included comments on invertebrates and the habitat. For each shell mound surveyed, one transect was conducted per year and consisted of a complete circuit made between the platform itself and the edge of the shell mound. Lasers mounted on either side of the camera provided reference spots 20 cm apart on the videos. The shell mounds under seven platforms were surveyed in at least five different years; the remaining shell mounds were surveyed only once or, in one case, twice (Table 1). We did not include the transect conducted in 1997 under Platform Holly, owing to navigational problems and the likelihood that much of that transect was
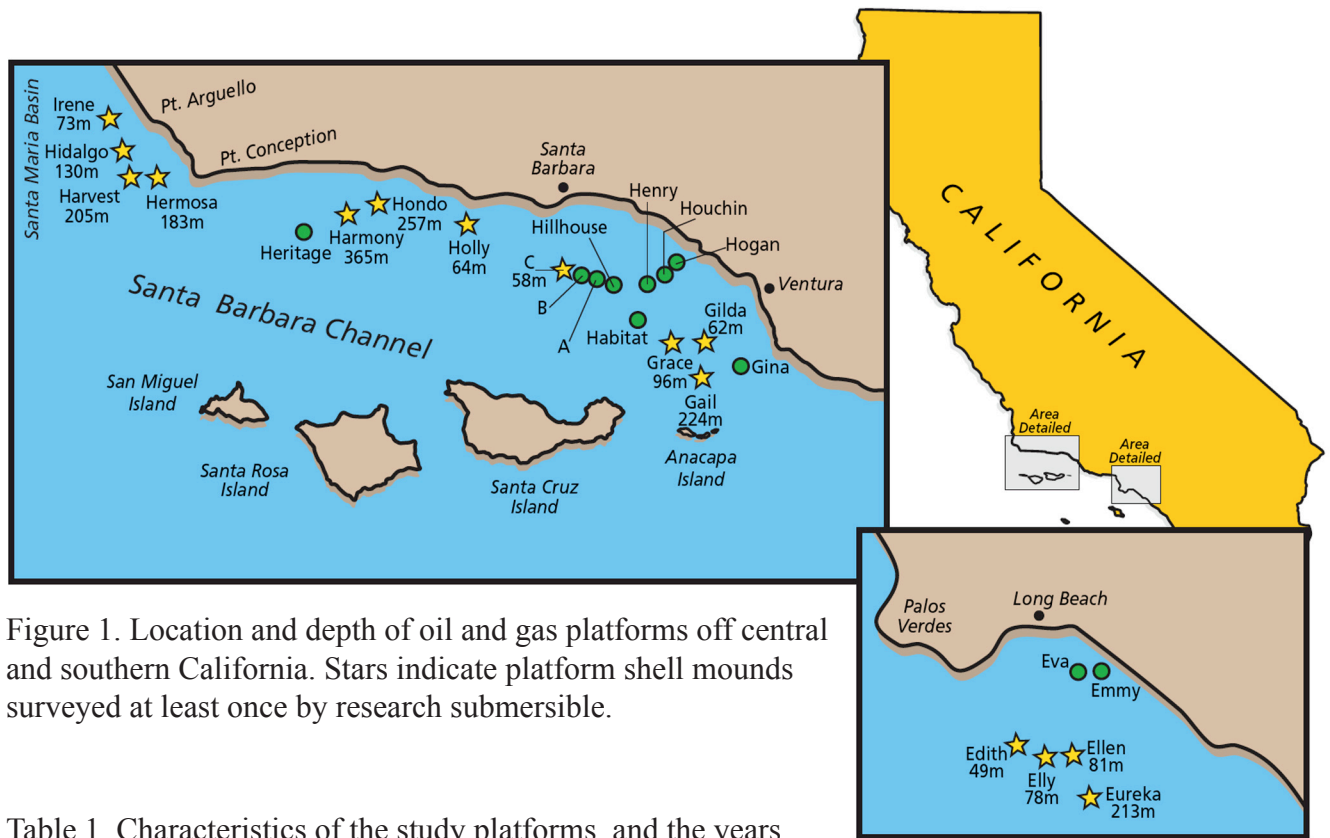
Figure 1. Location and depth of oil and gas platforms off central and southern California. Stars indicate platform shell mounds surveyed at least once by research submersible.

Table 1. Characteristics of the study platforms, and the years that their associated shell mounds were surveyed using the research submersible *Delta*. One circular transect was conducted per year for each shell mound.

Platform	Year installed	Water depth (m)	Distance to land (km)	Geographic location	Years surveyed	No. years surveyed
Edith	1983	49	13.7	San Pedro Bay	1998	1
Ellen	1980	81	13.8	San Pedro Bay	2005	1
Elly	1980	78	13.8	San Pedro Bay	2005	1
Eureka	1984	213	14.5	San Pedro Bay	2005	1
Platform C	1977	58	9.2	Santa Barbara Channel	2000	1
Gail	1987	225	20	Santa Barbara Channel	1997, 1999-05	8
Gilda	1981	62	14.2	Santa Barbara Channel	2003-04	2
Grace	1979	97	16.9	Santa Barbara Channel	1997-05	9
Holly	1966	64	2.9	Santa Barbara Channel	1998, 2001, 2003-05	5*
Harmony	1989	365	10.3	Santa Barbara Channel	2004	1
Hondo	1976	257	8.2	Santa Barbara Channel	2004	1
Harvest	1985	206	10.8	Santa Maria Basin	1997-00, 2004	5
Hermosa	1985	184	10.9	Santa Maria Basin	1997-00, 2004	5
Hidalgo	1986	131	9.5	Santa Maria Basin	1997-01, 2004-05	7
Irene	1985	74	7.6	Santa Maria Basin	1997-01, 2004-05	7

* A mussel mound transect was also surveyed under Platform Holly in 1997, but owing to its questionable location in relationship to the platform, we did not include this transect in the present study.

actually between the legs of the platform. We analyzed a total of 55 shell mound transects in this study.

To measure density, we made direct counts of macro invertebrates in 40 randomly selected quadrats, each approximately 2 m², per transect (60 quadrats were sampled for three transects estimated to be longer than 400 m). First, each transect was reviewed to note the invertebrates present and to note sections of the videos that were inappropriate for sampling (e.g., if *Delta* had moved off the bottom to pass over a pipeline). Then, using the starting and ending times of each transect, 40 random clock times were computer generated. These were culled to (1) remove times overlapping with the periods inappropriate for sampling mentioned above, and (2) replace times that might result in spatially overlapping quadrats. The videos were stopped at the pre-selected times, and a still image, representing one quadrat, was captured using the DVD viewing software. A quadrat included the entire part of the image between the *Delta* and the laser points. When the submersible was noted to be higher or lower than 1 m off of the bottom (as indicated by the size of the shells and the distance between the laser points), the outlines of the quadrat were estimated visually. For each quadrat, the % cover of shell material not covered by soft sediments was visually estimated, and all recognizable invertebrates were identified to the lowest possible taxonomic level and counted. Reviewing the relevant segment of a video and obtaining views from different angles and under different degrees of lighting assisted identification of questionable or partially obscured organisms.

We recorded the density of brittle stars qualitatively as none, few, moderate, or abundant, and owing to the low resolution of the videos, simply counted the number of clumps of the colonial corallimorpharian anthozoan *Corynactis californica* and the non-native bryozoan *Watersipora subtorquata*. We enumerated individual vase and foliose sponges, but did not attempt to count or measure the % cover of irregularly encrusting sponges or other encrusting fauna owing to the frequently low resolution and our inability to distinguish them in the videos from shell material. Small anemones of the genus *Metridium* were present on many of the shell mounds, but owing to lack of resolution, we counted only individuals of *Metridium* greater than approximately 10 cm in height. These therefore included the large, solitary *M. farcimen*, and possibly also larger individuals of the clonal *M. senile*.

Given the importance of large sessile invertebrates in providing biotic structure and habitat in marine benthic ecosystems, we investigated the importance of shell mounds as habitat for these species by comparing the number of individuals/colonies of all large sessile taxa found on different substrata in the transects, including shell hash, rock, and platform debris. We also counted the number of individuals on pipelines crossing the shell mounds. To do this, we enumerated substrata for vase and foliose sponges combined, gorgonians, and the crinoid *Florometra serratissima* in transects on all shell mounds on which these taxa were found. To ensure that the samples were independent we limited these counts to single years (transects) per shell mound, sampling the sponges under Platform Hermosa in 2000, Gail in 2003 and Hondo in 2004, gorgonians on Holly 2001, Platform C in 2000, and Elly in 2005, and crinoids on Eureka 2005, Gail 2000, and Hidalgo 2001. For the large anemone *Metridium*, which occurred under all platforms and at much higher densities than the above taxa, we enumerated substrata under individuals > 15 cm high on the transect under Grace in 1997 and the first half of the transect under Gail in 1997. Counts for all taxa were made using the entire video transects, not just the quadrats used in the density sampling.

The cover of shell hash varied widely, both between and within transects, depending on the

shape of each shell mound, depth of platform, current regime on the bottom, and actual course taken by *Delta* during each transect. Some of the deeper platforms had relatively low cover of shell hash, presumably owing to the larger target area hit by falling shell. Shells mound under some platforms appeared to be highly elliptical in shape owing to uneven deposition of shell caused by bottom currents. Since we were interested in the invertebrate community associated with the shell hash and not soft sediments per se, we estimated the densities of each taxon in each transect based on the numbers counted in quadrats with at least 10 % cover of shell. Sample size therefore ended up varying from 19 to 40 quadrats per transect per year, depending on the amount of soft bottom habitat covered by the transect and the randomly selected position of the quadrats.

Substrata on the shell mounds consisted of the shell hash itself, soft sediments, and anthropogenic platform debris in the form of building materials, automobile tires, machine parts, and even office furniture (see Figures 2o and 2p). Small amounts of rock in the form of cobble or bedrock were observed at a few of the shell mounds. Oil and gas pipelines also crossed some of the shell mounds, providing additional hard substratum. To quantify the coverage by rock and density of anthropogenic debris, we visually estimated the % cover of rock and counted all separate pieces of debris in all quadrats in the most recent year each shell mound was sampled.

Identifications

No specimens were collected, and all identifications were based on the video images and still images obtained by Milton Love and his colleagues. For identifications, we relied on Fisher, 1911-1930; Hopkins and Crozier, 1966; Austin, 1985; Maluf, 1988; Gotshall, 1994; Jensen, 1995; Kozloff, 1996; Lambert, 2000, and the multi-volume Taxonomic Atlas of the Benthic Fauna of Santa Maria Basin and Western Santa Barbara Channel published by the Santa Barbara Museum of Natural History.

Owing to the sampling methods and lack of collection, a number of common taxa could not be fully resolved in this study, despite their relatively large size. The sea stars we refer to below as "*Dermasterias*-like" were the most problematic. At Platform Irene most individuals were clearly the leather star *Dermasterias imbricata*, an identity also confirmed on one dive at Platform Irene by the observer aboard the *Delta*. However, as observed in the videos from that shell mound, the distinctive red and gray color pattern of this species is often washed out by the *Delta*'s floodlights, resulting in a uniformly pale yellow appearance. Sea stars of similar size (up to 20 cm diameter), shape, and pale yellow color were observed under six other platforms, but their identity as *D. imbricata* could not be confirmed by any images showing the typical color pattern of this species. Moreover, *D. imbricata* has only been recorded in the literature as occurring down to 91 m (Maluf 1988; Lambert 2000), while we recorded *Dermasterias*-like sea stars as deep as 213 m, at Platform Eureka. Assuming *D. imbricata* does not occur naturally at these depths, then two explanations for its occurrence there seem likely: (1) *Dermasterias imbricata* have fallen with clumps of shell to these depths, or (2) we have included more than one species in this taxon. Some individuals included in this taxon were more inflated-looking and had less triangular shaped rays than *D. imbricata*, and superficially resembled *Poraniopsis inflata* without spines or *Pteraster militaris*, which has only been recorded from as far south Oregon (Lambert 2000). Other specimens superficially resembled *Gephyreaster swifti*, an even more northerly species. Specimens and (or) higher resolution still images of this sea star, especially from the deeper part of its range on the shell mounds, are therefore needed to confirm their identity. Two
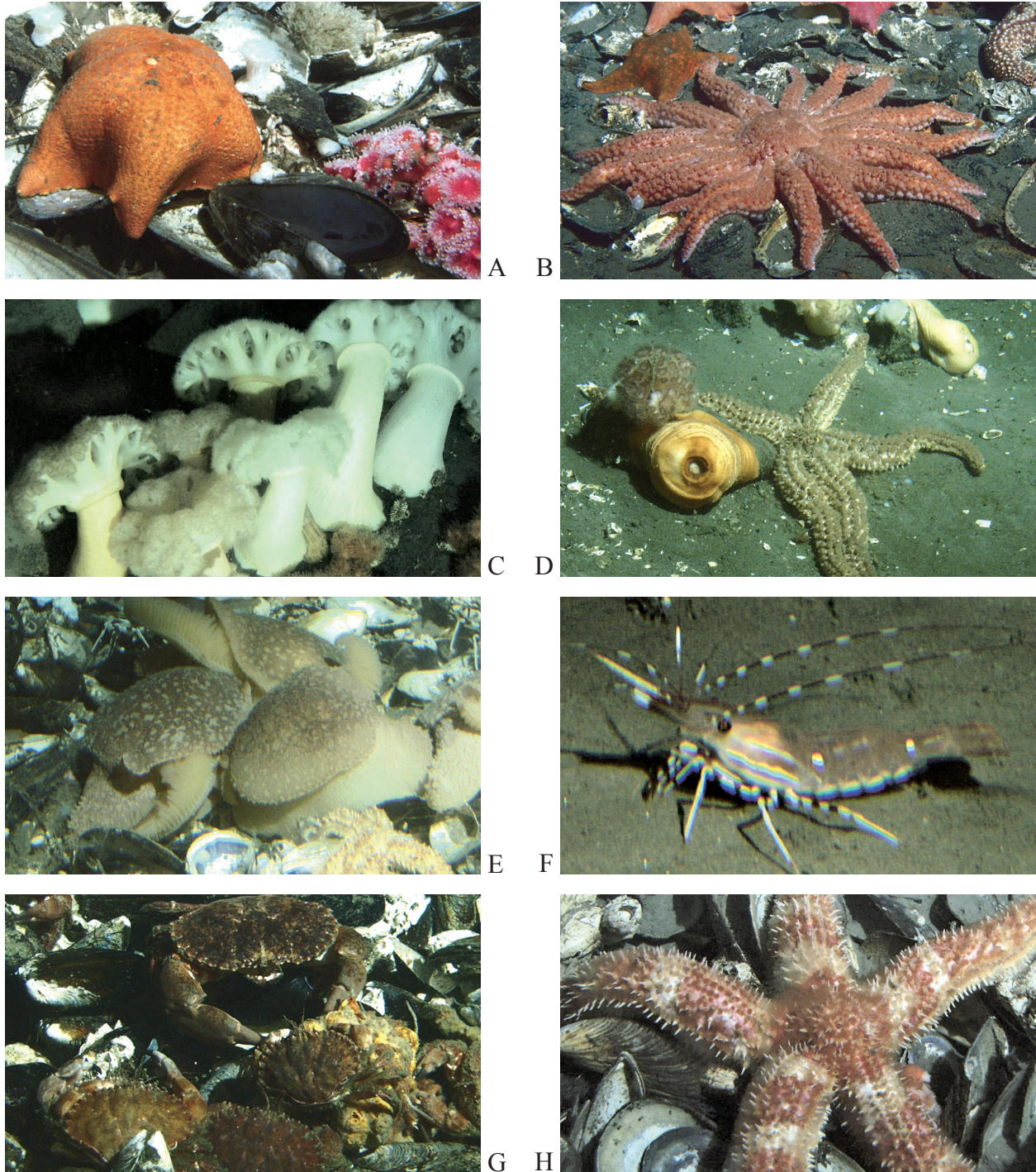
Figure 2. Some major megabenthic invertebrates on shell mounds associated with oil and gas platforms off southern CA: (A) Bat star (*Asterina miniata*) and club anemones (*Corynactis californicus*), (B) Sunstar (*Rathbunaster californicus*) surrounded by bat stars, and one giant-spined seastar (*Pisaster giganteus,* upper right), (C) White-plumed anemones (*Metridium farcimen*), (D) Long-rayed seastar (*Stylasterias forreri*), (E) Side-gilled slugs (*Pleurobranchaea californica*), (F) Spot prawn (*Pandalus platyceros*), (G) Rock crabs (*Cancer antennarius*), (H) Rainbow star (*Orthasterias koehleri*). Photographs by the Love Lab, UC Santa Barbara.
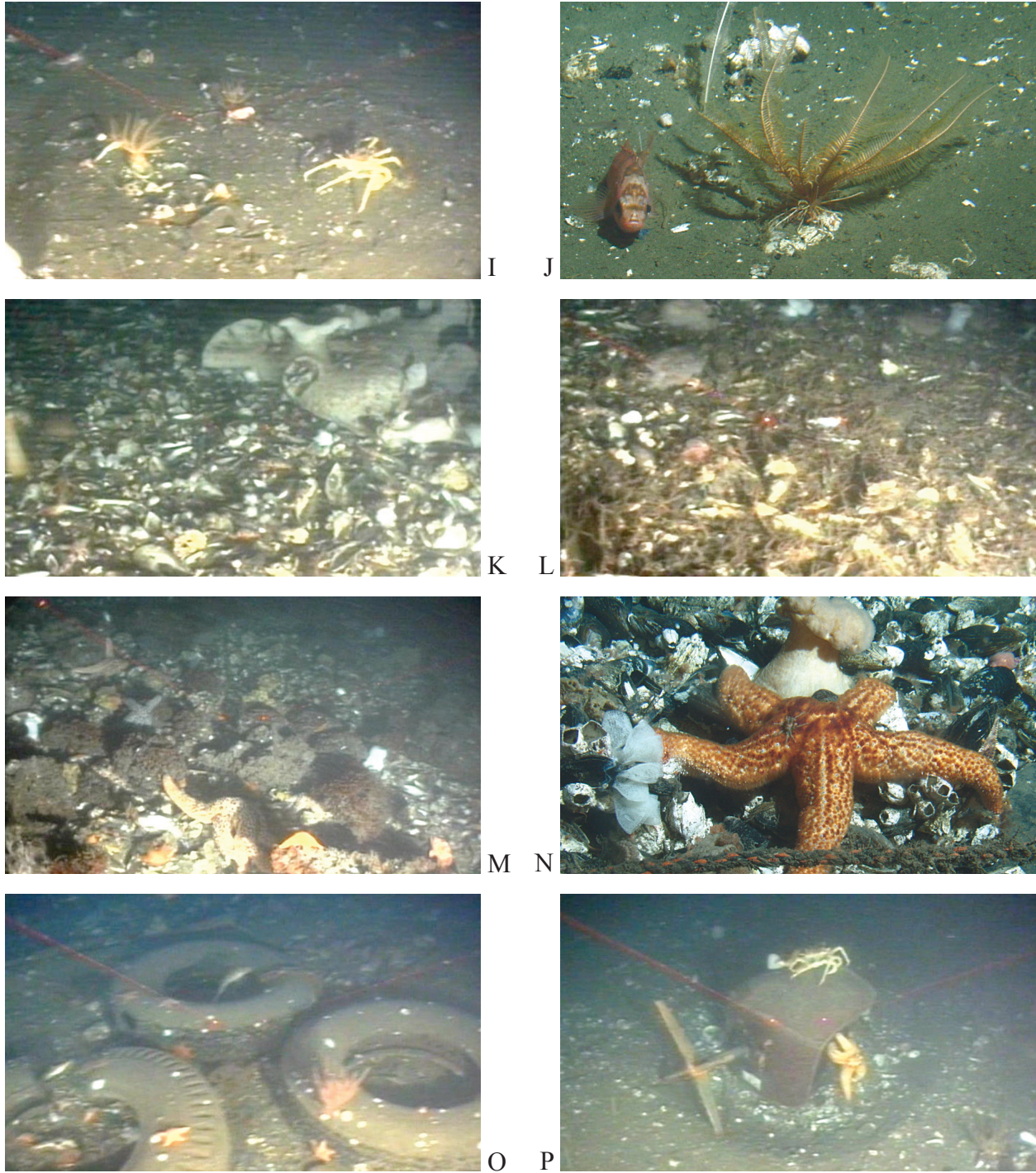
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Figure 2 (continued). (I) Crinoid (*Florometra serratissima,* upper center and left center) and King crab (*Paralithodes californiensis,* right), (J) Crinoid (*Florometra serratissima,* center) and sea pen (upper left), (K) Large foliose sponge (upper right) under Platform Hermosa, (L) Brittle stars (*Ophiuroidea*) under Platform Hidalgo 2000, (M) Clumps of the foliose bryozoan (*Watersipora subtorquata*) under Platform Gilda, (N) Giant-spined seastar (*Pisaster giganteus,* center), White-plumed anemone (*Metridium farcimen,* upper center), and egg ribbon of side-gilled slug (*Pleurobranchaea californica,* left center), (O) Gorgonian (on right tire), (P) King crab (*Paralithodes californiensis*) and seastar (*Pisaster* sp.) on platform debris. Red laser points 20 cm apart.

separate requests (including images) for assistance in identifying this taxon sent to Dr. Gordon Hendler at the Los Angeles County Museum of Natural History and USC were not answered.

The bat star *Asterina miniata* was common in the shell mound transects and is known for its broad, triangular arms and extremely variable color pattern. At low resolution and low viewing angles (which obscure the shape of the arms), *Mediaster aequalis*, *Hippasteria spinosa*, young *Dermasterias imbricata* and perhaps *Poraniopsis inflata* might be mistaken for *A. miniata*. We did not identify any *Mediaster aequalis* in the transects, but did observe two unequivocal specimens on the shell mounds under Platforms Harvest and Hermosa prior to the start of the1998 and 2000 transects, respectively.

In the videos we were usually unable to distinguish between *Pisaster giganteus*, P. *brevispinus*, and *P. ochraceus*. Consequently, we lumped these three species together as *Pisaster* spp. Most specimens on the shell mounds appeared to be *P. giganteus*. Likewise, we were unable to distinguish between the rock crabs *Cancer productus*, *C.*, *anthonyi*, and *C. jordani* and lumped these as *Cancer* spp. (however, *C. magister* were distinctive in the videos).

Sampling biases

Because only one video transect was conducted per platform shell mound per year per year, the quadrat sampling is representative of that transect, not necessarily the entire shell mound. Moreover, owing to limitations on the *Delta*'s pilot to circumnavigate a shell mound - most notably the need to keep a platform's legs and crossbeams in sight - the transects at a given platform probably overlap in successive years, meaning that successive transects are not entirely spatially independent. With these caveats in mind, we assumed that each transect was reasonably representative of each shell mound in the year surveyed.

The use of DVD's allowed for the capture of still images of reasonably good quality, permitting the quadrat sampling, but some loss of resolution occurred in copying the original Hi-8 videos to DVD. Variable speed by the *Delta* also resulted in variable resolution (the faster the submersible's speed the lower the resolution in a still image). This lack of resolution limited our ability to identify some taxa, especially those defined by spines and other structures less than a few millimeters in diameter, and also limited our ability to discern individuals smaller than a few cm in length. Consequently, our estimates of density for many of the organisms are underestimates that do not include juveniles, a limitation further compounded by the spatial complexity of the shell mounds themselves, with abundant interstices and refuges for small individuals. Finally, some medium-sized organisms (e.g. the chestnut cowrie, *Zonaria spadicea*, which grows to about 35 mm in length) were conspicuous to and verbally noted by the observer on the *Delta* but were not visible at all in the videos.

Results

Substrata

Percent cover of shell hash, based on quadrats with at least 10 % cover shell, ranged from 100 % under Platform Edith, which was located in shallow water and sampled once, to about 40 % under the two deepest platforms, both of which were also sampled only once (Tables 1 and 3, Figure 3). The shell matrix consisted mainly of mussels, *Mytilus* spp. (*californianus* and the non-native *galloprovincialis*) and barnacles (*Balanus* spp.), but also contained rock scallops (*Crassodoma gigantea*), jingle shells (*Pododesmus cepio*) and varying amounts of encrusting
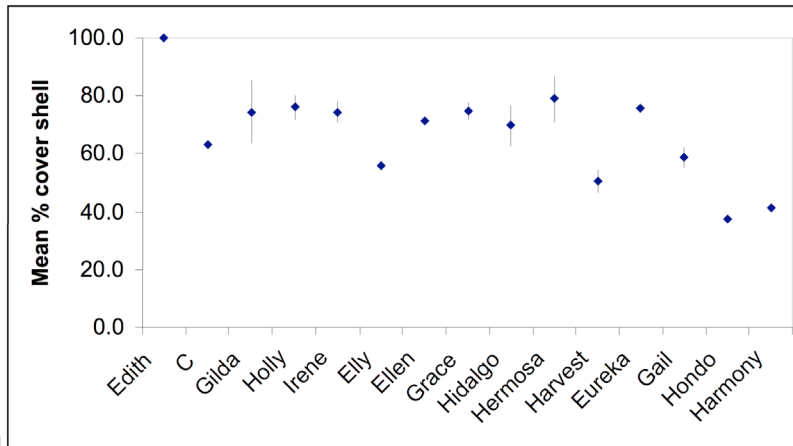
Figure 3. Mean % cover shell on shell mounds under California oil and gas platforms. Based on all quadrats with at least 10 % cover shell from transects conducted 1997-2005. For the 8 platforms surveyed in multiple years the values are grand means ± one standard error, sample size (= number of years surveyed) for these are given in Table 1.

sponges and the anthozoans *Corynactis californicus* and *Metridium senile*. Rock was observed only under platforms C, Holly and Irene, comprising low mean % cover on all three shell mounds (Table 3). At Platforms C and Holly the rock substratum consisted of localized outcrops of bedrock, while that under Platform Irene consisted of scattered cobble. Anthropogenic platform debris, providing additional hard substrata for invertebrates (e.g., Figure 2o and 2p), was observed on all but two shell mounds and was densest on the mounds in less than 100 m of water (Tables 1 and 3). Tires, screens, grates, and pipes appeared especially prevalent. All substrata other than the above mentioned shell hash, rock and platform debris consisted of fine sediments and the occasional pipeline.

Megabenthic invertebrates

Thirty-two invertebrate taxa, not including ophiuroids, were identified in the video transects (Table 2). The most widely distributed and abundant taxa, accounting for 90% of the total number of individuals counted, were three sea stars (*Asterina miniata*, *Pisaster* spp. [primarily *P. giganteus*] and *Stylasterias forreri*), large, white-plumed anemones, *Metridium* spp. (primarily *M. farcimen*), Side-gilled sea slugs, *Pleurobranchaea californica*, and Spot prawns, *Pandalus platyceros* (Figure 2). *Asterina miniata* and *Metridium* occurred at all shell mounds, while *Pisaster* spp. were observed at all but two shell mounds (Table 3). Other abundant taxa included *Dermasterias*-like sea stars, the sun star *Rathbunaster californicus*, the echinoid *Allocentrotus fragilis*, and rock crabs, *Cancer* spp. (primarily *C. productus*, *C. antennarius* and *C. jordani*) (Figure 2). One non-native species was observed; this was the foliose bryozoan *Watersipora subtorquata*, which occurred in large clumps under Platform Gilda (Figure 2m). Overall, echinoderms were the most abundant taxon, with sea stars alone comprising 77 % of the total number of organisms counted.

Mean densities of shell mound invertebrate taxa, averaged across all years for each platform, are given in Table 3, and the densities of the most common taxa are shown in Figure 4.

Table 2. Total numbers of megabenthic invertebrates observed in quadrat sampling in all transects at all platforms, 1997-2005. Does not include ophiuroids, whose abundance was estimated qualitatively.

Taxon	All quadrats (n = 2260)		Quadrats with ≥ 10 % cover of shell (n = 1976)	
	N	% of total	N	% of total
Bat star *Asterina miniata*	6384	58.67	6184	59.28
Large, white-plumed anemone *Metridium farcimen*	1367	12.56	1297	12.43
Sea stars *Pisaster* spp.	839	7.71	833	7.99
Long-rayed sea star *Stylasterias forreri*	478	4.39	467	4.48
Side-gilled slug *Pleurobranchaea californica*	385	3.54	366	3.51
Spot prawns *Pandalus platyceros*	279	2.56	270	2.59
Dermasterias-like sea stars	230	2.11	229	2.20
Sun star *Rathbunaster californicus*	161	1.48	154	1.48
Fragile sea urchin *Allocentrotus fragilis*	156	1.43	150	1.44
Rock crabs *Cancer* spp.	145	1.33	138	1.32
Sea pens (Virgulariidae)	106	0.97	12	0.12
Rainbow star *Orthasterias koehleri*	70	0.64	70	0.67
Sunflower star *Pycnopodia helianthoides*	69	0.97	69	0.66
Clumps of club anemone *Corynactis californicus*	51	0.47	51	0.49
Clumps of bryozoan *Watersipora subtorquata*	47	0.43	47	0.45
Unidentified holothurians	22	0.20	16	0.15
Sea cucumber *Parastichopus californicus*	19	0.17	16	0.15
Crinoid *Florometra serratissima*	12	0.11	12	0.12
Octopuses	11	0.10	10	0.10
Gorgonians (Gorgonacea)	10	0.09	5	0.05

Table 2 continued

Taxon	All quadrats (n = 2260)		Quadrats with ≥ 10 % cover of shell (n = 1976)	
	N	% of total	N	% of total
Sheep crab *Loxorhynchus grandis*	9	0.08	9	0.09
King crab *Paralithodes californiensis*	9	0.08	6	0.06
Dungeness crab *Cancer magister*	6	0.06	6	0.06
Vase & barrel sponges	5	0.05	4	0.04
Dorid nudibranch sea slugs	4	0.04	4	0.04
Spiny sea star *Poraniopsis inflata*	2	0.02	2	0.02
Box crab *Lopholithodes foraminatus*	1	0.01	1	0.01
Galatheid crustaceans	1	0.01	1	0.01
Foliose sponges	1	0.01	1	0.01
Sea pen *Ptilosarcus gurneyi*	1	0.01	1	0.01
Unidentified anemone	1	0.01	1	0.01
Whelk (Gastropoda)	1	0.01	1	0.01
Total	10882		10432	

Excluding brittle stars, *Asterina miniata* attained the highest densities, reaching nearly 100 individuals per 10 m² under Platform Elly. This species had a wide depth distribution, but was most abundant in waters less than 100 m deep. Other taxa more abundant in waters less than 100 m deep included *Pisaster* spp., *Dermasterias*, and rock crabs (Figure 4). The large, side-gilled slug *Pleurobranchaea californica* was most abundant at intermediate depths (100 – 200 m). *Metridium*, *Stylasterias*, *Allocentrotus*, *Orthasterias*, *Florometra*, *Paralithodes* and sea pens were all most abundant below 200 m (Figure 4). Spot prawns, *Pandalus platyceros*, were only seen in abundance under Platform Gail, in 225 m, with a few more seen at Platform Hondo, in 257 m. Both of the sun stars (*Pycnopodia* and *Rathbunaster*) were found in abundance both above 100 m and a little below 200 m, but were less abundant under the platforms in intermediate depths. *Metridium*, unidentified sea cucumbers and *Allocentrotus* were the only macro invertebrates abundant under the Platform Harmony, in 365 m of water.

Seven types of large, sessile, structure-forming invertebrates were observed on the shell mounds: *Metridium*, gorgonian octocorals, vase and foliose sponges, the crinoid *Florometra*, *Watersipora*, and sea pens, including a single colony of *Ptilosarcus* (Tables 2 and 3). Sea pens, which inhabit soft sediments, were mostly observed in quadrats with less than 10 % cover of shell (Table 2) and will not be considered further. Clumps of the non-native bryozoan

Table 3. Substratum characteristics and densities (per 2 m²) of shell mound invertebrates. Mean values ± 1 standard deviation, based on all quadrats with ≥ 10 % cover of shell across all years at each platform. Mean % cover of rock (cobble to bedrock) and densities of platform debris based on all quadrats (n = 40 per shell mound) in the most recent year each platform shell mound was sampled (see Table 1). Densities for *Corynactis* and *Watersipora* are of clumps (see Methods). See Table 2 for complete names of taxa. A value of 0.00 indicates a mean value of < 0.005, and blanks indicate that the taxon or substratum type was not observed in the quadrats

Substratum Taxon	Platform (shallow to deep) (Total no. quadrats with ≥ 10 % cover of shell/Total no. quadrats sampled)													
	Edith (40/40)		C (33/40)		Gilda (77/80)		Holly (147/200)		Irene (270/280)		Elly (36/40)		Ellen (30/40)	
% cover shell	100.0	± 0.0	62.9 ±	38.4	74.6	± 30.9	77.5	± 30.6	74.4	± 29.2	55.7	± 30.4	71.3	± 26.7
% cover rock			7.9	± 24.7			1.9	± 5.7	0.5	± 3.2				
Platform debris[1]			0.68	± 1.14	0.23	± 0.58	0.80	± 1.20	0.08	± 0.27	0.60	± 0.93	0.68	± 1.56
Metridium	0.10	± 0.38	0.06	± 0.24	0.09	± 0.33	0.04	± 0.23	0.24	± 0.52	0.08	± 0.28	0.27	± 0.58
ophiuroids/50							0.07	± 0.36	1.57	± 5.11	7.28	± 9.70	16.21	± 7.71
Pycnopodia									0.07	± 0.29				
Rathbunaster														
Stylasterias														
Asterina	10.28	± 3.36	3.45	± 3.27	6.08	± 7.17	3.07	± 2.66	3.21	± 3.91	19.25	± 8.83	13.93	± 6.34
Pisaster	0.43	± 0.64	0.12	± 0.33	0.14	± 0.48	0.39	± 0.86	0.76	± 1.36	0.25	± 0.50	0.33	± 0.76
Dermasterias-like									0.59	± 0.95			0.07	± 0.37
Orthasterias									0.00	± 0.06				
Poraniopsis														
Parastichopus					0.01	± 0.11	0.01	± 0.12			0.06	± 0.23	0.13	± 0.35
other holothuroids														
Pleurobranchaea									0.14	± 0.54				
octopuses	0.03	± 0.16							0.00	± 0.06				
Spot prawns														
Cancer spp.					0.49	± 2.17			0.14	± 0.59				
Paralithodes			0.06	± 0.35			0.01	± 0.12			0.03	± 0.17		
gorgonians														
sea pens														
Florometra														
Cancer magister									0.01	± 0.12				
Loxorhynchus														
Allocentrotus														
Ptilosarcus														
vase sponges														
foliose sponges														
Lopholithodes														
Watersipora					0.61	± 1.65								
Corynactis	0.13	± 0.33	0.09	± 0.29	0.01	± 0.11					0.03	± 0.17	0.07	± 0.25
unid. anemones														
dorid nudibranchs									0.01	± 0.14				
unid. whelk	0.03	± 0.16												
Total no. taxa	6		5		7		6		12		7		7	
Mean no. taxa/yr.	6		5		5		4		7		7		7	

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Table 3 continued

Substratum / Taxon	Grace (334/360)	Hildalgo (252/280)	Hermosa (200/200)	Harvest (213/220)	Eureka (32/40)	Gail (36/40)	Hondo (24/40)	Harmony (32/40)
% cover shell	74.6 ± 31.2	71.3 ± 30.3	79.0 ± 22.0	51.4 ± 29.3	75.6 ± 31.1	59.6 ± 37.6	37.3 ± 29.0	41.1 ± 25.9
% cover rock								
Platform debris[1]	0.40 ± 0.67	0.08 ± 0.27	0.13 ± 0.33	0.08 ± 0.27	0.25 ± 0.54	0.05 ± 0.22	0.25 ± 0.49	
Metridium	0.64 ± 1.02	0.65 ± 1.15	0.86 ± 1.02	1.35 ± 1.29	0.56 ± 0.72	1.27 ± 1.84	0.08 ± 0.3	0.69 ± 1.00
ophiuroids/50	0.19 ± 1.58	5.74 ± 8.80	0.34 ± 2.04		0.01 ± 0.05			0.01 ± 0.04
Pycnopodia	0.01 ± 0.09	0.03 ± 0.19	0.02 ± 0.14	0.13 ± 0.33	0.03 ± 0.18	0.03 ± 0.16		
Rathbunaster	0.21 ± 0.57	0.00 ± 0.06	0.02 ± 0.12	0.32 ± 0.57	0.28 ± 0.46	0.01 ± 0.09		
Stylasterias	0.16 ± 0.52	0.01 ± 0.11	0.09 ± 0.90	0.79 ± 1.66	1.41 ± 2.03	0.70 ± 1.78		
Asterina	6.03 ± 4.99	0.75 ± 2.13	0.08 ± 0.33	0.61 ± 1.33	9.88 ± 11.97	0.09 ± 0.36	3.00 ± 3.7	0.03 ± 0.18
Pisaster	1.11 ± 2.34	0.18 ± 0.55	0.01 ± 0.07	0.12 ± 0.35	0.03 ± 0.18	0.30 ± 0.77		
Dermasterias-like	0.11 ± 0.37	0.05 ± 0.25	0.01 ± 0.10	0.07 ± 0.27	0.03 ± 0.18			
Orthasterias	0.03 ± 0.19	0.05 ± 0.24	0.01 ± 0.10	0.11 ± 0.35	0.09 ± 0.30	0.06 ± 0.26		
Poraniopsis					0.00 ± 0.07	0.00 ± 0.06		
Parastichopus					0.00 ± 0.07			0.19 ± 0.54
other holothuroids							0.50 ± 0.7	0.13 ± 0.42
Pleurobranchaea	0.70 ± 0.42	0.49 ± 0.89	0.25 ± 0.58	0.44 ± 0.81	0.03 ± 0.18	0.14 ± 0.48	0.04 ± 0.2	
octopuses	0.01 ± 0.13	0.01 ± 0.09				0.00 ± 0.06	0.04 ± 0.2	
Spot prawns						1.05 ± 2.23	0.04 ± 0.2	
Cancer spp	0.01 ± 0.08	0.01 ± 0.09	0.07 ± 0.27	0.01 ± 0.10		0.16 ± 0.64		0.03 ± 0.18
Paralithodes						0.02 ± 0.14	0.04 ± 0.2	
gorgonians								
sea pens				0.00 ± 0.07	0.06 ± 0.25	0.04 ± 0.26		
Florometra		0.02 ± 0.18			0.03 ± 0.18	0.02 ± 0.19		
Cancer magister		0.00 ± 0.06	0.01 ± 0.07					
Loxorhynchus	0.03 ± 0.24							
Allocentrotus					0.53 ± 1.67			4.16 ± 4.11
Ptilosarcus						0.00 ± 0.06		
vase sponges			0.01 ± 0.07			0.01 ± 0.11		
foliose sponges							0.04 ± 0.2	
Lopholithodes						0.00 ± 0.06		
Watersipora								
Corynactis	0.10 ± 0.30		0.01 ± 0.07	0.00 ± 0.07	0.06 ± 0.25	0.00 ± 0.06		
unid. anemones	0.00 ± 0.05							
dorid nudibranchs			0.01 ± 0.07					
unid. whelk								
Total no. taxa	6	5	7	6	12	7	7	
Mean no. taxa /yr.	6	5	5	4	7	7	7	

Platform (shallow to deep)
(Total no. quadrats with ≥ 10 % cover of shell/Total no. quadrats sampled)

[1] Anthropogenic debris, including tires, pipe, grates, screens, machine parts, sheet metal, furniture, etc.

Watersipora certainly added structure to the shell mound under Platform Gilda (Figure 2m), but these colonies originate from the shallow reaches of the platform (Page et al. 2006), and it is unknown if they remain alive and continue growing on the shell mound. Of the remaining taxa, only *Metridium* was widespread on the shell mounds, reaching mean densities two orders of magnitude greater than gorgonians, sponges, and crinoids (Table 3). Ophiuroids (brittle stars) were abundant under some platforms (Table 3), but their arms are an order of magnitude smaller than the above taxa and retractile into the shell hash, and we did not consider them structure forming on the same scale as the other taxa.

   Metridium occurred on all types of hard substrata (Figures 2c, 2n, and 5), approximately in proportion to availability (personal observations), and an additional 49 individuals were counted on pipelines crossing the two shell mounds sampled for this taxon. Gorgonians, conspicuously absent from the shell hash, occurred only on rock and platform debris (Figures 2o and 5), and another 23 colonies were observed on pipelines. Crinoids (Figures 2i, 2j, and 5) were observed mainly on shell hash, and since no rock was observed in the transects used in this analysis, probably also occurred roughly in proportion to the availability of the different types of substrata. A total of only 6 large vase and foliose sponges were observed in the three video transects examined for this taxon; two were on shell hash (Figure 2k), while the substrata under the remaining four could not be determined.

Discussion

   Asteroid and ophiuroid echinoderms, the large sea anemone, *Metridium*, the large side-gilled slug *Pleurobranchaea californica*, and rock crabs *Cancer* spp. dominated the deepwater shell mound epifauna (Tables 2 and 3). In addition, spot prawns, *Pandalus platyceros* and the sea urchin *Allocentrotus fragilis* were dense at a few shell mounds, and the non-native bryozoan *Watersipora subtorquata* was dense under Platform Gilda. On the two shell mounds where it occurred *Allocentrotus fragilis* was often observed on mixed shell/soft sediment habitat and indeed, was densest under Platform Harmony, which had the second lowest % cover of shell (Table 3).

   The species composition of megabenthic invertebrates on the shell mounds overlaps with that known from the surrounding soft sediments. However, few of the numerically dominant taxa on the shell mounds are the same as found on soft sediments. Of the shell mound taxa, only *Allocentrotus fragilis* and depending on their specific identity, possibly also the ophiuroids, were recorded as comprising greater than 1% of the total abundance of megabenthic invertebrates on soft sediments on the southern California continental shelf (Allen et al. 2007, Tables V-11, V-12). In terms of total biomass, *Allocentrotus fragilis* was the top-ranked species on soft sediments, the sea cucumber *Parastichopus californicus* was third, and *Metridium farcimen* was 10th (Allen et al. 2007, Table V-13). None of the asteroids found on the shell mounds was numerically abundant on the soft sediments, but the sunflower star *Pycnopodia helianthoides* did account for 0.8 % of the total megabenthic invertebrate biomass on the southern California self from depths of 2 to 476 m in 2003, ranking it 13th (Allen et al. 2007, Table V-13).

   Except for ophiuroids and *Metridium*, both of which are suspension feeders and are using the platforms primarily as habitat, most of the dominant taxa on the shell mounds are carnivorous or omnivorous predators or scavengers, preying on living components of the shell matrix itself, or in the case of *Pycnopodia helianthoides* (and possibly also *Rathbunaster californicus*), occasionally on other members of this predatory guild (Carey 1972; Morris et al. 1980; Battle

and Nybakken 1998; Lambert 2000). The numbers of suspension-feeding taxa were few, and deposit-feeding taxa such as some holothurians and the sea urchin *Allocentrotus fragilis* were relatively uncommon, except on the deepest shell mounds. These results are consistent with those reported from shallow water shell mounds under existing platforms (Wolfson et al. 1979; Bomkamp et al. 2004) but as discussed further below, contrast with the comparative dominance of large, structure-forming, suspension-feeding species found on natural reefs at similar depths (Lissner and Dorsey 1986; SAIC and MEC, 1995, Tissot et al. 2006). Predatory asteroids comprised the only diverse taxon observed on the deepwater shell mounds.

As emphasized by Wolfson (1979) and elaborated on by Bomkamp et al. (2004), both of whom worked on shallow water (<50 m deep) shell mounds, the high density and diversity of sea stars on the shell mounds is dependent in large part on a food subsidy of mussels and other fouling organisms growing on the upper reaches of each platform. Asteroids are using the platforms primarily for food, and once this subsidy is cut off (e.g., by any of decommissioning options resulting in no platform structure in shallow water), the shell mounds become increasingly covered by sediments, and community composition shifts toward a higher proportion of omnivorous, suspension and deposit feeding species (de Wit 2001; Bomkamp 2003). Predatory sea stars would still remain, especially those whose diets include sponges, anemones and holothurians (e.g., *Asterina miniata*, *Dermasterias imbricata*, and *Pycnopodia helianthoides*). Rock crabs, which use shell mounds for habitat and recruitment (Page et al. 1999), would also persist but probably at lower densities owing to the absence of the shallow water food subsidy, particularly the molluscs and barnacles.

Pycnopodia helianthoides in particular is known to take both sea urchins and sea cucumbers as prey (summarized by Morris et al. 1980 and Lambert 2000), and it is noteworthy that the highest densities of both of these taxa were observed in the present study were on the deepest shell mounds, where neither *Pycnopodia* nor *Rathbunaster* were observed (Table 3, Figure 4).

During this study evidence of reproduction by shell mound taxa was limited to two species. Pairs of the large side-gilled opisthobranch sea slug *Pleurobranchaea californica* were observed in the side to side orientation characteristic of reciprocal copulation in most opisthobranchs, and the white, curtain-like egg ribbons of this species (Figure 2n) were often abundant on the shell mounds and could be seen fluttering in the presence of water currents. Individuals of the long-rayed sea star, *Stylasterias forreri*, were occasionally observed in the video transects humped up and elevated on the tips of their arms, a position assumed when spawning its gametes into the water column (Lambert 2000). Both species have small eggs and long-term planktotrophic development (Miller 2001; Goddard 2004), almost certainly ensuring transport of their larvae away from the shell mounds.

The sources of the organisms on the shell mounds undoubtedly varies by species, with some immigrating as juveniles or adults from the surrounding soft sediments or platform jackets, some recruiting as larvae, some simply arriving with the fouling organisms falling from the shallow water portions of the platform jackets, or some combination of these mechanisms. The sunstars *Pycnopodia* and *Rathbunaster*, both of which occur on soft sediments and are large and fast moving as adults (at least for asteroids; Lambert 2000) probably both immigrate and recruit to the shell mounds. The same is probably true for *Pleurobranchus californicus*, which is known from a variety of deepwater substrata, especially soft sediments (Chivers 1967; Battle and Nybakken 1998). However, this species, like other opisthobranchs, is relatively short lived (on the order of a year) compared to the asteroids, and the populations observed on the shells
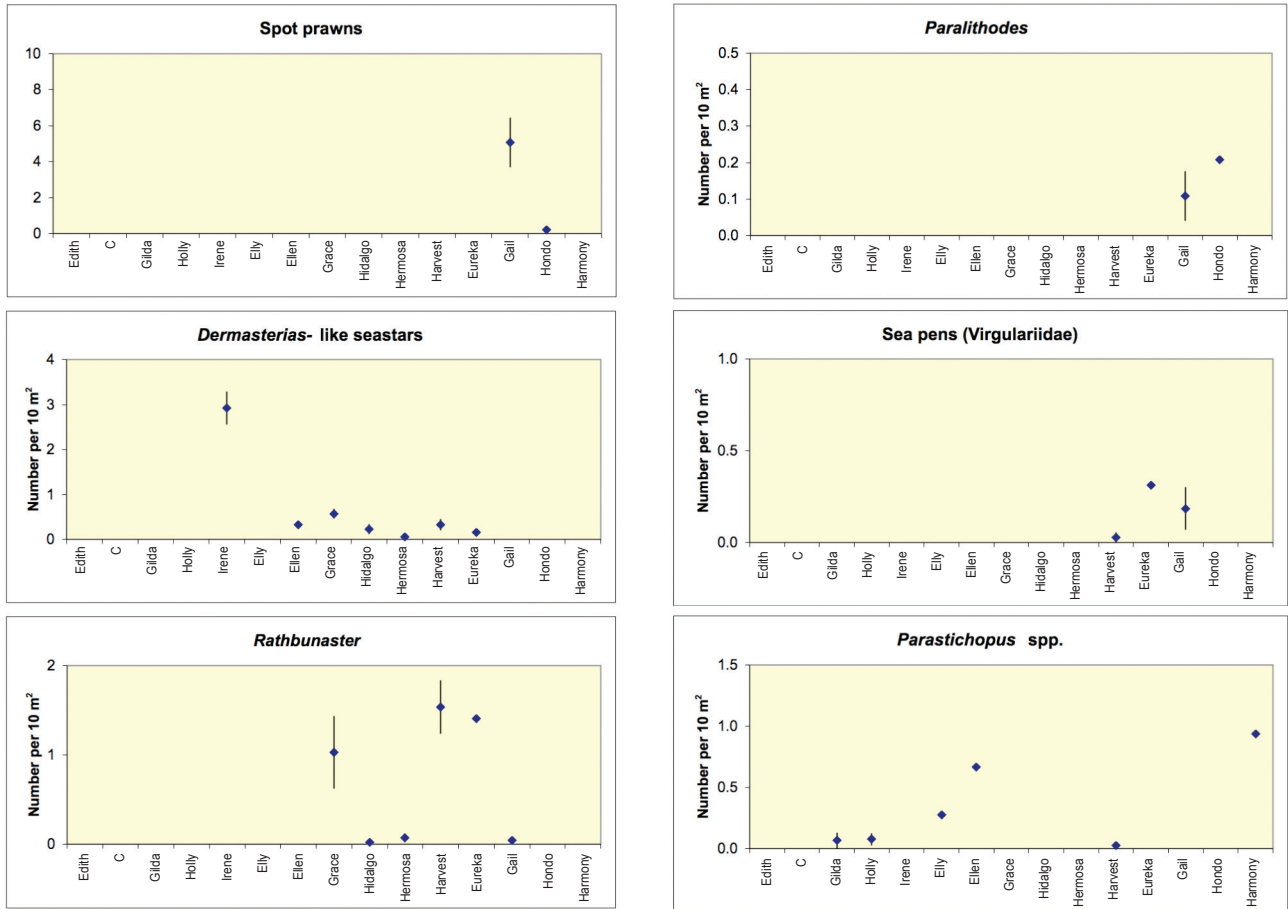
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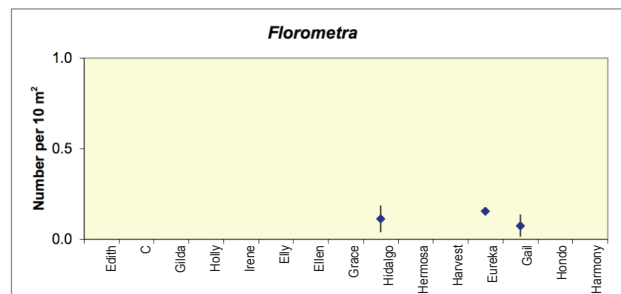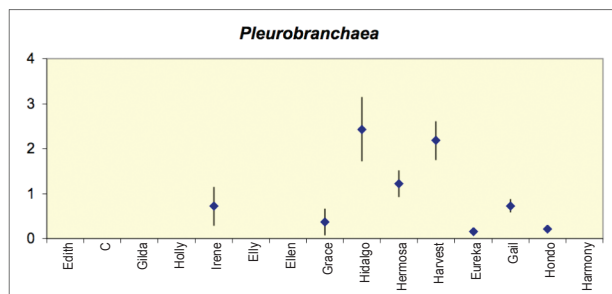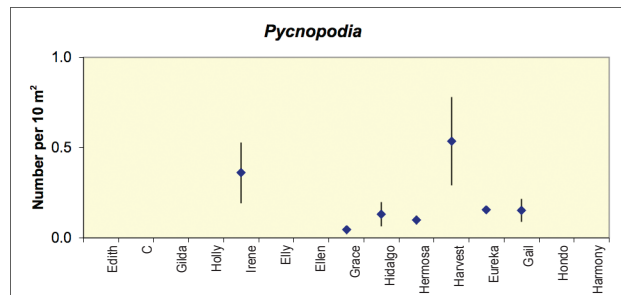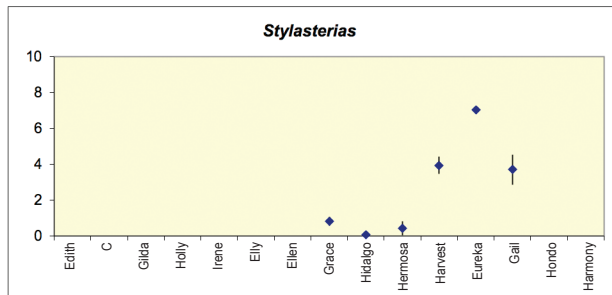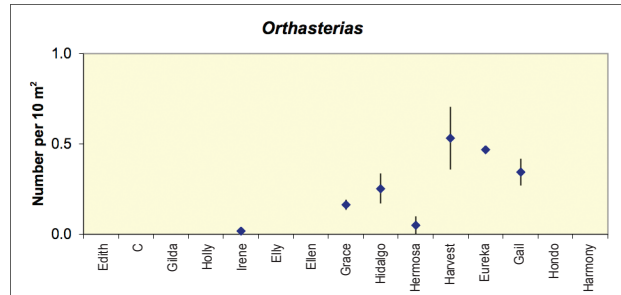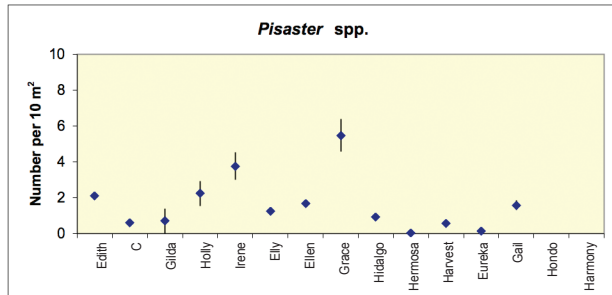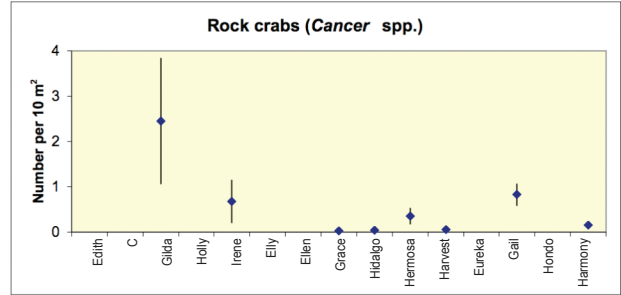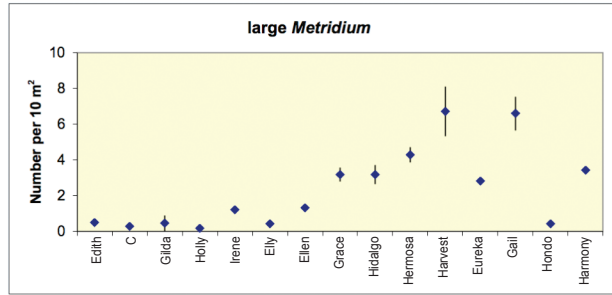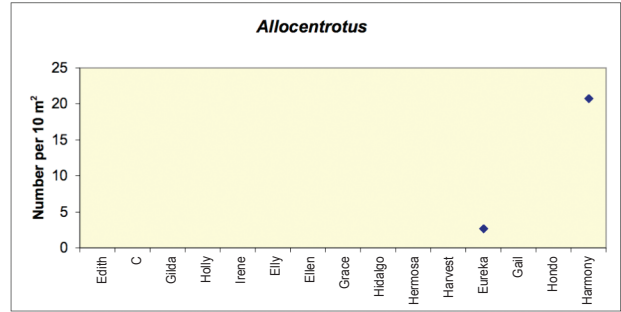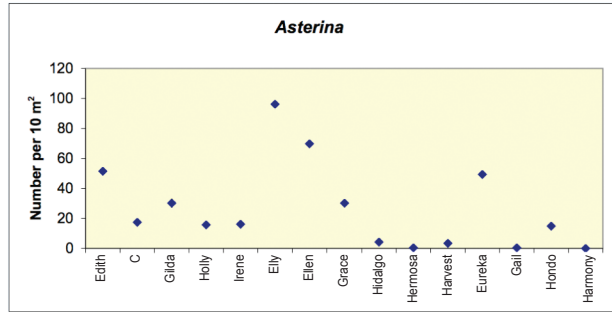
Figure 4. Mean densities of the most abundant megabenthic invertebrate taxa found on shell mounds under California oil and gas platforms. Platforms are listed left to right from shallowest to deepest. Full species names are given in Table 2. Based on all quadrats with at least 10 % cover shell from transects conducted 1997-2005. For the 8 platforms surveyed in multiple years the values are grand means with the associated standard errors; sample size (= number of years surveyed) for these are given in Table 1, right column.

mounds must arise at least in part through larval recruitment. Other sea stars, such as *Pisaster giganteus*, are specific to hard substrata (Hopkins and Crozier 1966; Maluf 1988) and therefore must arrive on the shell mounds as either larval recruits, or as juveniles and adults from the platform jackets. Given the long lengths of the deeper water platform jackets, vertical sections of which are dominated by anemones that species of *Pisaster* may not cross (e.g., Wolfson 1979), immigration of *P. giganteus* to the shell mounds may only be via falling shellfish. Sea stars such as *Orthasterias* and *Poraniopsis* occur naturally on a wide variety of substrata, including soft sediments Maluf 1988; Lambert 2000), but are slow moving as adults and to our knowledge are unknown from the platform jackets. They therefore probably arrive to the shell mounds as larval recruits. *Metridium farcimen* is abundant on platform jackets (e.g., see images in Love et al.

2003), can move very slowly as adults, but also has a free-swimming planula larva so probably populates the shell mounds through a variety of mechanisms.

The white-plumed anemone *Metridium farcimen* was the only large, structure-forming, sessile invertebrate prevalent on the shell mounds. It occurred on shell hash and artificial substrates on all shell mounds but reached its highest densities (> 0.3 per m^2) on the shell mounds in greater than 90 m of water. The other large, structure-forming taxa growing on the shell mounds (vase and foliose sponges, gorgonians and crinoids) each occurred at low density (< 0.03 per m^2) on only a few shell mounds. Where they occurred, sponges and crinoids were prevalent on shell hash, while gorgonians were restricted to rock and artificial substrates. Brittle stars were dense (> 40 per m^2) on four shell mounds, but their relatively small size and slender arms (which are retractable into the shell hash) do not contribute the same large-scale structure to the shell mounds as the above organisms.

When they did occur on shell mounds, vase and foliose sponges and crinoids were one to three orders of magnitude less dense than reported by Lissner and Dorsey (1986) and Tissot et al. (2006) for natural banks and reefs in the region. *Metridium*, not reported by Lissner & Dorsey (1986) from the Cortez and Tanner Banks, was up to two orders of magnitude denser on the shells mounds than reported by Tissot et al. (2006). When the suitable rock and artificial substrates were available, gorgonians were one to two orders of magnitude denser on shells mounds than reported by Tissot et al. (2006), but two to three orders of magnitude less dense than reported by Lissner and Dorsey (1986).

The relative lack of large sessile structure-forming taxa on the shell mounds other than *Metridium* may be due to avoidance by the larval stages of these species of settling on the relatively small, calcareous components of the shell hash, but might also result from high rates of predation on the post-metamorphic and juveniles stages by the abundant predatory sea stars, many of which, for example, include sponges in their diets (summarized by Lambert 2000). Regardless of the cause of their scarcity and low species richness, the lack of these structure-forming species, which typically shelter a wide variety of both sessile and mobile macro invertebrates and fishes (e.g., Tissot et al. 2006) probably results in significantly reduced overall biodiversity on the shell mounds compared to natural reefs (see also Task 3 below). These components of the shell mound benthic community could be enhanced in classic artificial reef style by the addition of large, non-shell, hard substrata. Because they are suspension feeders not as dependent as the mobile species on the food subsidy of shellfish growing on the platforms, enhancement of the large, structure-forming organisms would occur on the shell mound regardless of the presence or absence of a standing platform, and indeed, on a large scale could be accomplished by the platform decommissioning option that calls for toppling entire platforms. Given the large dimensions but relatively simple design of the platform jackets (the legs and crossbeams supporting both the topside structures and oil and gas conductors), huge amounts of artificial secondary structure and surface area could be added to toppled platforms, providing sites for settlement and growth of *Metridium* at all depths, gorgonians in at least shallow waters, and perhaps large sponges and crinoids and other taxa, such as black corals (Antipaththaria) in deeper waters. Separate from the growth of this biotic structure, the physically enhanced, toppled jackets would likely also provide many more spatial refuges for mobile invertebrates and fishes than exist on standing, unmodified platforms.

Efforts should be undertaken to determine if the large masses of *Watersipora subtorquata* on the shell mound under Platform Gilda are viable and reproducing. The occurrence of this non-native
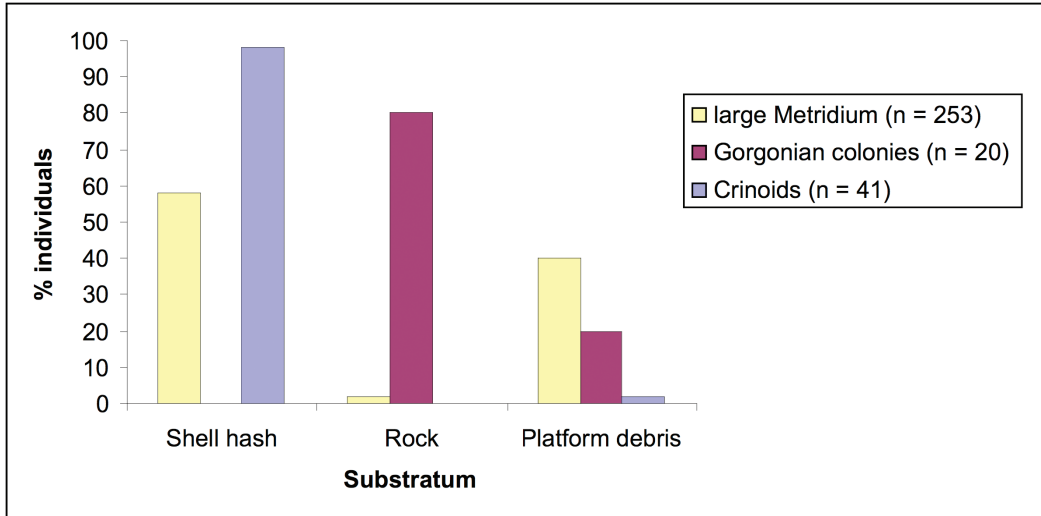
Figure 5. Percentage of large, structure-forming invertebrates on different substrata on shell mounds under California oil and gas platforms. Counts of *Metridium* were from a total of two transects under platforms Grace and Gail; gorgonians, from three transects under platforms C, Holly, and Elly; crinoids from under platforms Hidalgo, Eureka, and Gail.

species on the shell mound in 62 m of water 14 km from the mainland is a entirely a consequence of its establishment and vigorous growth on the shallow portions of the platform jacket (Page et al. 2006). In California *Watersipora subtorquata* had previously been known only from harbors and embayments, with a few records from shallow water (Cohen 2005), and its transfer to this platform (probably via boat or a submerged prefabricated platform component) and its shell mound (probably via platform maintenance) presents new risks for spread to previously unavailable deepwater habitats, including ecologically valuable natural reefs. Although these risks are ameliorated by the short (< one day) duration of the larval stage in this species (Cohen 2005), Platform Gilda is close enough to other platforms and the Channel Islands (Figure 1), that successive generations of larvae may be able to spread in steps from one suitable site to another.

Task 2: **Compare shell mound invertebrate species richness and community composition among platforms, and test for differences in community structure by year, depth, geographic location, and age of platform.**

Rationale

   Compared to natural hard-bottom communities, little known about the major environmental determinates of community structure on shell mounds. Armed with this basic ecological information, decisions concerning the decommissioning of the platforms can made taking into account the effects of various options on shell mound biodiversity. For example, knowledge of the depth and geographic distribution of species richness on the shell mounds is necessary if species rich mounds are targeted for conservation. Likewise, an understanding of geographic variation in the community composition on the shell mounds, which off California lie in three oceanographic basins and two biogeographic provinces, would be useful information if MMS decides that conservation of a variety of shell mound communities is desirable.

Methods

   We compared the number of taxa ("species richness") observed per year on each shell mound by (1) geographic location (Santa Maria Basin, Santa Barbara Channel, and San Pedro Bay), (2) age of platform (calculated by taking the midpoint of the range of years that each platform shell mound was sampled, and then subtracting from that the year that each platform was installed (Table 1)), and (3) depth of platform.

   We used the multivariate statistics package in the PRIMER (Version 5) statistical package (Primer-E, Ltd.) to test for significant differences in community composition between platform shell mounds, and between shell mounds grouped by the following environmental factors: (1) depth into categories of < 100m, 100 – 200 m, > 200m, (2) geographic location (as above), and (3) age of platform as calculated above, grouped into < 20 years, 20 – 25 years, and > 25 years. In the first test, years (= transects) served as replicates, while in the second group of tests, shell mounds, each averaged across all years sampled, served as replicates. First, a similarity matrix based on the Bray-Curtis coefficient was generated based on the density data (see below) for each pair of platforms, using PRIMER. Non-metric multi-dimensional scaling (MDS) was then used to plot a point, representing community composition at each shell mound, in a 2-dimensional ordination space. One-way analysis of similarity (ANOSIM) (Clarke and Green 1988; Clarke and Warwick 2001), a permutation test based on the difference between the average rank similarities among replicates between and within sites/groups, was then used to test for differences in community composition. The null hypothesis actually tested was that there are no differences in community composition between sites/groups.

   We conducted the above analyses using mean densities per 2m^2 of each taxon for each transect sampled, or for the analyses by environmental factor, the mean densities for each taxon, averaged across all years at each platform (as in Table 3). Densities for *Corynactis* and *Watersipora* are based on the numbers of clumps counted. To calculate densities of brittle stars, we converted the qualitative measure (none, few, moderate, abundant) to an order of magnitude number (0, 10, 100, 1000) per 2 m^2. Because brittle stars are relatively small compared to the other taxa we sampled, we divided the mean density per transect by 50 to avoid unduly weighting them in the community analyses.

   The density data were square root transformed before calculating the Bray-Curtis similarity

coefficients, as recommended by Clarke and Warwick (2001) for balancing the relative contribution of the common and rare species. The significance level of the observed sample statistic (R) for all ANOSIMs was calculated by PRIMER by comparing the observed R to its permutation distribution based on 999 random permutations of the sample labels or the maximum number of permutations possible, whichever was larger. R varies from 1 (all replicates are more similar to each other than to any replicates from other sites/groups) to 0 (similarities between and among sites/groups are on average the same), and can technically reach –1 if all similarities across sites are higher than those within sites (Clarke & Warwick 2001). R-values of 0.75 or greater indicate good discrimination between samples (Clarke & Warwick 2001).

Results

   The total cumulative number of taxa observed on each shell mounds varied from 5 at Platform C, which was sampled once, to 19 at Platform Gail, which was sampled 8 times (Table 3). The number of taxa observed per shell mound overlapped substantially by geographic location (Figure 6) and showed no pattern with age of platform (Figure 7A), especially omitting Platform Holly, which was the outlier with the fewest taxa and oldest age. However, the number of taxa per shell mound was positively correlated with depth for platforms sampled at least five times, spanning a depth range from 64 and 225 m (Figure 7B).
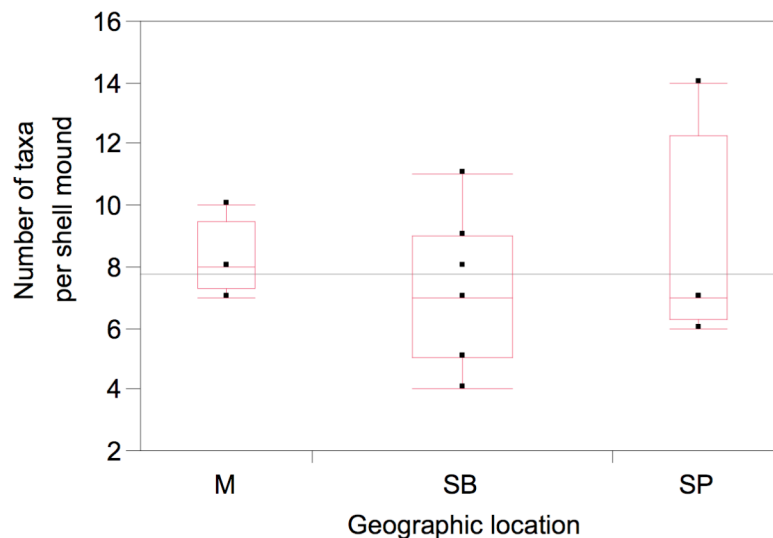

Figure 6. Box plots of the number of taxa on each shell mound by geographic location. M = Santa Maria Basin, SB = Santa Barbara Basin, SP = San Pedro Bay. For shell mounds sampled more than once the number of taxa is the yearly mean, n = 2-9 years per shell mound, with one transect conducted per year (see Table 1).
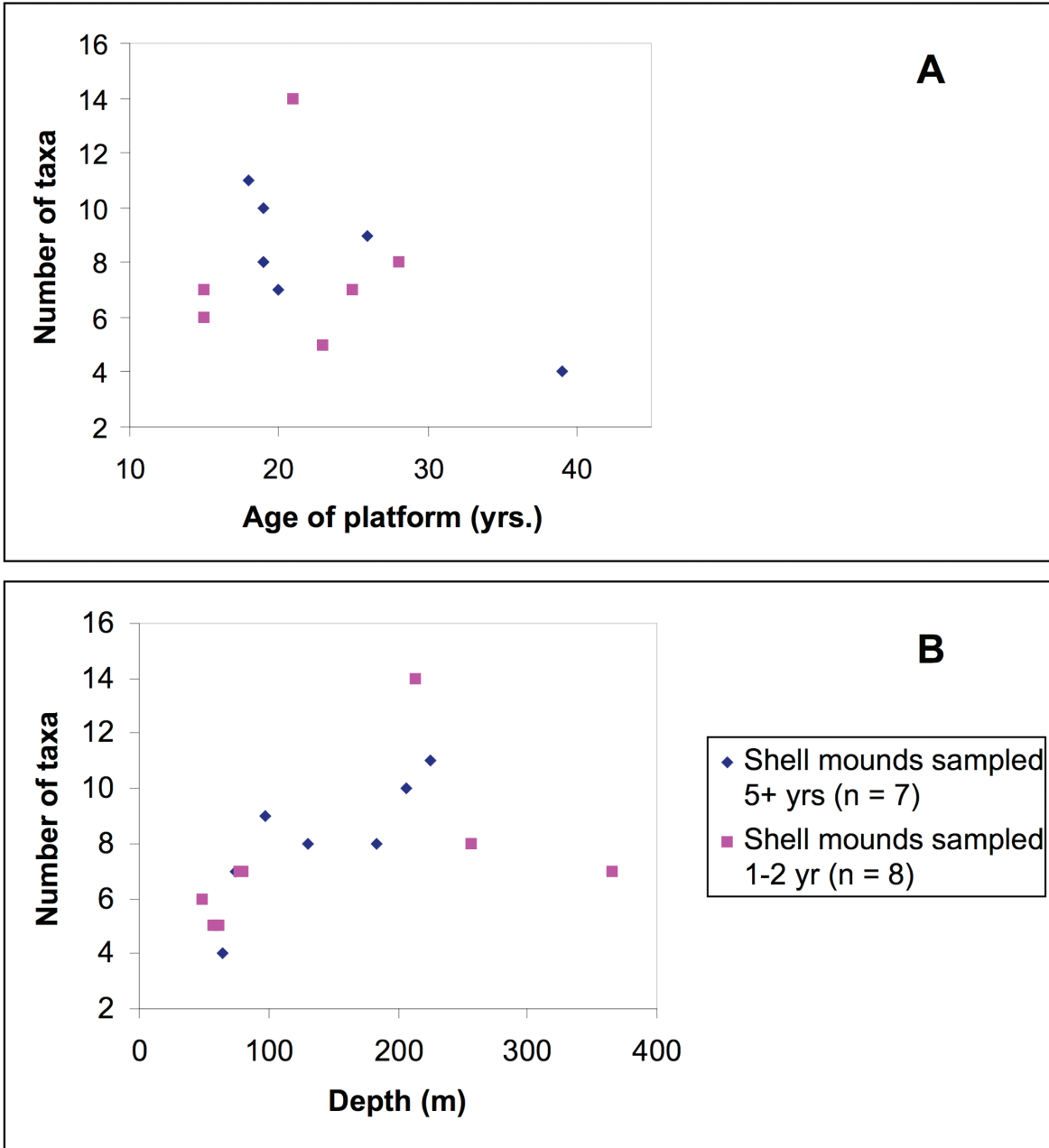
Figure 7. Relationship between the number of taxa observed on each shell mound and (A) age of platform, and (B) depth of platform. For platforms sampled more than once the number of taxa is the yearly mean, n = 2-9 years per shell mound. All points based on data from quadrats containing at least 10 % cover of shell.

MDS ordination of the species density data for all years at all platforms showed that each platform had a distinctive community composition (Figure 8), with the shell mound at Platform Hidalgo appearing to have the most temporally variable composition. The stress value of 0.14 in this MDS indicates that the ordination is reasonably well represented in 2 dimensions and would be only slightly improved in 3 dimensions. The global ANOSIM test for these data showed that these differences in community composition were highly significant (R = 0.926; P =

0.001). Furthermore, pair-wise ANOSIM analyses showed that community composition differed significantly between all combinations of platforms that were sampled at least twice (Table 4). The least significant of these pair-wise tests all included Platform Gilda which was only sampled twice, resulting in an order of magnitude fewer possible permutations (the equivalent of a reduced sample size) for the analysis of similarity (Table 4). The shells mounds at Platforms Hermosa and Hidalgo were the most similar in community composition, followed by the shell mounds at platforms Hidalgo and Irene and Harvest and Hidalgo (Figure 8, Table 4); all four of these platforms are located in the Santa Maria Basin (Figure 1).
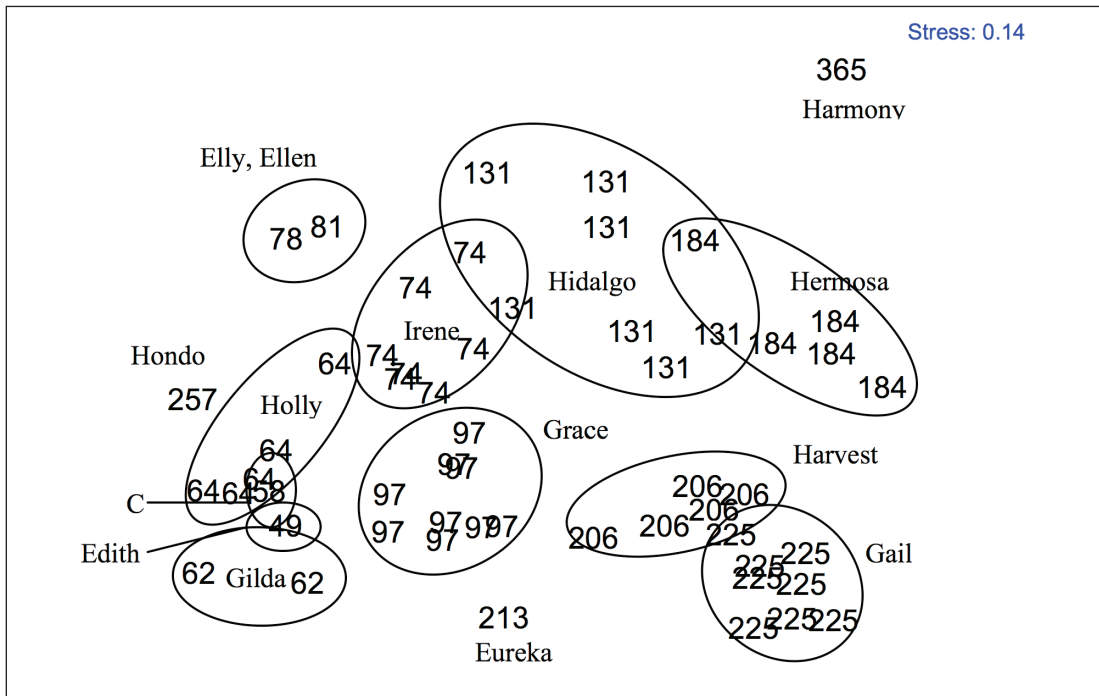

Figure 8. Non-metric MDS ordination of shell mound invertebrate assemblages, based on square root transformed densities of all taxa at each shell mound for each sampling period (see Methods). The numbers are the depths of the shell mounds, with replicates representing transects conducted in different years. The shell mounds under 6 platforms (e.g., Platform Harmony) were only sampled once.

The obvious clustering of the different sampling years at each shell mound (Figure 8) justified averaging the species densities across all years for each platform and then using those means to examine the influence of depth, geographic location, and age of platform on shell mound community composition.

The MDS ordinations of the average shell mound communities by depth and geographic location are shown in Figures 9A and 9B, respectively. The shell mound communities were well separated by these factors, particularly depth, and the stress value of 0.11 in both ordinations indicates that the ordinations are well represented in 2 dimensions. The global ANOSIM tests for shell mound communities grouped by, geographic location, and age of platform revealed significant differences by depth only, although the global ANOSIM tests for the other two

Table 4. ANOSIM (analysis of similarity) tests for differences between shell mound invertebrate assemblages at each platform sampled two or more times.

Test	R	P	No. of possible permutations	No. of permuted statistics ≥ observed R
Global	0.920	0.001	> 999	0
Pairwise:				
Gail, Gilda	1	0.022	45	1
Gail, Grace	1	0.001	> 999	0
Gail, Harvest	0.929	0.002	> 999	1
Gail, Hermosa	1	0.001	> 999	0
Gail, Hidalgo	0.927	0.001	> 999	0
Gail, Holly	1	0.003	> 999	2
Gail, Irene	1	0.001	> 999	0
Gilda, Grace	0.994	0.018	55	1
Gilda, Harvest	1	0.048	21	1
Gilda, Hermosa	1	0.048	21	1
Gilda, Hidalgo	0.994	0.028	36	1
Gilda, Holly	0.873	0.048	21	1
Gilda, Irene	0.987	0.028	36	1
Grace, Harvest	0.978	0.003	> 999	2
Grace, Hermosa	1	0.003	> 999	2
Grace, Hidalgo	0.899	0.002	> 999	1
Grace, Holly	0.929	0.002	> 999	1
Grace, Irene	0.859	0.001	> 999	0
Harvest, Hermosa	0.960	0.008	126	1
Harvest, Hidalgo	0.731	0.003	792	2
Harvest, Holly	1	0.008	126	1
Harvest, Irene	1	0.001	792	1
Hermosa, Hidalgo	0.552	0.008	792	6
Hermosa, Holly	1	0.008	126	1
Hermosa, Irene	0.993	0.001	792	1
Hidalgo, Holly	0.945	0.001	792	1
Hidalgo, Irene	0.705	0.001	> 999	0
Holly, Irene	0.948	0.001	792	1

Table 5. ANOSIM (analysis of similarity) tests for differences between invertebrate assemblages from groups of shell mounds based on (1) depth, (2) geographic location, and (3) age of platform.

Factor	Test	R	*P*	No. of possible permutations	No. of permuted statistics ≥ observed R
Depth	Global	0.554	0.002	> 999	1
	< 100 m vs. > 200 m	0.591	0.004	> 999	3
	< 100 m vs. 100 – 200 m	0.681	0.022	45	1
	> 200 m vs. 100 – 200 m	-0.091	0.571	21	12
Geographic location	Global	0.197	0.055	> 999	54
	San Pedro Bay vs. Santa Barbara Channel	0.069	0.267	330	88
	San Pedro Bay vs. Santa Maria Basin	0.719	0.029	35	1
	Santa Barbara Channel vs. Santa Maria Basin	0.111	0.236	330	78
Age of platform	Global	0.172	0.083	> 999	82
	< 20 years vs. 20 – 25 years	0.156	0.087	> 999	86
	< 20 years vs. > 25 years	0.182	0.278	33	10
	20 – 25 years vs. > 25 years	0.302	0.179	28	5

factors were nearly significant (Table 5). In the pair-wise geographic comparisons, shell mound communities in the Santa Maria Basin differed significantly from those in San Pedro Bay (Figure 9B, Table 5). The nearly significant effect of platform age probably simply reflects the relationship between platform age and depth: with the notable exception of platform Hondo, shallower platforms tend to be older, and visa versa (Table 1).

Discussion

The average number of megabenthic taxa observed on the shell mounds per year did not appear to differ significantly by age of platform or geographic region. However sample sizes for the latter comparison were low, with only four platforms in two each of the three basins studied, and the number of years each platform was sampled varied widely. Given the positive correlation between the number of taxa and depth (Figure 7B), it is noteworthy that the only shell mound sampled in the Santa Maria Basin in less than 100 m (at Platform Irene) had more taxa (7 per year) than any of the four shallow water shell mounds from the other two regions (range, 4 – 6 taxa per year). The Santa Maria Basin, which lies just inside the colder and more biologically
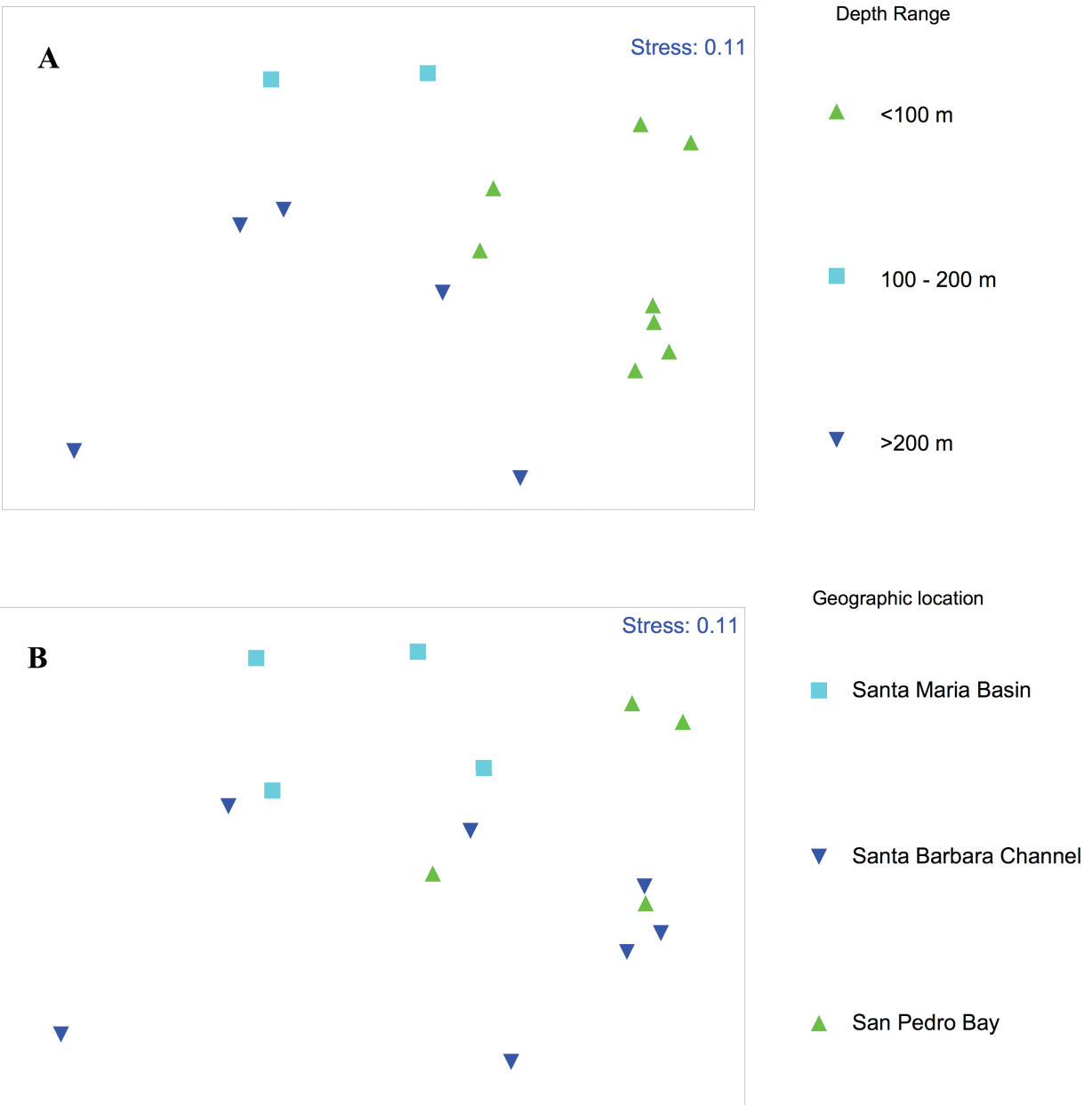
Figure 9. Non-metric MDS ordination of shell mound invertebrate assemblages, grouped by (A) depth range and (B) geographic location. Ordination based on square root transformed densities, averaged across all years at each shell mound, of all taxa. Each point represents a shell mound under a different platform.

productive Oregonian biogeographic province, may indeed be found to harbor more species than the other two regions over similar depth ranges.

Despite the obvious overlap in species composition between platforms (Table 3), the MDS ordination of the species density data showed that each platform had a distinctive community composition (Figure 8, Table 4), with the shell mound at Platform Hidalgo having the most

temporally variable community composition. The platforms with the most similar communities were all from the Santa Maria Basin (Tables 1 and 5), likely reflecting (1) their more limited depth and age ranges compared to the platforms in the other two regions studied (Table 1) and (2) close physical proximity of the platforms to each other (Figure 1). The taxon most characteristic of these four platforms was the side-gilled opisthobranch *Pleurobranchaea californica* (Table 3, Figures 2E and 10), a carnivorous, scavenging and even cannibalistic species that grows to over 20 cm long (Battle and Nybakken 1998; Behrens and Hermosillo 2005).

   Of the three environmental factors examined, depth was found to be the most important determinate of community structure, a result consistent with previous studies on natural reefs in the region (Lissner and Dorsey 1986; SAIC and MEC 1995). Geographic location was also important in distinguishing between shell mound communities from the Santa Maria Basin and San Pedro Bay, the two areas at either end of the study region (Figure 1). Because the Santa Maria Basin lies northwest of Point Conception, the oceanographic boundary separating the Oregonian and Californian biogeographic provinces (Briggs 1974; Wares et al. 2001), community-level differences might also be expected between shell mounds in the Santa Barbara Channel and Santa Maria Basin, especially in shallow waters, where differences in current and thermal regimes are pronounced (reviewed by Wares et al. 2001, also see Harms and Winant 1998). However, the lack of shallow water platforms in the Santa Maria Basin (Irene is the only one in less than 100 m) precluded a meaningful analysis of this comparison. The difference in shell mound communities between the Santa Maria Basin and San Pedro Bay, while consistent with their location in different biogeographic provinces, is also compounded by differences in the their proximity to urbanized environments, and possibly therefore, levels of anthropogenic impacts on their respective benthic communities.

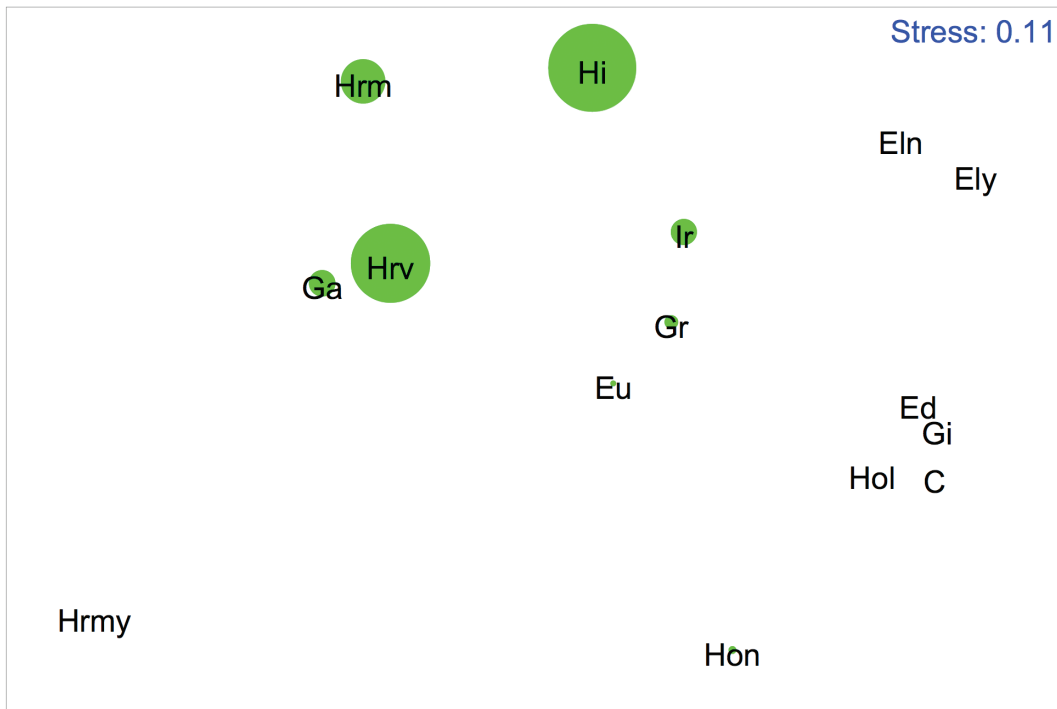Figure 10. Bubble plot showing mean density (per 2 m², as circles of differing sizes) of *Pleurobranchaea californica* by platform shell mound, with the shell mounds in the same MDS ordination as in Figure 9. Platforms abbreviations: Ed = Edith, Eln = Ellen, Ely = Elly, Eu = Eureka, C = Platform C, Ga = Gail, Gi = Gilda, Gr = Grace, Hol = Holly, Hrmy = Harmony, Hon = Hondo, Hrv = Harvest, Hrm = Hermosa, Hi = Hidalgo, Ir = Irene.

Task 3: **Investigate the relationship between the density of structure-forming invertebrates and fishes commonly associated with shell mounds.**

Rationale

   Given the increasing recognition of the importance of large sessile invertebrates in benthic ecosystems on the continental shelf and slope (e.g., Fossa et al. 2002; Heifetz 2002; Krieger and Wing 2002; Tissot et al. 2006), and especially the role these organisms might play in providing biotic structure and habitat for economically important species, we decided to test for association between fishes commonly observed on shell mounds and large, structure-forming invertebrates. As emphasized by Tissot et al. 2006, such associations do not necessarily demonstrate any functional importance of these invertebrates to the fishes. However, they might yield insights into existing field observations and suggest testable hypotheses concerning the underlying nature of the associations.

Methods

   We considered invertebrates as structure-forming if they were sessile or sedentary and rose 10 cm or more above a shell mound or above soft sediments interspersed with shell mound. At this scale, such invertebrates might provide, for example, a physical refuge from predation for juvenile fishes. Although the sea urchin *Allocentrotus fragilis* only reached about 5 cm in height, with its spines and high density on mixed shell-soft sediment habitat under two of the deeper platforms (Table 3), we decided to include it as a structure-forming species in the analysis for one of the deeper water fish. We also included ophiuroids as potentially structure-forming. Ophiuroids were abundant on some of the shell mounds (Table 3), and if not exactly adding structure as defined above, certainly added texture to some of the shell mounds.

   To identify which structure-forming invertebrates might form potentially important associations with shell mound fish, we used the BIO-ENV procedure in the PRIMER (Version 5) multivariate statistical package to compare a similarity matrix based on the densities of the most abundant shell mound fishes with each of the possible matrices based on the mean densities (averaged across the years 1997-2001 at each shell mound) of the four most common structure-forming invertebrates, including ophiuroids. To reduce the correlations in both matrices due simply to depth, we did this for shallow (< 95 m) shell mounds (n = 4) and for deep (>95 m) shells mounds (n = 5). The fish data were from Love et al. (2003) on the 12 fishes, not including halfbanded rockfish, most commonly associated with shell mounds underneath nine platforms and were mean densities calculated from shell mound transects conducted from 1996 to 2001. We excluded halfbanded rockfish based on the assumption that their schooling behavior, unique among these fishes (Love et al. 2002, 2003), would reduce, if not eliminate, any dependence on structure-forming invertebrates, at least those few observed in this study. Halfbanded rockfish were also at least an order of magnitude more abundant than any of the other shell mound fishes (Love et al. 2003), and without severe transformation of the data, would unduly influence the results. Because the BIO-ENV procedure requires matrices with matching sets of sample labels, we limited the analyses by using invertebrate densities from the same subset of nine platforms as the fish. Also, since we were comparing two similarity matrices of biotic nature, we used, as recommended by Clarke and Gorley (2001), Bray-Curtis similarity coefficients calculated from square-root transformed density data for both data sets. The BIO-ENV procedure rank correlated the matching elements in the two matrices and identified which structure-forming invertebrates

correlated best with the fish assemblages. For these analyses, we used the default Spearman rank correlation method.

We then calculated the correlations between the densities of each of the fish with those of each of the structure-forming invertebrates identified in the above analyses. Again, to match the fish data set, we used the mean invertebrate densities based on transects conducted from 1997 to 2001. For each correlation we chose depth/platform range spanning the depth range of occurrence of each fish as reported in Love et al. (2003), plus the next shallowest and next deepest platforms. To increase the number of data points for the correlations for the deeper water fishes, we also used fish and invertebrate densities (see Table 3) calculated from the shell mound transects conducted in single years at Platform Eureka in 2005, Hondo in 2004 and (for fish only) 2006, and Harmony in 2004. We used Excel 9.0 to conduct the correlation analyses.

Results

As defined above, only a few types of structure-forming invertebrates were observed on the shell mounds, and consisted of, in order of overall density (and with maximum size observed in parentheses): large *Metridium* (50 cm), clumps of the foliose bryozoan *Watersipora* (60 cm), the crinoid *Florometra* (15 cm), sea pens, including *Ptilosarcus* (30 cm), and the rare gorgonians (30 cm), and vase and foliose sponges (40 cm) (Tables 2 and 3, Figure 2). *Watersipora* was only observed under platform Gilda, and along with the masses, mentioned previously, of yellow demosponge observed there, originates from the upper reaches of platform. Platform Gilda was only surveyed for fishes after 2001 and therefore, these two structure-forming invertebrates will not be considered further. Sea pens, primarily of the family Virgulariidae, were restricted to soft sediments, while the gorgonians were observed only on hard substrates including rock, pipelines and platform debris. Large *Metridium* were also common on pipelines and platform debris. As mentioned above, we also considered ophiuroids and the sea urchin *Allocentrotus* as structure forming in some of the analyses.

The similarity matrix based on fishes from the four shallow platforms was most highly correlated with ophiuroids and gorgonians, and more highly correlated with gorgonians alone than ophiuroids alone (Table 6). Fishes from the five deeper platforms were most highly correlated with large *Metridium* and sea pens, and fairly highly correlated with large *Metridium* alone (Table 6).

Table 6. Best correlations between similarity matrices based on densities of common fishes and common structure-forming invertebrates (plus ophiuroids) from shallow (< 95 m) and deep (> 95 m) shell mounds. Based on data from 1996-2001 (see Methods).

Fish assemblage	Spearman Correlation Coefficient	Invertebrate taxa
Shallow (5 species)	0.845	Ophiuroids, gorgonians
	0.655	Gorgonians
	0.393	Ophiuroids
	-0.143	Large *Metridium,* ophuroids
Deep (10 species)	0.891	Large *Metridium,* sea pens
	0.806	Large *Metridium,* sea pens, *Florometra*
	0.782	Large *Metridium, Florometra*
	0.745	Large *Metridium*
	0.539	Ophiuroids, sea pens

The densities of painted greenling and four species of rockfish, including greenstriped rockfish, were significantly correlated with the densities of invertebrates identified as important in the above multivariate analysis (Table 7, Figure 11). Greenblotched rockfish were significantly correlated with sea pens in combination with the sea urchin *Allocentrotus fragilis* (Table 7), but not with either species alone (r = 0.33, 0.28, *P* = 0.52, 0.59, respectively).

Table 7. Correlations between mean yearly densities (per 100 m^2) of fishes and densities (per 2m^2) of invertebrates listed in Table 6 as highly correlated with fish assemblages. N = number of shell mounds on which each correlation is based.

Fish	Invertebrate taxon	Depth Range (m)	r	t	P	N
Painted Greenling	Gorgonians	49-184	0.83	3.38	0.02	7
Vermilion rockfish	Gorgonians	49-184	0.99	19.45	<0.001	7
Greenstriped rockfish	Large *Metridium*	74-257	0.88	4.53	0.004	8
Pinkrose rockfish	Sea pens	184-365	0.94	5.36	0.006	6
Greenblotched rockfish	Sea pens and *Allocentrotus*	131-257	0.99	12.05 -11.83	0.002	6

Discussion

   The correlation between the densities of both painted greenling and vermilion rockfish with gorgonians probably simply reflects the association of all three species with rocky substrata, rather than a direct relationship between the fish and gorgonians themselves. In temperate waters gorgonians are primarily occupants of rocky reefs, and in this study were observed only on rock outcrops (present only at Platform C), rock bench (Platform Holly), pipelines, or on hard platform debris, such as tires and pipes. Painted greenling are described by Love (1996) as "solitary bottom dwellers found on or near hard bottom," while vermilion rockfish, after settling to the bottom, move from sand patches adjacent to biotic or abiotic structures to high-relief rock as they grow from juveniles to adults (Love et al. 2002).
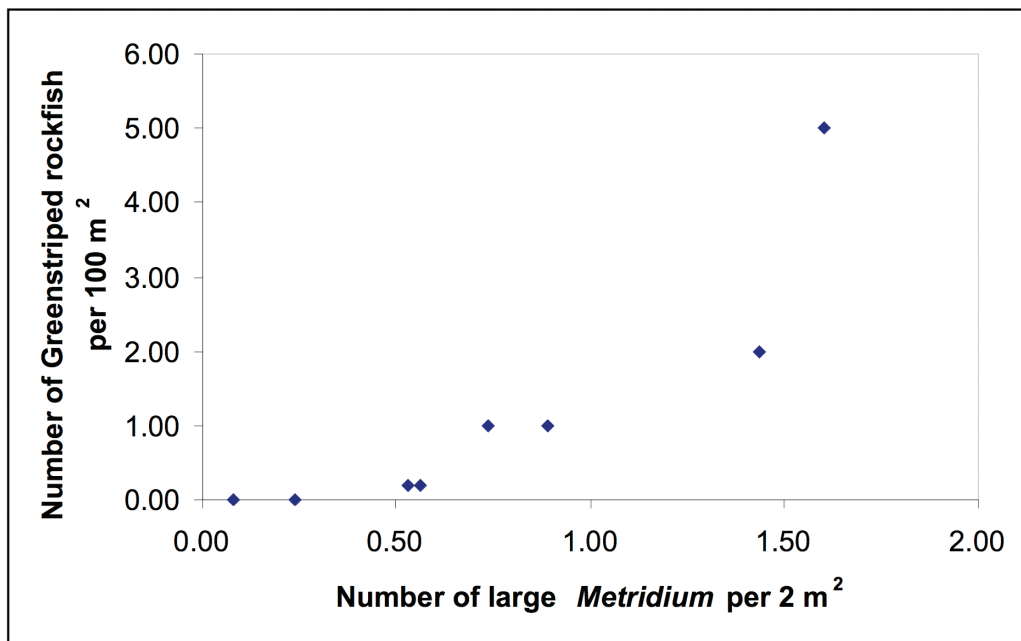

Figure 11. Relationship between the densities of greenstriped rockfish and densities of large *Metridium* on eight shell mounds, 74 to 257 m deep. Densities of the fish are means for 1996-2001, and for *Metridium,* 1997-2001, except at platforms Eureka and Hondo, whose invertebrates were sampled only in 2005 and 2004, respectively.

   The density of greenblotched rockfish was correlated with the density of sea pens and *Allocentrotus*, both of which are typically associated with soft sediments, but were also observed in this study in mixed shell mound/soft sediment habitat. Evidence exists that greenblotched rockfish settle to soft bottoms, and then move to high relief rock and mixed rock and mud habitats as they grow and age (Love et al. 2003). Consistent with this transition, Love et al. (2003) found that greenblotched rockfish were smaller on one shell mound compared to individuals found next to the adjacent platform bottom, which obviously has higher relief. The young of these rockfish may utilize the structure provided by sea pens and *Allocentrotus*, perhaps as spatial refuges from predation or as feeding sites. Interestingly, Brodeur (2001) found that Pacific Ocean perch, *Sebastes alutus*, also associate with sea pens and sea urchins on soft

sediments. Further, these invertebrates may also provide structural "stepping stones" of sorts for growing greenblotched rockfish on their way to the definitive adult habitat. Alternatively, sea pens and sea urchins may be the only significant three-dimensional habitat available on low relief shell mounds to young fish being excluded from higher relief habitat by older conspecifics, especially if the more abundant, large *Metridium* are being monopolized as habitat by other species of fish (see below).

According to Love et al. (2003), little is known about the ontogenetic changes in habitat preferences of pinkrose rockfish, but the correlation of this species with sea pens might provide a clue to the habits of the young fish, especially given that individuals found over at least one shell mound were also smaller than those on the adjacent platform bottom (Love et al. 2003). Tissot et al. (2006) did not include sea pens in their analysis of associations between fishes and structure-forming invertebrates on deep banks off southern California. They did, however, find a significant association between pinkrose rockfish and foliose sponges, which in this study were recorded only on the shell mound under platform Hondo (Table 3). Platform Hondo was also one of the few platforms with pinkrose rockfish (Love et al., personal communication).

Greenstriped rockfish was the only species of fish whose density was found in this study to be significantly correlated with the density of large *Metridium*, the most abundant structure-forming invertebrate on the shell mounds. The nature of this association can only be surmised, but might be related to feeding by the fish or refuge from predation. Regardless, the lack of correlation with other species of common fishes with this large anemone, combined with the correlations discussed above, suggests that some fishes may be partitioning, as habitat, the few structure-forming invertebrates found on shell mounds.

Task 4: **Compare sea star densities on shell mounds with those on natural reefs.**

Rationale

   Wolfson et al. (1979) reported that sea star densities were up to three orders of magnitude higher on a shallow water (18 m deep) shell mound than on natural reefs, and preliminary observations suggested similarly high densities on the deeper water OCS mussel mounds. Shallow water populations of these ecologically important predators have experienced declines in southern California and Mexico in recent years, apparently owing to the long-term warming trend in sea-surface temperatures and increased outbreaks of a microbial wasting disease (Dungan et al., 1982; Eckert et al., 2000). Deepwater populations of these species may occupy a cold-water refuge from outbreaks of this disease and therefore might provide an important source of reproductive propagules and recruits to impacted shallow water populations. This would be especially true for dense populations of large adults, owing to the relationship between fertilization success and adult density and size in broadcast spawning species like sea stars (Pennington 1985; Levitan and Petersen 1995; Claereboudt 1999; Metaxas et al. 2002). We therefore decided to include in this study a comparison of sea star densities on deepwater shell mounds with information available on the densities of the same species on natural reefs at similar depths. Note: We had originally planned on also comparing sea star densities on shell mounds with those from soft bottom habitats. However, soft bottoms are already known to support low densities of asteroids of generally differing species composition (Hopkins and Crozier 1966; Blake 1993; SCAMIT 2001).

Methods

   We compared data obtained in this study on the densities of species of asteroids with data obtained as part of the Biological California offshore Monitoring Program (CAMP) from natural reefs and soft bottom habitats, in waters 105 to 212 m deep, in the Santa Maria Basin and Santa Barbara Channel. Although the methods in these latter studies included the counting of individuals of solitary species (e.g., SAIC 1985; SAIC and MEC 1995), the results reported for the overall abundances of benthic epifauna are in terms of mean percentage covers, rather than densities, for shallow (105-119 m) and deep (160-212 m) reefs (SAIC and MEC 1995, Appendix D: Table 3). To better compare the two sets of results, we therefore converted our density data for the 20 most abundant shell mound taxa to % cover data by estimating the area covered, as % m^2, of average-sized adults of each taxa and multiplying that factor by the mean density per m^2. We did this for shallow (49-97 m) and deep (131-257 m) shell mounds. We also visually searched the raw data reported in Appendix H of SAIC (1985) (which reported some density data collected from photo quadrats, as well from direct observations using an ROV) for the highest densities of asteroids reported from each of the 23 transects conducted as part of that study. We obtained additional estimates of sea star densities from Lissner and Dorsey (1986), who documented hard-bottom invertebrate communities from 14 to 150 m deep on the Tanner and Cortes Banks and Santa Rosa-Cortes Ridge off southern California.

Results

   The twenty most about taxa, including ophiuroids, from shallow and deep shell mounds, are listed by rank order of abundance in Tables 8 and 9, respectively. Sea stars constituted approximately half of the 10 most abundant taxa from both shallow and deep shell mounds, with

Table 8. Twenty most abundant megabenthic invertebrate taxa, ranked by estimated mean % cover, at eight shallow (49-97 m) shell mounds, 1997-2005. See Table 2 for complete names of taxa.

Rank	Taxon	Mean # /m² (a)	Estimated % m²/ind. (b)	Estimated mean % cover (a x b)
1	ophiuroids	79	0.1	7.9
2	*Asterina miniata*	4.087	1	4.087
3	*Pisaster* spp.	0.223	2.5	0.557
4	*Watersipora* clumps	0.038	10	0.377
5	*Dermasterias*-like	0.048	2	0.096
6	large *Metridium*	0.095	1	0.095
7	*Cancer* spp.	0.039	1.5	0.059
8	*Corynactis* clumps	0.027	2	0.053
9	*Rathbunaster*	0.013	4	0.052
10	*Pycnopodia*	0.005	10	0.051
11	*Pleurobranchaea*	0.014	2	0.027
12	*Stylasterias*	0.010	2	0.020
13	*Parastichopus*	0.014	1	0.014
14	gorgonians	0.006	2	0.013
15	*Orthasterias*	0.002	2	0.005
16	*Loxorhynchus*	0.002	2.5	0.004
17	octopus	0.003	1	0.003
18	*Cancer magister*	0.001	2	0.002
19	unid. whelk	0.002	0.5	0.001
20	dorid nudibranch	0.001	0.5	0.000

Table 9. Twenty most abundant megabenthic invertebrate taxa, ranked by estimated mean % cover, at six deep (131-257 m) shell mounds, 1997-2005. See Table 2 for complete names of taxa.

Rank	Taxon	Mean # /m² (a)	Estimated % m²/ind. (b)	Estimated mean % cover (a x b)
1	ophiuroids	26	0.1	2.6
2	*Asterina miniata*	1.210	1	1.210
3	*Stylasterias*	0.253	2	0.506
4	large *Metridium*	0.400	1	0.400
5	*Pleurobranchaea*	0.115	2	0.231
6	*Rathbunaster*	0.051	4	0.205
7	*Pycnopodia*	0.018	10	0.179
8	*Pisaster* spp.	0.054	2.5	0.136
9	Spot prawns	0.088	1	0.088
10	*Orthasterias*	0.027	2.5	0.069
11	*Allocentrotus*	0.044	1	0.044
12	other holothurians	0.042	1	0.042
13	*Cancer* spp.	0.021	1.5	0.032
14	*Dermasterias*-like	0.013	2	0.025
15	foliose sponges	0.003	5	0.017
16	*Paralithodes*	0.005	2.5	0.013
17	*Corynactis* clumps	0.006	2	0.013
18	*Florometra*	0.006	2	0.011
19	octopus	0.005	1	0.005
20	vase sponges	0.001	0.003	0.003

Asterina miniata heading both lists of sea stars at 4.1 and 1.2 mean % cover, respectively. In contrast, no sea stars are included in the top 20 most abundant species in Table 3 of SAIC and MEC (1995, Appendix D), and the most abundant mobile organisms included in that table are galatheids at 1.4 mean % cover on deep reefs, and galatheids and pagurids at 0.5 and 0.2 mean % cover, respectively, on shallow reefs. The abundance of the 20th most abundant species from both shallow and deep reefs was on the order of 0.1 mean % cover. Therefore, in terms of mean % cover, asteroids were at least one order of magnitude more abundant on the shell mounds than on the reefs.

The highest sea star density reported in Appendix H of SAIC (1985) was 5 *Mediaster aequalis* from a single square meter of hard bottom at 111 m depth on transect 27 A/B, located in the Santa Maria Basin. *Stylasterias forreri* was qualitatively noted as "many" per square meter during a number of sections of Transect 13 A/B, also on hard bottom in the Santa Maria Basin. Otherwise, sea stars densities reported in that study from individual time segments and 1200 1 m^2 photo quadrats ranged from 0 to 3 per square meter, with the majority of segments and quadrats lacking sea stars. Sea star densities from individual quadrats on the shell mounds were an order of magnitude higher. For example, out of the 2260 total quadrats sampled, 43, adjusted to an area of 1 m^2, had 10 or more *Asterina miniata*, 54 had two or more *Pisaster* spp., 37 had two or more *Stylasterias forreri*, and 26 had two or more *Rathbunaster californicus*. The most individuals of a given asteroid species observed in a single quadrat, adjusted to 1 m^2, was 22 *Asterina miniata* at Platform Eureka.

Finally, Lissner and Dorsey (1986) reported qualitative density estimates of 2 – 3 individuals per m^2 for both *Asterina miniata* and *Mediaster aequalis*, from between 36 and 97 m depth on the Tanner and Cortes Banks and Santa Rosa-Cortes Ridge. The estimate for *A. miniata* is comparable to the average density of 4.1 *A. miniata*/m^2 from the seven shallow (49 – 97 m) shell mounds combined, and less than half the average density of 7.3 *A. miniata*/m^2 from the shallow shell mounds in San Pedro Bay (Table 3), closer to the bank-ridge area studied by Lissner and Dorsey (1986).

Discussion

Asteroid echinoderms were among the most abundant macroinvertebrates observed on the shell mounds (Tables 2, 3, 9, 10), and were at least an order of magnitude denser than reported by SAIC (1985) and SAIC and MEC (1995) for rocky reefs at similar depths in the Santa Maria Basin and Santa Barbara Channel. Although SAIC and MEC (1995) reported invertebrate abundances as percentage cover, and had a methodology that recorded more encrusting species than was possible in the present study, the inclusion of mobile species such as galatheid and pagurid crustaceans in their tabulation of the 20 most abundant species indicates that asteroids would have also been included, had they been abundant enough (Lissner and Benech (1993), utilizing some of the same data, reported that three species of asteroids (see below) were among the 30 most frequently encountered megabenthic taxa). Overall, our result from the shell mounds is consistent with Wolfson et al. (1979), who reported even higher asteroid densities from a single shallow water (18 m) shell mound off Huntington Beach in San Pedro Bay.

Lissner and Dorsey (1986) reported densities of two sea stars on hard bottoms comparable to that of *Asterina miniata* on the shallow water (49 – 97 m) shell mounds. However, their results are not strictly comparable to those from the CAMP studies or the present study owing to their more qualitative nature and the location of their study area farther offshore and to the south than

the Santa Maria Basin and Santa Barbara Channel.

The most common asteroid species on the shell mounds also appeared to differ from those on rocky reefs. Two of the three species whose quantitative densities are reported in SAIC (1985, Appendix H), *Mediaster aequalis* and *Odontaster* (= *Peridontaster*) *crassus*, were not even recorded from the shell mound transects, although a few individuals of *M. aequalis* were observed prior to the start of the transects at Platforms Harvest and Hermosa (also, as mentioned previously, some *M. aequalis* may have been lumped with *Asterina miniata*, owing to the low resolution of the video recordings). The third species, *Stylasterias forreri*, was common on some shell mounds, as well as in some of the transects conducted on rocky reefs. *Asterina miniata* (=*Patiria miniata*) was only recorded a handful of times in the 23 transects conducted on hard bottoms (SAIC 1985), compared to 1039, or 46%, of 2260 total quadrats sampled from all 15 shell mounds in the present study.

Given the scarcity of hard bottom habitat on the outer continental shelf (Blake and Lissner 1993; SAIC 1995), and its relatively low densities of sea stars, the denser populations of sea stars found on deepwater shell mounds may be important to the region as spawning aggregations and sources of larvae, especially if the geographically more extensive, shallow water populations of the same species continue to be impacted by the microbial wasting disease described by Eckert et al. (2000) or other anthropogenic impacts. If the wasting disease is related to long-term warming trends in surface waters (see Bograd and Lynn 2003; Field et al. 2006), deepwater shell mounds might provide a cold-water refuge, especially those below the thermocline, which off southern California typically occurs above 100 m (Bograd and Lynn 2003). An evaluation of the potential magnitude of the reproductive contribution by asteroids associated with deepwater shell mounds is beyond the scope of this study and would require much new information. However, it should be emphasized that any lasting contribution, whatever its magnitude, depends on the continued transfer of live mussels, barnacles, and other fouling organisms – the prey of most of the sea stars - from the upper reaches of the platform to the shell mound. As documented by Bomkamp et al. (2004) for shallow water shell mounds, without this food subsidy, the composition of the mobile macroinvertebrates associated with the shell mounds shifts from predatory and omnivorous species to omnivorous and deposit-feeding species. Any platform decommissioning options resulting in the loss of platform structure in shallow water (see Love et al. 2003; Schroeder and Love 2004) would cut the food subsidy to the predatory sea stars on the shell mounds, eventually resulting in significantly reduced densities and reproductive output.

An additional possible, but largely unexplored, consequence of high asteroid density on the shell mounds might be an increased susceptibility to disease outbreaks, should the shell mound populations be exposed to infectious agents (e.g., Ford and Smolowilz 2007). Depending on vectors and agents involved, this may be less likely on deeper shell mounds compared to shallow ones. However, artificially high sea star densities may present new opportunities for agents known to infect sea stars, such as the wasting disease mentioned above or parasitic, castrating ciliates (Byrne et al. 1997; Stickle et al. 2001). One species of particular concern is the ciliate *Orchitophyra stellarum* a parasitic castrator introduced from the north Atlantic Ocean. This parasite apparently has a wide range of host and has been found in *Pisaster ochraceus* from British Columbia (Leighton et al. 1991; Byrne et al.1997).

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