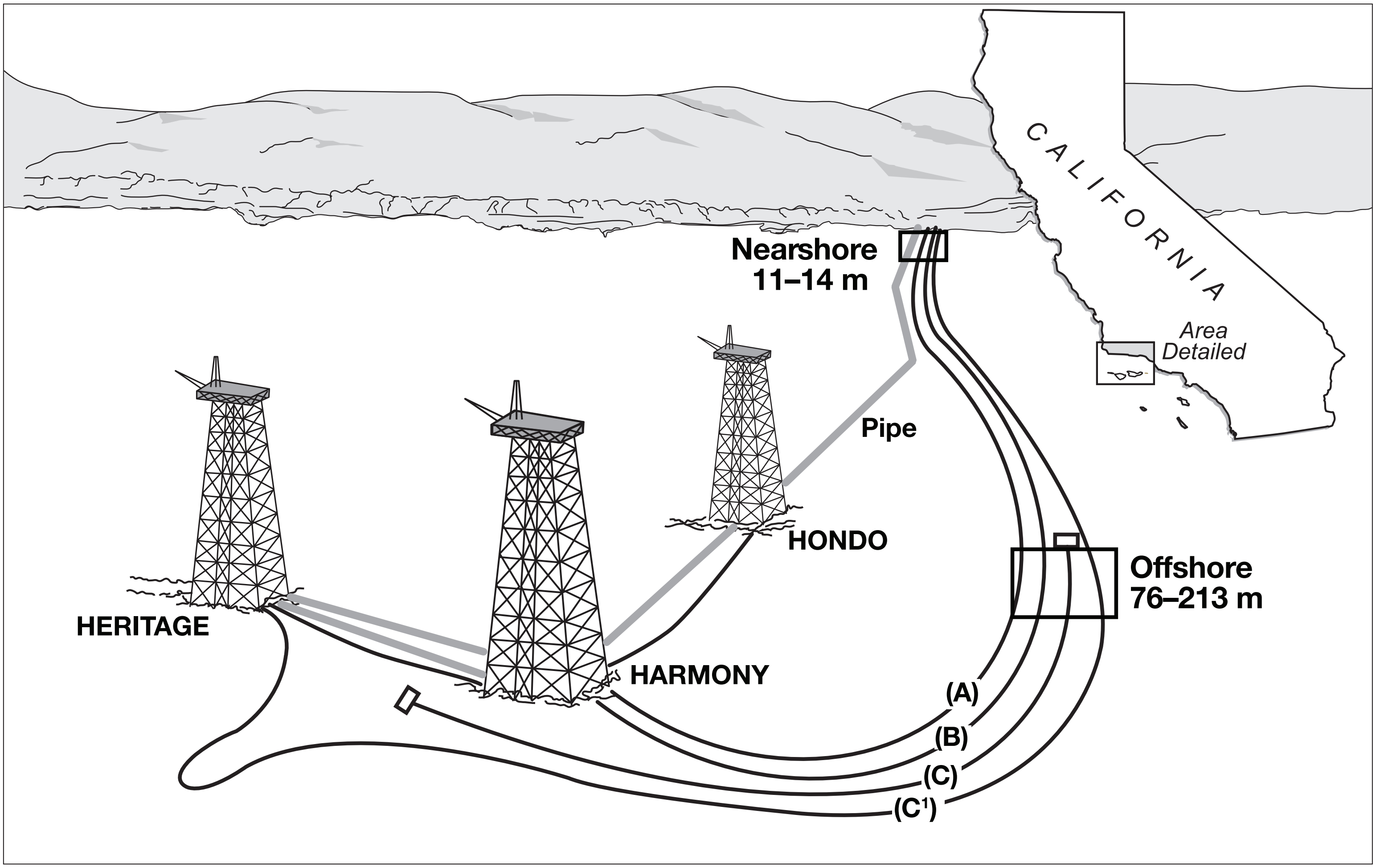
Pacific Outer Continental Shelf Region

OCS Study
BOEM 2016-008

RENEWABLE ENERGY IN SITU

POWER CABLE OBSERVATION



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RENEWABLE ENERGY IN SITU POWER CABLE OBSERVATION

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Report Availability

Citation

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TECHNICAL SUMMARY

Study Title: Renewable Energy in situ Power Cable Observation
Report Title: Renewable Energy in situ Power Cable Observation
Contract Number: M11AC00008
Sponsoring OCS Region: Pacific
Applicable Planning Area: Southern California
Fiscal Years of Project Funding: 2011, 2012, 2013
Completion Date of the Report: April 2016
Costs: FY 2011: $849,395; FY 2012: $100,000; FY 2013: $283,265
Cumulative Project Cost: $1,232,660
Principal Investigator: Milton Love
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Principal Investigator: Milton Love
Key Words: EMF, electromagnetic fields, renewable energy, power cables

Background and Objectives

It is likely that for the foreseeable future, offshore renewable energy technologies (e.g., wind and wave) will focus on the generation of electricity. These technologies harness energy from an array of individual devices and, through power cables, send electricity to shore via cables. These cables will transmit either alternating current or direct current, and, if the cable uses alternating current, this current will generate both electric and magnetic fields.

Research has shown that some cartilaginous and bony fishes, as well as at least some invertebrates, are sensitive to electromagnetic fields (EMF) and that these fields can alter the behavior of these organisms (Kalmin 1982, Formicki et al. 2004, Tanski et al. 2005). However, worldwide, very few studies have been conducted to document the effects of EMF on marine organisms in situ (Ohman et al. 2007). Only one survey on the Pacific Coast has examined, in the marine environment, the role that EMF emitted from a cable might play. That study, Barry et al. (2008), found that longnose skate (*Raja rhina*) appeared to have been attracted to an energized sea-bed cable. However, it should be noted that rather than comparing energized and unenergized cables, this survey compared organism densities along a sea bed before and after an energized cable was installed. Thus it was difficult to differentiate the effects of the EMF emanating from the cable from the effects of the cable structure itself.

Submarine transmission cables that power offshore oil platforms in the Pacific Region provide a unique opportunity to assess potential behavior and reaction of electromagnetic-sensitive species to industry activities. In particular, the chance occurrence of both energized and unenergized cables in a corridor on the seafloor within the Santa Ynez Unit Offshore Southern California Planning Area, allows for an experiment testing the effects of EMF on marine organisms. The identical cables stretch several miles from Platforms Heritage, Harmony, and Hondo (at depths to about 326 m) to Los Flores on the mainland. The cables run from the platforms toward the mainland to a sea floor depth of 10 m and from there are buried inshore. One unenergized cable runs from a platform to the border of federal and state waters at a bottom depth of about 150 m. All of these cables use the industry standards of the power cables that will be used for connecting devices (35 KV) within renewable energy installations. These cables were emplaced concurrently by the manufacturer. Thus, the cables form a natural experiment, allowing a comparison of an energized power cable with one that is unenergized to determine the potential impacts from electromagnetic fields while controlling for the habitat effect contributed by the cables themselves.

The goal of this study was to more fully understand the potential effects of energized, seabed deployed, power cables on marine organisms.

Specific objectives of this study were to determine:

1) The differences among fish and invertebrate communities associated with energized and unenergized cable habitat and those communities in soft seafloor habitats lacking cables.
2) Whether electrosensitive species that are regionally important such as sharks and rays respond (via either attraction or repulsion) to the EMF's of an in situ power transmission cable.
3) The strength, spatial extent, and variability of EMF's along both energized and unenergized cables.
4) The potential effectiveness of the commonly proposed mitigation of cable burial.

Knowledge gained from this study will be directly applicable to renewable energy projects not only in the Pacific OCS region, but to any OCS planning area.

Description

The research was divided into two parts: Task 1 took place in inshore waters (10–14 m) and Task 2 in offshore waters (76–213 m). Here following, we will divide the descriptions and significant results of our research into those two categories.

Task 1

Between 1 February 2012 and 26 February 2014 using scuba, we surveyed the fishes, invertebrates, and marine plants living on two energized submarine power cables, adjacent pipe, and natural habitat. Along cable, pipe, and over sandy bottom, we installed six permanent 30 m-long transects; three at a shallow depth (10–11 m) and three in slightly deeper waters (13–14 m depth). The end of the shallow transects and beginning of the deep ones were separated by about 120 m. The beginning and ending of each transect at each site was marked by sand anchors as was each 5 m segment along each transect. Transects were 2 m wide, centered on the pipe or cable or an imaginary line between sand anchors that delineated the sandy control transect. During the surveys, we measured the electromagnetic fields (EMF) emitted by the cable, pipe, and natural habitat. Fishes and plant surveys were conducted from the beginning to end of the study — from 1 February 2012 to 26 February 2014. Invertebrate surveys were conducted beginning on 22 June 2012 and continued until the end of the study. We conducted a total of 38 days of fish surveys, 30 days of invertebrate studies, and 38 days of plant studies during the three years.

Task 2

We conducted surveys of energized and unenergized cables and of the nearby sea floor during 2012 (6–9 October), 2013 (3–5 October) and 2014 (23–25 October) at depths between 76 and 213 m using a manned submersible. During 2012, only the east side of each cable was surveyed, while in 2013 and 2014 we surveyed both sides of the cables at similar depths. All natural habitat surveys were conducted between 100 and about 500 m from the nearest cable.

In 2012, we measured the EMF levels at three distances from energized Cable A. These measurements were taken at four locations along the cable (at bottom depths of 108 m, 112 m, 135 m, and 158 m). In 2013 and 2014, we measured EMF on all energized and unenergized cables on the cable at one location each, and on the sea floor.

Significant Results

Task 1

Over the course of the study, average EMF levels at the two cables (A and B) were statistically similar (Cable A = 73.0µT, Cable B = 91.4µT) and were much higher at the two cables than at either the pipe (average = 0.5µT) or sand (0µT)

Fishes

Overall, our study demonstrated that 1) the fish communities on cables, pipe, and natural habitat strongly overlapped (global R=0.097, p=0.01) and 2) the difference between the shallower and deeper fish communities was negligible (global R=0.097, p=0.001).

Over all habitats, we observed 4,671 individuals of a minimum of 44 species. Dominant species included adults of benthic-oriented, schooling taxa (i.e., kelp perch, senorita, white seaperch, and shiner perch), young-of-the-year (YOY) rockfishes that had newly settled out of the plankton (particularly black-and-yellow, gopher, and kelp rockfishes), and relatively solitary substrate-oriented species (i.e., sanddabs and kelp perch). Senorita, sanddabs, white seaperch, YOY rockfishes, and kelp perch were the most abundant taxa. *Cables:* At least 35 species and 1,721 individuals were observed over the energized cables. Senorita, sanddabs, kelp perch, white seaperch, and YOY rockfishes were most abundant (Table 2-4). *Pipe*: The number of taxa (37) and individuals (1,829) were similar to those observed on the cables. Senorita, YOY rockfishes, vermilion rockfish YOY, pile perch, black perch, and sanddabs were the most important taxa on the pipe (Table 2-5). *Natural Habitat*: Fewest species (25) and individuals (1,121) were observed over the natural habitat. Shiner perch, sanddabs, senorita, YOY shortbelly rockfish, white seaperch, and tubesnout were most often observed here (Table 2-6).

All of the fish communities were composed primarily of small fishes and the majority of these individuals were less than 20 cm long. The mean length of fishes varied significantly among the three habitats (Welch's Test, F = 43.7, df = 2, p <.0001) as did the size distributions. However, we note that the difference of mean lengths among sites is very small and it is unlikely that these differences, although statistically significant, are biologically meaningful. The abundance of all fishes combined varied seasonally at every site. In general, fishes were more abundant from early spring through early fall at all sites. This was reflective of the seasonal influx of newly settled rockfishes, young seaperches, and the general increase in fish abundance in nearshore waters that takes place as the turbulent winter waters subside.

Invertebrates

Similar to the fish assemblages, the invertebrate communities on the cables, pipe, and natural habitats were quite similar overall (global R=0.111, p=0.001) and the shallower and deeper invertebrate assemblages were indistinguishable (global R=0.000, p=0.51).

Over all habitats, we observed a total of 822 individuals comprising a minimum of 19 species. Bat star, several species of sea stars, purple urchin (but noted on only one occasion), California sea hare, Comb sea star, and Kellet's whelk were observed most often. By group, sea stars were the most abundant, comprising 56.8% of all invertebrates recorded. *Cables*: We observed 157 individuals of at least 15 species at the cable sites. Bat star, sea stars, and California sea hare were most abundant. *Pipe*: Four hundred and forty two individual invertebrates, the most of any site, were observed at the pipe. However, 100 of these individuals were comprised of a one-time recorded aggregation of purple sea urchin. Like the cables, we recorded 15 species along the pipe. *Natural Habitat*: Bat star and Kellet's whelk predominated in the natural habitat, where we recorded 223 individuals, of 13 species.

Overall, the numbers of invertebrates living at the study sites remained fairly constant over the course of the study. What changes occurred were due to influxes of sea stars and bat stars. Of the eight most common species observed, the densities of five species (sea stars, bat star, sea cucumbers, and rock crabs) varied with site. Between cables and pipe, densities of four species (sea stars, bat stars, sea cucumbers, and rock crabs) were different. sea stars, bat stars, and sea cucumbers were more abundant at the pipe and rock crabs were more often encountered at the cable. The densities of three taxa or taxa groups, sea stars, California sea hare, and sea cucumbers were higher at the pipe than at the natural habitat. Lastly, rock crabs and California sea hare were found at higher densities at the cables compared to natural habitat and, contrarily, bat stars were more abundant at the natural habitat.

Plants

Unlike the fish and invertebrate assemblages, the plant communities of the three sites were different. First, there were intra-site differences in the shallower and deeper plant communities within the cables and pipe habitats, although not in the natural habitat. In addition, there were differences in the plant communities between the three habitats (global R=0.986, p=0.001; R>0.8, p=0.001).

Over all habitats, a total of 72,999 individual plants (many likely observed repeatedly on sequential survey days) were tallied, comprising at least five species. Overall, *Zostera marina* was most abundant, followed by *Pterygophora californica, Cystoseira* spp., *Laminaria* spp., and *Macrocystis pyrifera. Cables*: Among all plants, Pterygophora californica dominated the cable community, although *Cystoseira* spp. and *Laminaria* spp. were not uncommon. *Pterygophora californica* was very abundant on Cable B (particularly shallower), but absent from Cable A (although both were energized). Eelgrass grew on the sand near the cable. *Macrocystis pyrifera* grew very sparsely on the shallower Cable B habitat, was more common on the shallower part of Cable A, and was essentially absent from the deeper cables. *Pipe*: *Cystoseira* spp. and *Laminaria* spp. were by far the most common plants on the pipe. *Cystoseira* spp. was nearly twice as abundant shallower than deeper while *Laminaria* spp. was almost absent from the shallower site and nearly as abundant as *Cystoseira* spp. deeper. Relatively few *P. californica* were observed on the pipe and both *M. pyrifera* and *Z. marina* were almost absent. *Natural Habitat*: *Zostera marina* was the only plant growing on the sandy sea floor of the natural habitat. It was dense at both the shallower and deeper sites. With the exception of *Z. marina* living on the natural habitat, we did not observe any strong seasonality in plant densities. Densities of *Z. marina* in both the shallower and deeper areas tended to increase over the course of the study.

Regarding the specific objectives of this study:

1) *The differences among fish and invertebrate communities associated with energized and unenergized cable habitat and those communities in soft seafloor habitats lacking cables.*

We did not find any biologically significant differences among fish and invertebrate communities between energized cables, pipe, and natural habitat. In particular, only three species of fish showed statistically significant, but slight, differences in densities between the cables and pipe. Plant communities did differ among habitats and within habitats between depths. These differences were almost certainly structure and depth, rather than EMF, related.

2) *Whether electro-sensitive species that are regionally important, such as sharks and rays, respond (via either attraction or repulsion) to the EMFs of an in situ power transmission cable.*

We observed only one elasmobranch individual, a swell shark, during the course of this study. Thus, it would appear that the EMFs generated by these energized cables are either unimportant to these organisms or that at least other environmental factors take precedence.

3) The strength, spatial extent, and variability of EMFs along both energized and unenergized cables.

The strength of the EMF along the energized cable was relatively stable over time and along its length. The EMF produced by the energized cables diminishes to background levels about one meter away from the cable. Similarly, both the pipe and natural habitat sites had extremely small or undetectable EMFs.

4) The potential effectiveness of the commonly proposed mitigation of cable burial.

Given the rapidity with which the EMF produced by the energized cables diminishes and the lack of response to that EMF by the shallower fish and invertebrates, cable burial would not appear necessary strictly for biological reasons. In this and similar cases, cable burial, at sufficient depth, would be an adequate tool to prevent EMF emissions from being present at the seafloor.

Task 2

In 2012, at all four locations along the energized cable, EMF levels dropped off precipitously with distance from the cable and, at one meter from the cable, approached background levels at three of the four locations. In general, field strengths on the energized cables were around 100 µT, while those on the unenergized cables were very low and near background (sea floor) levels.

Fishes

We found that fish species communities were structured by depth more so than by habitat type (Global R=0.176, p=0.001). There was no statistical difference between the fish assemblages along the energized and unenergized cables. The natural habitat community statistically differed from both the energized cable and unenergized cable communities. Within species (or in several cases species-groups) that formed at least one percent of the fishes observed, we found no differences in densities between energized and unenergized cables. We did find differences based on cable side (shortspine combfish densities were higher on the west side of cables), depth strata (stripetail rockfish, unidentified poachers, shortspine combfish, greenstriped rockfish, lingcod, and unidentified eelpouts), and year (halfbanded rockfish, stripetail rockfish, and lingcod). Total fish densities were significantly higher around the cables than over the natural habitat. Among the more important species, densities of halfbanded, stripetail, and greenstriped rockfishes, shortspine combfish, and lingcod were higher at the cables and eelpouts were found at higher densities over natural habitat. There were no significant differences in the densities of unidentified sanddabs and unidentified poachers. There were very slight, but statistically significant, differences in both mean lengths and size distributions of fishes among the three study habitats as fishes at the unenergized cables tended to be slightly larger (mean = 14.8 cm) than those at both natural habitats (mean = 13.7 cm) and energized cables (mean = 13.0 cm).

Over all habitats we observed 9,675 individuals of at least 41 species. Dominant species included halfbanded, stripetail, and greenstriped rockfishes, and lingcod, and unidentified flatfishes, poachers, and combfishes. *Energized cables*: In the vicinity of the energized cables, we observed at least 33 species of fishes, comprising 4,455 individuals. Halfbanded rockfish dominated this habitat, comprising 56% of all fishes observed and present during 82.3% of the transects. Other important species or species groups included unidentified flatfishes and poachers, stripetail and shortspine combfish. *Unenergized cables*: Similar to the fish assemblage found around energized cables, there were at least 35 fish species in proximity to the unenergized cables and 3,691 individuals. As with the energized cables, halfbanded rockfish were by far the most abundant species, comprising 37.4% of all fish observed. Other important species included stripetail and greenstriped rockfishes and unidentified flatfishes, poachers, and combfishes. *Natural habitats*: Fewest species (at least 23) and fishes (1,529) were observed on the natural habitats. Here, unidentified flatfishes, eelpouts, poachers, combfishes, sanddabs and halfbanded rockfish predominated.

Invertebrates

The structure of the invertebrate communities living around energized and unenergized cables and natural habitats was similar to that of fishes. We found that invertebrate communities were structured by habitat type and depth. Similar to the fishes, there was no statistical difference between the invertebrate assemblages along the energized and unenergized cables. The natural habitat community of invertebrates strongly differed from the energized cable and unenergized cable communities.

To determine if there were significant differences in species densities between energized and unenergized cables, we compared the densities of those important species that comprised at least 1% of individuals observed in this study in the same way as for fishes. We did note slight but statistically significant differences in densities for only two of nine of the most abundant species. Sand star and black crinoid densities differed between unenergized and energized cables [sand star greater at unenergized cables, 4/1/m^3 v 2.7 m^3, and black crinoid at energized cables, 1.7/m^3 v 0.3/m^3]. Three species, thin sea pen, red octopus, and white sea urchin differed between cable sides. Seven species, white-plumed anemone, spot prawn, thin sea pen, California sea cucumber, red octopus, unidentified *Urticina* anemone, and black crinoid exhibited bottom depth differences. Densities of two species, thin sea pen and sand star, varied among years.

A number of species were more abundant around the cables than over the natural habitats. Important species that were more abundant around cables were white-plumed anemone, spot prawn, thin sea pens, California sea cucumber, sand star, and unidentified *Urticina* anemone. Red octopus and white sea urchin were denser over natural habitats and densities of black crinoid did not differ between the two habitats.

Over all habitats, we observed a total of 30,523 invertebrates of at least 43 invertebrate species. The white-plumed anemone was by far the most abundant animal and comprised 43.4% of all invertebrates recorded. Spot prawns, thin sea pens, California sea cucumbers, sand stars, and the red octopuses were also found at relatively high densities. *Energized cables*: We observed 13,388 individuals, of at least 36 species, living on or near the energized cables. White-plumed anemones, thin sea pens and spot prawns were the species found in highest densities, forming in aggregate 79.7% of all invertebrates observed. California sea cucumbers, sand stars, red octopuses, black crinoids, and *Urticina* anemones were also common. *Unenergized cables*: At least 35 species and 14,619 individuals were observed along the unenergized cables. Three species, white-plumed anemones, spot prawns, and thin sea pens, were by far the most dense, in aggregate forming 79.2% of all invertebrates surveyed. California sea cucumbers, sand stars, red octopus, unidentified *Urticina* anemones, and serpulid worms were also characteristic of this habitat. *Natural habitats*: We observed the fewest number of species (a minimum of 27) and individuals (2,516) over the natural habitat. Thin sea pens, red octopuses, white sea urchins and sand stars dominated this habitat, along with smaller numbers of white-plumed anemones, fragile pink urchins, California sea cucumbers, and sea slugs.

Regarding the specific objectives of this study:

1) *The differences among fish and invertebrate communities associated with energized and unenergized cable habitat and those communities in soft seafloor habitats lacking cables.*

We did not observe any significant differences in the fish communities living around energized and unenergized cables and natural habitats. A very slight, and likely biologically insignificant, difference in mean sizes was observed as fishes at unenergized cables were marginally larger than those around energized ones. Overall species diversity and the densities of the most important fish species (define as comprising at least 1% of all fishes observed) were higher at the cables than at the natural habitats. This is likely reflective of the more complex habitats afforded by the cables than the primarily soft substrata natural habitats.

Similar to the fish communities, the invertebrate assemblages living around energized and unenergized cables and natural habitats were similar to one another and variability between these communities was primarily driven by sea floor depth. Among the three habitat types, there were some statistically significant differences in densities for all nine of the most abundant species. These differences included: 1) two species, sand star and black crinoid, whose densities differed between energized and unenergized cables, 2) three species, thin sea pen, red octopus, and white sea urchin which differed between cable sides, 3) seven species, white-plumed anemone, spot prawn, thin sea pen, California sea cucumber, red octopus, unidentified *Urticina* anemone, and black crinoid that exhibited bottom depth differences, and 4) two species, thin sea pen and sand star, whose densities varied among years. Sand star densities were greater at unenergized cables, $4/1/m^3$ v $2.7\ m^3$, and black crinoid densities were greater at energized cables, $1.7/m^3$ v $0.3/m^3$.

2) Whether electro-sensitive species that are regionally important, such as sharks and rays, respond (via either attraction or repulsion) to the EMFs of an in situ power transmission cable.

We observed very few individuals of electro-sensitive species on the energized or unenergized cables or on the natural habitats. Only five ratfish (three at the energized cables and two on the unenergized ones) and one California skate (at the unenergized cable) were noted. Thus, we found no compelling evidence that the EMF produced by the energized power cables in this study were either attracting or repelling these fishes.

3) The strength, spatial extent, and variability of EMFs along both energized and unenergized cables.

The EMFs produced by the energized cables were similar both over the three years of the study and along the cables. EMF strength dissipated relatively quickly with distance from the cable and approached background levels at about one meter from the cable. The EMF at unenergized cables was similar to that found at the natural habitats.

4) The potential effectiveness of the commonly proposed mitigation of cable burial.

Given the rapidity with which the EMF produced by the energized cables diminishes and the lack of response to that EMF by the fishes and invertebrates in this study, cable burial would not appear necessary strictly for biological reasons. In this and similar cases, cable burial, at sufficient depth, would be an adequate tool to prevent EMF emissions from being present at the seafloor.

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RENEWABLE ENERGY IN SITU POWER CABLE OBSERVATION

EXECUTIVE SUMMARY

Information Needed

In the future, offshore renewable energy is likely to be a major source of power for the United States. Offshore renewable energy technologies (e.g., wind and wave) harness energy from an array of individual devices and, through power cables, send electricity to shore via cables. These cables will transmit either alternating current or direct current, and, if the cable uses alternating current, this current will generate both electric and magnetic fields.

Research has shown that some cartilaginous and bony fishes, as well as at least some invertebrates, are sensitive to electromagnetic fields (EMF) and that these fields can alter the behavior of these organisms. However, worldwide, very few studies have been conducted to document the effects of EMF on marine organisms in situ. Only one survey on the Pacific Coast has examined, in the marine environment, the role that EMF emitted from a cable might play. That study found that longnose skate (*Raja rhina*) appeared to have been attracted to an energized sea-bed cable. However, it should be noted that rather than comparing energized and unenergized cables, this survey compared organism densities along a sea bed before and after an energized cable was installed. Thus it was difficult to differentiate the effects of the EMF emanating from the cable from the effects of the cable structure itself.

Submarine transmission cables that power offshore oil platforms in the Pacific Region provide a unique opportunity to assess potential behavior and reaction of electromagnetic-sensitive species to industry activities. In particular, the chance occurrence of both energized and unenergized cables in a corridor on the seafloor within the Santa Ynez Unit Offshore Southern California Planning Area, allows for an experiment testing the effects of EMF on marine organisms. The identical cables stretch several miles from Platforms Heritage, Harmony, and Hondo (at depths to about 326 m) to Los Flores on the mainland. The cables run from the platforms toward the mainland to a sea floor depth of 10 m and from there are buried inshore. One unenergized cable runs from a platform to the border of federal and state waters at a bottom depth of about 150 m. All of these cables use the industry standards of the power cables that will be used for connecting devices (35 KV) within renewable energy installations. These cables were emplaced concurrently by the manufacturer. Thus, the cables form a natural experiment, allowing a comparison of an energized power cable with one that is unenergized to determine the potential impacts from electromagnetic fields while controlling for the habitat effect contributed by the cables themselves.

The goal of this study was to more fully understand the potential effects of energized, seabed deployed, power cables on marine organisms.

Specific objectives of this study were to determine:

1) The differences among fish and invertebrate communities associated with energized and unenergized cable habitat and those communities in soft seafloor habitats lacking cables.

2) Whether electrosensitive species that are regionally important such as sharks and rays respond (via either attraction or repulsion) to the EMF's of an in situ power transmission cable.

3) The strength, spatial extent, and variability of EMF's along both energized and unenergized cables.

4) The potential effectiveness of the commonly proposed mitigation of cable burial.

Knowledge gained from this study will be directly applicable to renewable energy projects not only in the Pacific OCS region, but to any OCS planning area.

Research Summary

The research was divided into two parts: Task 1 took place in inshore waters (10–14 m) and Task 2 in offshore waters (76–213 m). Here following, we will divide the descriptions and significant results of our research into those two categories.

Task 1

Between 1 February 2012 and 26 February 2014 using scuba, we surveyed the fishes, invertebrates, and marine plants living on two energized submarine power cables, adjacent pipe, and natural habitat. Along cable, pipe, and over sandy bottom, we installed six permanent 30 m-long transects; three at a shallow depth (10–11 m) and three in slightly deeper waters (13–14 m depth). The end of the shallow transects and beginning of the deep ones were separated by about 120 m. The beginning and ending of each transect at each site was marked by sand anchors as was each 5 m segment along each transect. Transects were 2 m wide, centered on the pipe or cable or an imaginary line between sand anchors that delineated the sandy control transect. During the surveys, we measured the electromagnetic fields (EMF) emitted by the cable, pipe, and natural habitat. Fishes and plant surveys were conducted from the beginning to end of the study — from 1 February 2012 to 26 February 2014. Invertebrate surveys were conducted beginning on 22 June 2012 and continued until the end of the study. We conducted a total of 38 days of fish surveys, 30 days of invertebrate studies, and 38 days of plant studies during the three years.

Over the course of the study, average EMF levels at the two cables (A and B) were statistically similar (Cable A = 73.0μT, Cable B = 91.4μT) and were much higher at the two cables than at either the pipe (average = 0.5μT) or sand (0μT).

Fishes

Overall, our study demonstrated that 1) the fish communities on cables, pipe, and natural habitat strongly overlapped (global R=0.097, p=0.01) and 2) the difference between the shallower and deeper fish communities was negligible (global R=0.097, p=0.001).

Over all habitats, we observed 4,671 individuals of a minimum of 44 species. Dominant species included adults of benthic-oriented, schooling taxa (i.e., kelp perch, senorita, white seaperch, and shiner perch), young-of-the-year (YOY) rockfishes that had newly settled out of the plankton (particularly black-and-yellow, gopher, and kelp rockfishes), and relatively solitary substrate-oriented species (i.e., sanddabs and kelp perch). Senorita, sanddabs, white seaperch, YOY rockfishes, and kelp perch were the most abundant taxa. *Cables*: At least 35 species and 1,721 individuals were observed over the energized cables. Senorita, sanddabs, kelp perch, white seaperch, and YOY rockfishes were most abundant (Table 2-4). *Pipe*: The number of taxa (37) and individuals (1,829) were similar to those observed on the cables. Senorita, YOY rockfishes, vermilion rockfish YOY, pile perch, black perch, and sanddabs were the most important taxa on the pipe (Table 2-5). *Natural Habitat*: Fewest species (25) and individuals (1,121) were observed over the natural habitat. Shiner perch, sanddabs, senorita, YOY shortbelly rockfish, white seaperch, and tubesnout were most often observed here (Table 2-6).

All of the fish communities were composed primarily of small fishes and the majority of these individuals were less than 20 cm long. The mean length of fishes varied significantly among the three habitats (Welch's Test, F = 43.7, df = 2, p <.0001) as did the size distributions. However, we note that the difference of mean lengths among sites is very small and it is unlikely that these differences, although statistically significant, are biologically meaningful. The abundance of all fishes combined varied seasonally at every site. In general, fishes were more abundant from early spring through early fall at all sites. This was reflective of the seasonal influx of newly settled rockfishes, young seaperches, and the general increase in fish abundance in nearshore waters that takes place as the turbulent winter waters subside.

Invertebrates

Similar to the fish assemblages, the invertebrate communities on the cables, pipe, and natural habitats were quite similar overall (global R=0.111, p=0.001) and the shallower and deeper invertebrate assemblages were indistinguishable (global R=0.000, p=0.51).

Over all habitats, we observed a total of 822 individuals comprising a minimum of 19 species. Bat star, several species of sea stars, purple urchin (but noted on only one occasion), California sea hare, Comb sea star, and Kellet's whelk were observed most often. By group, sea stars were the most abundant, comprising 56.8% of all invertebrates recorded. *Cables*: We observed 157 individuals of at least 15 species at the cable sites. Bat star, sea stars, and California sea hare were most abundant. *Pipe*: Four hundred and forty two individual invertebrates, the most of any site, were observed at the pipe. However, 100 of these individuals were comprised of a one-time recorded aggregation of purple sea urchin. Like the cables, we recorded 15 species along the pipe. *Natural Habitat*: Bat star and Kellet's whelk predominated in the natural habitat, where we recorded 223 individuals, of 13 species.

Overall, the numbers of invertebrates living at the study sites remained fairly constant over the course of the study. What changes occurred were due to influxes of sea stars and bat stars. Of the eight most common species observed, the densities of five species (sea stars, bat star, sea cucumbers, and rock crabs) varied with site. Between cables and pipe, densities of four species (sea stars, bat stars, sea cucumbers, and rock crabs) were different. sea stars, bat stars, and sea cucumbers were more abundant at the pipe and rock crabs were more often encountered at the cable. The densities of three taxa or taxa groups, sea stars, California sea hare, and sea cucumbers were higher at the pipe than at the natural habitat. Lastly, rock crabs and California sea hare were found at higher densities at the cables compared to natural habitat and, contrarily, bat stars were more abundant at the natural habitat.

Plants

Unlike the fish and invertebrate assemblages, the plant communities of the three sites were different. First, there were intra-site differences in the shallower and deeper plant communities within the cables and pipe habitats, although not in the natural habitat. In addition, there were differences in the plant communities between the three habitats (global R=0.986, p=0.001; R>0.8, p=0.001).

Over all habitats, a total of 72,999 individual plants (many likely observed repeatedly on sequential survey days) were tallied, comprising at least five species. Overall, *Zostera marina* was most abundant, followed by *Pterygophora californica*, *Cystoseira* spp., *Laminaria* spp., and *Macrocystis pyrifera. Cables:* Among all plants, *Pterygophora californica* dominated the cable community, although *Cystoseira* spp. and *Laminaria* spp. were not uncommon. *Pterygophora californica* was very abundant on Cable B (particularly shallower), but absent from Cable A (although both were energized). Eelgrass grew on the sand near the cable. *Macrocystis pyrifera* grew very sparsely on the shallower Cable B habitat, was more common on the shallower part of Cable A, and was essentially absent from the deeper cables. *Pipe: Cystoseira* spp. and *Laminaria* spp. were by far the most common plants on the pipe. *Cystoseira* spp. was nearly twice as abundant shallower than deeper while *Laminaria* spp. was almost absent from the shallower site and nearly as abundant as *Cystoseira* spp. deeper. Relatively few P. californica were observed on the pipe and both *M. pyrifera* and *Z. marina* were almost absent. *Natural Habitat: Zostera marina* was the only plant growing on the sandy sea floor of the natural habitat. It was dense at both the shallower and deeper sites. With the exception of *Z. marina* living on the natural habitat, we did not observe any strong seasonality in plant densities. Densities of *Z. marina* in both the shallower and deeper areas tended to increase over the course of the study.

Task 2

Our surveys of the offshore marine communities were conducted off the coast of Las Flores Canyon, southern California (34°27.6´N, 120°02.7´W). At this site there are four, variously energized and unenergized, 8” diameter submarine power cables providing power to three offshore oil platforms. Surveys were conducted aboard the research submersibles *Dual DeepWorker* (2012 and 2014) and *DeepWorker* (2013). The Dives were made in September and October, during daylight hours.

We conducted belt transects along cables and on the nearby sea floor. These were documented with an externally mounted high-definition video camera positioned on the starboard bow of the submersible. All transects were 2-m wide and a set of lasers was used to measure transect width. A green and a red laser were set at an angle such that they intersected one another at a distance 2 m away from the submersible. The submersible followed a path parallel to the cable such that the intersection of the lasers landed on the cable. For off-cable (natural sea floor) transects, the crossing lasers were used to delineate the outside edge of each transect with the submarine continuing along a straight path along a compass heading for the duration of that transect. We identified both fishes and invertebrates to the lowest possible taxon.

In 2012, we measured the EMF levels at three distances from an energized cable. These measurements were taken at four locations along the cable (at bottom depths of 108 m, 112 m, 135 m, and 158 m). At all four locations, EMF levels dropped off precipitously with distance from the cable and, at one meter from the cable, approached background levels at three of the four locations. During 2013 and 2014, we measured energized and unenergized cable EMFs at one point on the cable and at nearby natural sea floors. In general, field strengths on the energized cables were around 100 µT, while those on the unenergized cables were very low and near background (sea floor) levels.

Fishes

We found that fish species communities were structured by depth more so than by habitat type (Global R=0.176, p=0.001). There was no statistical difference between the fish assemblages along the energized and unenergized cables. The natural habitat community statistically differed from both the energized cable and unenergized cable communities. Within species (or in several cases species-groups) that formed at least one percent of the fishes observed, we found no differences in densities between energized and unenergized cables. We did find differences based on cable side (shortspine combfish densities were higher on the west side of cables), depth strata (stripetail rockfish, unidentified poachers, shortspine combfish, greenstriped rockfish, lingcod, and unidentified eelpouts), and year (halfbanded rockfish, stripetail rockfish, and lingcod).

Total fish densities were significantly higher around the cables than over the natural habitat. Among the more important species, densities of halfbanded, stripetail, and greenstriped rockfishes, shortspine combfish, and lingcod were higher at the cables and eelpouts were found at higher densities over natural habitat. There were no significant differences in the densities of unidentified sanddabs and unidentified poachers. There were very slight, but statistically significant, differences in both mean lengths and size distributions of fishes among the three study habitats as fishes at the unenergized cables tended to be slightly larger (mean = 14.8 cm) than those at both natural habitats (mean = 13.7 cm) and energized cables (mean = 13.0 cm).

Over all habitats we observed 9,675 individuals of at least 41 species. Dominant species included halfbanded, stripetail, and greenstriped rockfishes, and lingcod, and unidentified flatfishes, poachers, and combfishes. *Energized cables*: In the vicinity of the energized cables, we observed at least 33 species of fishes, comprising 4,455 individuals. Halfbanded rockfish dominated this habitat, comprising 56% of all fishes observed and present during 82.3% of the transects. Other important species or species groups included unidentified flatfishes and poachers, stripetail and shortspine combfish. *Unenergized cables*: Similar to the fish assemblage found around energized cables, there were at least 35 fish species in proximity to the unenergized cables and 3,691 individuals. As with the energized cables, halfbanded rockfish were by far the most abundant species, comprising 37.4% of all fish observed. Other important species included stripetail and greenstriped rockfishes and unidentified flatfishes, poachers, and combfishes. *Natural habitats*: Fewest species (at least 23) and fishes (1,529) were observed on the natural habitats. Here, unidentified flatfishes, eelpouts, poachers, combfishes, sanddabs and halfbanded rockfish predominated.

Invertebrates

The structure of the invertebrate communities living around energized and unenergized cables and natural habitats was similar to that of fishes. We found that invertebrate communities were structured by habitat type and depth. Similar to the fishes, there was no statistical difference between the invertebrate assemblages along the energized and unenergized cables. The natural habitat community of invertebrates strongly differed from the energized cable and unenergized cable communities.

To determine if there were significant differences in species densities between energized and unenergized cables, we compared the densities of those important species that comprised at least 1% of individuals observed in this study in the same way as for fishes. We did note slight but statistically significant differences in densities for only two of nine of the most abundant species. Sand star and black crinoid densities differed between unenergized and energized cables [sand star greater at unenergized cables, 4/1/m^3 v 2.7 m^3, and black crinoid at energized cables, 1.7/m^3 v 0.3/m^3]. Three species, thin sea pen, red octopus, and white sea urchin differed between cable sides. Seven species, white-plumed anemone, spot prawn, thin sea pen, California sea cucumber, red octopus, unidentified *Urticina* anemone, and black crinoid exhibited bottom depth differences. Densities of two species, thin sea pen and sand star, varied among years.

A number of species were more abundant around the cables than over the natural habitats. Important species that were more abundant around cables were white-plumed anemone, spot prawn, thin sea pens, California sea cucumber, sand star, and unidentified *Urticina* anemone. Red octopus and white sea urchin were denser over natural habitats and densities of black crinoid did not differ between the two habitats.

Over all habitats, we observed a total of 30,523 invertebrates of at least 43 invertebrate species. The white-plumed anemone was by far the most abundant animal and comprised 43.4% of all invertebrates recorded. Spot prawns, thin sea pens, California sea cucumbers, sand stars, and the red octopuses were also found at relatively high densities. *Energized cables*: We observed 13,388 individuals, of at least 36 species, living on or near the energized cables. White-plumed anemones, thin sea pens and spot prawns were the species found in highest densities, forming in aggregate 79.7% of all invertebrates observed. California sea cucumbers, sand stars, red octopuses, black crinoids, and *Urticina* anemones were also common. *Unenergized cables*: At least 35 species and 14,619 individuals were observed along the unenergized cables. Three species, white-plumed anemones, spot prawns, and thin sea pens, were by far the most dense, in aggregate forming 79.2% of all invertebrates surveyed. California sea cucumbers, sand stars, red octopus, unidentified *Urticina* anemones, and serpulid worms were also characteristic of this habitat. *Natural habitats*: We observed the fewest number of species (a minimum of 27) and individuals (2,516) over the natural habitat. Thin sea pens, red octopuses, white sea urchins and sand stars dominated this habitat, along with smaller numbers of white-plumed anemones, fragile pink urchins, California sea cucumbers, and sea slugs.

Conclusions

Regarding the specific objectives of these studies:

Task 1

1) *The differences among fish and invertebrate communities associated with energized and unenergized cable habitat and those communities in soft seafloor habitats lacking cables.*

We did not find any biologically significant differences among fish and invertebrate communities between energized cables, pipe, and natural habitat. In particular, only three species of fish showed statistically significant, but slight, differences in densities between the cables and pipe. Plant communities did differ among habitats and within habitats between depths. These differences were almost certainly structure and depth, rather than EMF, related.

2) *Whether electro-sensitive species that are regionally important, such as sharks and rays, respond (via either attraction or repulsion) to the EMFs of an in situ power transmission cable.*

We observed only one elasmobranch individual, a swell shark, during the course of this study. Thus, it would appear that the EMFs generated by these energized cables are either unimportant to these organisms or that at least other environmental factors take precedence.

3) *The strength, spatial extent, and variability of EMFs along both energized and unenergized cables.*

The strength of the EMF along the energized cable was relatively stable over time and along its length. The EMF produced by the energized cables diminishes to background levels about one meter away from the cable. Similarly, both the pipe and natural habitat sites had extremely small or undetectable EMFs.

4) *The potential effectiveness of the commonly proposed mitigation of cable burial.*

Given the rapidity with which the EMF produced by the energized cables diminishes and the lack of response to that EMF by the shallower fish and invertebrates, cable burial would not appear necessary strictly for biological reasons. In this and similar cases, cable burial, at sufficient depth, would be an adequate tool to prevent EMF emissions from being present at the seafloor.

Task 2

1) *The differences among fish and invertebrate communities associated with energized and unenergized cable habitat and those communities in soft seafloor habitats lacking cables.*

We did not observe any significant differences in the fish communities living around energized and unenergized cables and natural habitats. A very slight, and likely biologically insignificant, difference in mean sizes was observed as fishes at unenergized cables were marginally larger than those around energized ones. Overall species diversity and the densities of the most important fish species (define as comprising at least 1% of all fishes observed) were higher at the cables than at the natural habitats. This is likely reflective of the more complex habitats afforded by the cables than the primarily soft substrata natural habitats.

Similar to the fish communities, the invertebrate assemblages living around energized and unenergized cables and natural habitats were similar to one another and variability between these communities was primarily driven by sea floor depth. Among the three habitat types, there were some statistically significant differences in densities for all nine of the most abundant species. These differences included: 1) two species, sand star and black crinoid, whose densities differed between energized and unenergized cables, 2) three species, thin sea pen, red octopus, and white sea urchin which differed between cable sides, 3) seven species, white-plumed anemone, spot prawn, thin sea pen, California sea cucumber, red octopus, unidentified *Urticina* anemone, and black crinoid that exhibited bottom depth differences, and 4) two species, thin sea pen and sand star, whose densities varied among years. Sand star densities were greater at unenergized cables, 4/1/m^3 v 2.7 m^3, and black crinoid densities were greater at energized cables, 1.7/m^3 v 0.3/m^3.

2) Whether electro-sensitive species that are regionally important, such as sharks and rays, respond (via either attraction or repulsion) to the EMFs of an in situ power transmission cable.

We observed very few individuals of electro-sensitive species on the energized or unenergized cables or on the natural habitats. Only five ratfish (three at the energized cables and two on the unenergized ones) and one California skate (at the unenergized cable) were noted. Thus, we found no compelling evidence that the EMF produced by the energized power cables in this study were either attracting or repelling these fishes.

3) The strength, spatial extent, and variability of EMFs along both energized and unenergized cables.

The EMFs produced by the energized cables were similar both over the three years of the study and along the cables. EMF strength dissipated relatively quickly with distance from the cable and approached background levels at about one meter from the cable. The EMF at unenergized cables was similar to that found at the natural habitats.

4) The potential effectiveness of the commonly proposed mitigation of cable burial.

Given the rapidity with which the EMF produced by the energized cables diminishes and the lack of response to that EMF by the fishes and invertebrates in this study, cable burial would not appear necessary strictly for biological reasons. In this and similar cases, cable burial, at sufficient depth, would be an adequate tool to prevent EMF emissions from being present at the seafloor.

CHAPTER 1. INTRODUCTION TO CHAPTERS 2 AND 3

It is likely that for the foreseeable future, offshore renewable energy technologies will focus on the generation of electricity from renewable resources (e.g., wind and wave). These technologies harness energy from an array of individual devices and, through power cables, send electricity to shore via cables. These cables will transmit either alternating current or direct current, and, if the cable uses alternating current, this current will generate both electric and magnetic fields around these cables.

Research has shown that cartilaginous and some bony fishes, as well as at least some invertebrates, are sensitive to electromagnetic fields (EMF) and that these fields can alter the behavior of these organisms (Kalmijn 1982, Formicki et al. 2004, Tanski et al. 2005 and summarized in Normandeu et al. 2011). However, worldwide, only a few studies have been conducted to document the effects of EMF on marine organisms in situ (DONG Energy and Vattenfall 2006, Ohman et al. 2007, Westerberg and Lagenfelt 2008) or in a semi-artificially enclosed mesocosm (Gill et al. 2012). These studies have yielded either equivocal, or at best subtle, evidence of marine organism responding to artificially induced EMF in a natural or semi-natural environment.

Submarine transmission cables that power offshore oil platforms in the Pacific Region provide a unique opportunity to assess potential behavior and reaction of electromagnetic-sensitive species to industry activities. In particular, the chance occurrence of both energized and unenergized cables, and a pipeline leading to the platforms, in a corridor on the seafloor within the Santa Ynez Unit Offshore Southern California Planning Area (Figure 1-1), allows for experiments testing the effects of EMF on marine organisms. Identical cables (emplaced concurrently by the manufacturer) stretch several miles from Las Flores on the mainland to Platforms Heritage, Harmony, and Hondo (at depths to about 326 m). The cables were laid on the surface of the seafloor and intentionally were buried from shore out to a depth of 10 m. One of the cables is unenergized, because it has been cut at the border of federal and state waters (about 150 m bottom depth), and the entire length of the cable in state waters has been removed. All of these power cables are industry standard, the type that will be used for connecting devices (35 KV) within renewable energy installations. Thus, the cables and pipe form a natural experiment, allowing a comparison of energized and unenergized power cables, and pipe to determine the potential impacts from electromagnetic fields while controlling for the habitat effect contributed by the cables themselves.

The goal of this study was to more fully understand the potential effects of energized and seabed deployed power cables on marine organisms.

Specific objectives of this study were to determine:

1) The differences among fish and invertebrate communities associated with energized and unenergized cable habitat and those communities in soft seafloor habitats lacking cables.
2) Whether electro-sensitive species that are regionally important, such as sharks and rays, respond (via either attraction or repulsion) to the EMFs of an in situ power transmission cable.
3) The strength, spatial extent, and variability of EMFs along both energized and unenergized cables.
4) The potential effectiveness of the commonly proposed mitigation of cable burial.

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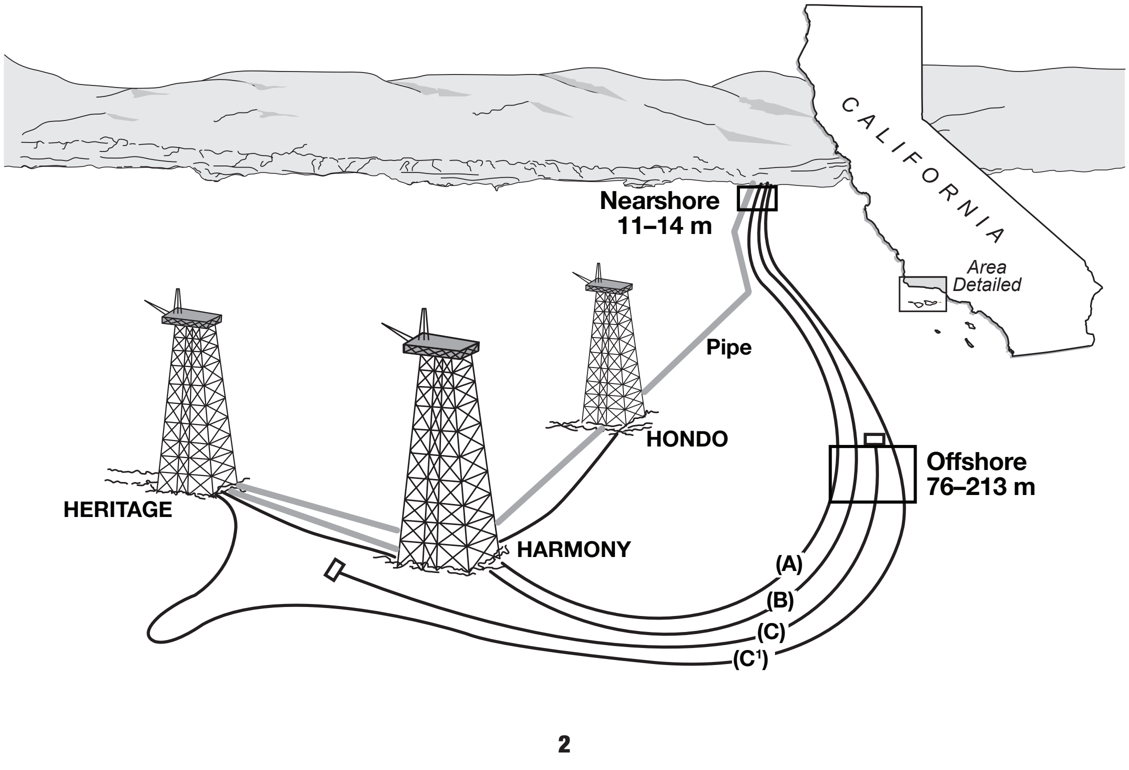
Figure Legend

Figure 1-1. Location of the energized and unenergized submarine power cables surveyed.



CHAPTER 2: INSHORE SURVEY

Abstract

Between 1 February 2012 and 26 February 2014 using scuba, we surveyed the fishes, invertebrates, and marine plants living on two energized submarine power cables, adjacent pipe, and natural habitat. Along cable, pipe, and over sandy bottom, we installed six permanent 30 m-long transects; three at a shallow depth (10–11 m) and three in slightly deeper waters (13–14 m depth). The end of the shallow transects and beginning of the deep ones were separated by about 120 m. The beginning and ending of each transect at each site was marked by sand anchors as was each 5 m segment along each transect. Transects were 2 m wide, centered on the pipe or cable or an imaginary line between sand anchors that delineated the sandy control transect. During the surveys, we measured the electromagnetic fields (EMF) emitted by the cable, pipe, and natural habitat. Fishes and plant surveys were conducted from the beginning to end of the study — from 1 February 2012 to 26 February 2014. Invertebrate surveys were conducted beginning on 22 June 2012 and continued until the end of the study. We conducted a total of 38 days of fish surveys, 30 days of invertebrate studies, and 38 days of plant studies during the three years. Over the course of the study, average EMF levels at the two cables (A and B) were statistically similar (Cable A = 73.0μT, Cable B = 91.4μT) and were much higher at the two cables than at either the pipe (average = 0.5μT) or sand (0μT).

Fishes

Overall, our study demonstrated that 1) the fish communities on cables, pipe, and natural habitat strongly overlapped (global R=0.097, p=0.01) and 2) the difference between the shallower and deeper fish communities was negligible (global R=0.097, p=0.001).

Over all habitats, we observed 4,671 individuals of a minimum of 44 species. Dominant species included adults of benthic-oriented, schooling taxa (i.e., kelp perch, senorita, white seaperch, and shiner perch), young-of-the-year (YOY) rockfishes that had newly settled out of the plankton (particularly black-and-yellow, gopher, and kelp rockfishes), and relatively solitary substrate-oriented species (i.e., sanddabs and kelp perch). Senorita, sanddabs, white seaperch, YOY rockfishes, and kelp perch were the most abundant taxa. *Cables*: At least 35 species and 1,721 individuals were observed over the energized cables. Senorita, sanddabs, kelp perch, white seaperch, and YOY rockfishes were most abundant (Table 2-4). *Pipe*: The number of taxa (37) and individuals (1,829) were similar to those observed on the cables. Senorita, YOY rockfishes, vermilion rockfish YOY, pile perch, black perch, and sanddabs were the most important taxa on the pipe (Table 2-5). *Natural Habitat*: Fewest species (25) and individuals (1,121) were observed over the natural habitat. Shiner perch, sanddabs, senorita, YOY shortbelly rockfish, white seaperch, and tubesnout were most often observed here (Table 2-6).

All of the fish communities were composed primarily of small fishes and the majority of these individuals were less than 20 cm long. The mean length of fishes varied significantly among the three habitats (Welch's Test, F = 43.7, df = 2, p <.0001) as did the size distributions. However, we note that the difference of mean lengths among sites is very small and it is unlikely that these differences, although statistically significant, are biologically meaningful. The abundance of all fishes combined varied seasonally at every site. In general, fishes were more abundant from early spring through early fall at all sites. This was reflective of the seasonal influx of newly settled rockfishes, young seaperches, and the general increase in fish abundance in nearshore waters that takes place as the turbulent winter waters subside.

Invertebrates

Similar to the fish assemblages, the invertebrate communities on the cables, pipe, and natural habitats were quite similar overall (global R=0.111, p=0.001) and the shallower and deeper invertebrate assemblages were indistinguishable (global R=0.000, p=0.51).

Over all habitats, we observed a total of 822 individuals comprising a minimum of 19 species. Bat star, several species of *Pisaster* sea stars, purple urchin (but noted on only one occasion), California sea hare, Comb sea star, and Kellet's whelk were observed most often. By group, sea stars were the most abundant, comprising 56.8% of all invertebrates recorded. *Cables:* We observed 157 individuals of at least 15 species at the cable sites. Bat star, *Pisaster* sea stars, and California sea hare were most abundant. *Pipe:* Four hundred and forty two individual invertebrates, the most of any site, were observed at the pipe. However, 100 of these individuals were comprised of a one-time recorded aggregation of purple sea urchin. Like the cables, we recorded 15 species along the pipe. *Natural Habitat:* Bat star and Kellet's whelk predominated in the natural habitat, where we recorded 223 individuals, of 13 species.

Overall, the numbers of invertebrates living at the study sites remained fairly constant over the course of the study. What changes occurred were due to influxes of *Pisaster* sea stars and bat stars. Of the eight most common species observed, the densities of five species (*Pisaster* sea stars, bat star, sea cucumbers, and rock crabs) varied with site. Between cables and pipe, densities of four species (*Pisaster* sea stars, bat stars, sea cucumbers, and rock crabs) were different. *Pisaster* sea stars, bat stars, and sea cucumbers were more abundant at the pipe and rock crabs were more often encountered at the cable. The densities of three taxa or taxa groups, *Pisaster* sea stars, California sea hare, and sea cucumbers were higher at the pipe than at the natural habitat. Lastly, rock crabs and California sea hare were found at higher densities at the cables compared to natural habitat and, contrarily, bat stars were more abundant at the natural habitat.

Plants

Unlike the fish and invertebrate assemblages, the plant communities of the three sites were different. First, there were intra-site differences in the shallower and deeper plant communities within the cables and pipe habitats, although not in the natural habitat. In addition, there were differences in the plant communities between the three habitats (global R=0.986, p=0.001; R>0.8, p=0.001).

Over all habitats, a total of 72,999 individual plants (many likely observed repeatedly on sequential survey days) were tallied, comprising at least five species. Overall, *Zostera marina* was most abundant, followed by *Pterygophora californica*, *Cystoseira* spp., *Laminaria* spp., and *Macrocystis pyrifera. Cables:* Among all plants, *Pterygophora californica* dominated the cable community, although *Cystoseira* spp. and *Laminaria* spp. were not uncommon. *Pterygophora californica* was very abundant on Cable B (particularly shallower), but absent from Cable A (although both were energized). Eelgrass grew on the sand near the cable. *Macrocystis pyrifera* grew very sparsely on the shallower Cable B habitat, was more common on the shallower part of Cable A, and was essentially absent from the deeper cables. *Pipe*: *Cystoseira* spp. and *Laminaria* spp. were by far the most common plants on the pipe. *Cystoseira* spp. was nearly twice as abundant shallower than deeper while *Laminaria* spp. was almost absent from the shallower site and nearly as abundant as *Cystoseira* spp. deeper. Relatively few *P. californica* were observed on the pipe and both *M. pyrifera* and *Z. marina* were almost absent. *Natural Habitat*: *Zostera marina* was the only plant growing on the sandy sea floor of the natural habitat. It was dense at both the shallower and deeper sites. With the exception of *Z. marina* living on the natural habitat, we did not observe any strong seasonality in plant densities. Densities of Z. marina in both the shallower and deeper areas tended to increase over the course of the study.

Regarding the specific objectives of this study:

1) The differences among fish and invertebrate communities associated with energized and unenergized cable habitat and those communities in soft seafloor habitats lacking cables.

We did not find any biologically significant differences among fish and invertebrate communities between energized cables, pipe, and natural habitat. In particular, only three species of fish showed statistically significant, but slight, differences in densities between the cables and pipe. Plant communities did differ among habitats and within habitats between depths. These differences were almost certainly structure and depth, rather than EMF, related.

2) Whether electro-sensitive species that are regionally important, such as sharks and rays, respond (via either attraction or repulsion) to the EMFs of an in situ power transmission cable.

We observed only one elasmobranch individual, a swell shark, during the course of this study. Thus, it would appear that the EMFs generated by these energized cables are either unimportant to these organisms or that at least other environmental factors take precedence.

3) The strength, spatial extent, and variability of EMFs along both energized and unenergized cables.

The strength of the EMF along the energized cable was relatively stable over time and along its length. The EMF produced by the energized cables diminishes to background levels about one meter away from the cable. Similarly, both the pipe and natural habitat sites had extremely small or undetectable EMFs.

4) The potential effectiveness of the commonly proposed mitigation of cable burial.

Given the rapidity with which the EMF produced by the energized cables diminishes and the lack of response to that EMF by the shallower fish and invertebrates, cable burial would not appear necessary strictly for biological reasons. In this and similar cases, cable burial, at sufficient depth, would be an adequate tool to prevent EMF emissions from being present at the seafloor.

Methods

Our scuba surveys of the subtidal marine community were conducted off the coast of Las Flores Canyon, southern California (34°27.6´N, 120°02.7´W) between 1 February 2012 and 26 February 2014 (Figure 2-1). At this site there are 1) three 8” diameter submarine power cables (variously energized and unenergized) providing power to three offshore oil platforms and 2) a 12” diameter pipe running from the platforms to shore (Figure 2-1). The furthest distance between the outermost cable and the pipe is about 40 m.

Prior to beginning the study, we found that sections of cable were exposed and buried by natural disturbances and that EMF levels were lower on the sandy substrate directly over the buried cable than on exposed cable. Thus to study the effect of the maximum EMF possible, we determined the survey would have to be conducted along unburied sections of the cable. Divers observed cables and pipeline for exposed continuous 30-m long sections, a standard transect length that we and other research groups have used for fish surveys in the region. We were able to find appropriate lengths of exposed energized cables (Cables A and B) where fixed 30-m long transects could be set at two bottom depths. As Cable C had been cut off and removed from state waters, we were unable to find such lengths along this structure. Lastly, unenergized Cable C1 was mostly buried and we did not find any exposed 30-m lengths. Thus, for these surveys, we used the nearby exposed pipe as a surrogate for the unenergized cable. Overall, then, we surveyed fishes, invertebrates, and plants along three habitats: 1) an energized submarine power cable, a pipe, and a sandy, natural, control area to the west of both cables and pipe (Figure 2-1).

Along cable, pipe, and over sandy bottom, we installed six permanent 30 m-long transects; three at a shallow depth (10–11 m) and three in slightly deeper waters (13–14 m depth). The end of the shallow transects and beginning of the deep ones were separated by about 120 m. The beginning and ending of each transect at each site was marked by sand anchors as was each 5 m segment along each transect. Transects were 2 m wide, centered on the pipe or cable or an imaginary line between sand anchors that delineated the sandy control transect. Two divers conducted each survey and surveys were conducted during daylight hours. The first diver surveyed fishes. All fishes encountered within 2 m above the substrate were identified to species, and counted, and sized (by eye) to the nearest centimeter. The fish survey diver also recorded water temperature and horizontal visibility during each transect and, using an EMF detector, recorded the magnitude of EMF at the beginning of each survey. Readings were taken with the detector placed directly against the cable, pipe, and sand. A second diver followed and recorded the number of plants in the 2 m swath around the cable and pipe or on the sand. Plant quantification was used to determine if these structure-forming organisms differentially modified the study habitats. The second diver also recorded macroinvertebrates (i.e., cnidarians, mollusca, crustaceans, and echinoderms) encountered within the same 2-m-wide sampling area. Only individual invertebrates of at least 10 cm in any dimension were recorded.

Statistical analyses included complete surveys comprised of three shallower and three deeper transects along the pipe, energized cable, and natural habitat (sand). Only one survey conducted on 22 June 2012 was incomplete and excluded. The number of individuals per transect of each species were treated as observations. We summarized the data by each shallower and deeper habitat type as time series using untransformed densities (observed count per 100 m^3) of fishes. Counts per transect were used for invertebrates and plants, because most of the taxa were observed directly on the cable and pipe structures, and density estimates based on the 2 m wide x 30 m long transects would be biased.

We used Primer v6 (Clarke and Gorley, 2006) to examine the biological assemblage data in relation to the shallower and deeper habitats. The multivariate analyses excluded taxa that occurred in only one survey. The observations of fish and invertebrate counts per transect were transformed to log (x+1). Counts of plants per transect were square root-transformed. Bray-Curtis similarity coefficients were calculated to quantify the resemblance between transect samples, and similarity matrices were generated for fish, invertebrates and plants, separately. Natural groupings of samples were examined using hierarchical clustering with the group average linkage option and multidimensional scaling (MDS) ordination. To test the null hypothesis that there are no assemblage differences between pipe, cable, and natural habitats (factor A), allowing that there may be shallower/deeper differences (factor B), we used a two-way crossed analysis of similarity (ANOSIM) that operates on the resemblance matrix. The ANOSIM sample test statistic, R, ranges from 0 (no difference between groups) to 1 (all dissimilarities between the groups are larger than any dissimilarities among samples with either group). A statistically significant ($p<0.05$) but negligibly small R value close to 0 indicates that species composition strongly overlap and the difference between groups may not be biologically meaningful.

To determine if the abundance of an individual species statistically differed among the three habitat types, we ran parametric or nonparametric tests, $\alpha=0.05$ (JMP, 2015). Analyses were performed on all plant taxa, and the most common fishes and invertebrates. Survey dates were excluded when the individual species was absent. The observations of counts per transect were transformed to log(x+1). A one-way analysis of variance (ANOVA) was performed on shallower and deeper data separately to test for differences among the three habitats, and a t-test was used to test for differences between shallower and deeper transects. The Tukey Honestly Significant Difference multiple comparison test was used when differences among habitats were detected. Alternatively when variances were unequal between groups as determined by the Levene test, the nonparametric Welch's ANOVA and Mann-Whitney test were used with the Wilcoxon method for multiple comparisons between habitats.

Results

At the beginning of the study we measured the EMF emitted by the power cables in our study site and found that two cables, A and B, were energized. We began our cable surveys on energized Cable B. However, on 15 May 2013, we noted that Cable B had become unenergized and we switched our surveys to energized Cable A for the duration of the study. Importantly, we note that both cables A and B had been energized for at least several years before Cable B was switched off (D. Gilbert, pers. comm. to M. L.). Fishes and plant surveys were conducted from the beginning to end of the study — from 1 February 2012 to 26 February 2014. Invertebrate surveys were conducted beginning on 22 June 2012 and continued until the end of the study. Surveys were conducted on a total of 38 days (Table 2-1).

Algae, primarily the brown algae *Cystoceira* spp., Laminaria spp., *Pterygophora californica*, and *Macrocystis pyrifera*, grew on some of the cables and pipe, and eelgrass, *Zostera marina*, lived primarily on the natural habitat. The algae were attached to the cables and pipe and the eelgrass was rooted in the soft sediment of the natural habitat. *Cystoceira* spp. was present throughout the year on both the shallow and deep transects (it was much more abundant on the pipe) (Figure 2-2); Laminaria spp. occurred almost entirely on the deeper pipe and cables (Figure 2-3); *P. californica* was present only on Cable B (more abundantly in shallow waters) (Figure 2-4); and *M. pyrifera* was primarily limited to the shallow areas of Cable A (Figure 2-5). The sandy, natural habitat harbored only scattered eelgrass plants early in the study; however this species became more abundant in both shallow and deep areas as the survey progressed (Figure 2-6). Although eelgrass did occur on the sand next to both cables, it was present in very low numbers.

EMF Levels

Over the course of the study, average EMF levels at the two cables (A and B) were statistically similar (Cable A = 73.0μT, Cable B = 91.4μT) and were much higher at the two cables than at either the pipe (average = 0.5μT) or sand (0μT) (Figure 2-7, Table 2-2).

Fishes

Overall, our study demonstrated that 1) the fish communities on cables, pipe, and natural habitat strongly overlapped (global R=0.097, p=0.01; Figure 2-8), and 2) the difference between the shallower and deeper fish communities was negligible (global R=0.097, p=0.001; Figure 2-9).

All Habitats: We conducted a total of 38 days of fish surveys during three years. Over all habitats, we observed 4,671 individuals of a minimum of 44 species (Tables 2-3, 2-4). Dominant species included adults of benthic-oriented, schooling taxa (i.e., kelp perch, senorita, white seaperch, and shiner perch), young-of-the-year (YOY) rockfishes that had newly settled out of the plankton (particularly black-and-yellow, gopher, and kelp rockfishes), and relatively solitary substrate-oriented species (i.e., sanddabs and kelp perch). Senorita, sanddabs, white seaperch, YOY rockfishes, and kelp perch were the most abundant taxa. *Cables:* At least 35 species and 1,721 individuals were observed over the energized cables. Senorita, sanddabs, kelp perch, white seaperch, and YOY rockfishes were most abundant (Table 2-4). *Pipe*: The number of taxa (37) and individuals (1,829) were similar to those observed on the cables. Senorita, YOY rockfishes, vermilion rockfish YOY, pile perch, black perch, and sanddabs were the most important taxa on the pipe (Table 2-5). *Natural Habitat*: Fewest species (25) and individuals (1,121) were observed over the natural habitat. Shiner perch, sanddabs, senorita, YOY shortbelly rockfish, white seaperch, and tubesnout were most often observed here (Table 2-6).

All of the fish communities were composed primarily of small fishes and the majority of these individuals were less than 20 cm long (Figure 2-10). The mean length of fishes varied significantly among the three habitats (Welch's Test, F = 43.7, df = 2, p <.0001) as did the size distributions (Table 2-8). However, we note that the difference of mean lengths among sites (Figure 2-10) is very small and it is unlikely that these differences, although statistically significant, are biologically meaningful. The abundance of all fishes combined varied seasonally at every site (Figure 2-11). In general, fishes were more abundant from early spring through early fall at all sites. This was reflective of the seasonal influx of newly settled rockfishes, young seaperches, and the general increase in fish abundance in nearshore waters that takes place as the turbulent winter waters subside. We note that an unusual increase in fish abundance occurred at the 10–11 m shallow cable and pipe stations during the winter of 2014. This may reflect an unusually mild winter, with few storms and thus little turbulence, allowing schools of kelp perch, senorita, and white seaperch to occupy shallower than usual waters (M. Love, pers. obs.).

While the overall composition of the fish communities of the various habitats was similar, at the species level we did observe some differences in abundances (Table 2-9). Although all of the 15 most abundant species were found at all sites, nine (i.e., senorita, sanddabs, rockfish YOY, kelp perch, black perch, rainbow perch, bocaccio, giant kelpfish, and copper rockfish) varied in abundances between sites. Most of these differences were between the cable or pipe and the natural habitat. The abundances of only three taxa or groups of taxa (black perch, rockfish YOY, and sanddabs) differed statistically between the cables and pipe. Black perch and rockfish YOY were found at higher densities over the pipe and sanddabs were more common along the cable.

Invertebrates

Not unlike the fish assemblages, the invertebrate communities in the cables, pipe, and natural habitats were quite similar overall (global R=0.111, p=0.001; Figure 2-12), and the shallower and deeper invertebrate assemblages were indistinguishable (global R=0.000, p=0.51; Figure 2-13).

All Habitats: We conducted a total of 30 days of invertebrate studies during three years. A total of 822 individuals were observed, comprising a minimum of 19 species (Table 2-10). Bat star, several species of *Pisaster* sea stars, purple urchin (but noted on only one occasion), California sea hare, Comb sea star, and Kellet's whelk were observed most often. By group, sea stars were the most abundant, comprising 56.8% of all invertebrates recorded. *Cables:* We observed 157 individuals of at least 15 species at the cable sites. Bat star, *Pisaster* sea stars, and California sea hare were most abundant (Table 2-11). *Pipe*: Four hundred and forty two individual invertebrates, the most of any site, were observed at the pipe. However, 100 of these individuals were comprised of a one-time recorded aggregation of purple sea urchin. Like the cables, we recorded 15 species along the pipe (Table 2-11). *Natural Habitat:* Bat star and Kellet's whelk predominated in the natural habitat, where we recorded 223 individuals, of 13 species (Table 2-11).

Overall, the numbers of invertebrates living at the study sites remained fairly constant over the course of the study (Figure 2-14). What changes occurred, for instance during fall 2012 at all deeper sites and summer-winter 2013-14 at the deeper pipe site, were due to influxes of *Pisaster* sea stars and bat stars (Figure 2-15). Of the eight most common species observed, the densities of five species (*Pisaster* sea stars, bat star, sea cucumbers, and rock crabs) varied with site (Table 2-12). Between cables and pipe, densities of four species (*Pisaster* sea stars, bat stars, sea cucumbers, and rock crabs) were different. *Pisaster* sea stars, bat stars, and sea cucumbers were more abundant at the pipe and rock crabs were more often encountered at the cable. The densities of three taxa or taxa groups, *Pisaster* sea stars, California sea hare, and sea cucumbers were higher at the pipe than at the natural habitat. Lastly, rock crabs and California sea hare were found at higher densities at the cables compared to natural habitat and, contrarily, bat stars were more abundant at the natural habitat.

Plants

Unlike the fish and invertebrate assemblages, the plant communities of the three sites were different. First, there were intra-site differences in the shallower and deeper plant communities (global R=0.626, p=0.001) within the cables and pipe habitats, although not in the natural habitat (Figure 2-16). In addition, there were differences in the plant communities between the three habitats (global R=0.986, p=0.001; R>0.8, p=0.001, for all pairwise comparisons; Figure 2-17).

All Habitats: We conducted a total of 38 days of plant studies during three years. A total of 72,999 individual plants (many likely observed repeatedly on sequential survey days) were tallied, comprising at least five species (Table 2-13). Overall, *Zostera marina* was most abundant, followed by *Pterygophora californica*, *Cystoseira* spp., Laminaria spp., and *Macrocystis pyrifera. Cables:* Among all plants, *P. californica* dominated the cable community, although *Cystoseira* spp. and *Laminaria* spp. were not uncommon (Table 2-14). Note that *P. californica* was very abundant on Cable B (particularly shallower), but absent from Cable A (Figure 2-4). Eelgrass grew on the sand near the cable. *Macrocystis pyrifera* grew very sparsely on the shallower Cable B habitat, was more common on the shallower part of Cable A, and was essentially absent from the deeper cables (Figure 2-5). *Pipe: Cystoseira* spp. and *Laminaria* spp. were by far the most common plants on the pipe (Table 2-14). *Cystoseira* spp. was nearly twice as abundant shallower than deeper while *Laminaria* spp. was almost absent from the shallower site and nearly as abundant as *Cystoseira* spp. deeper (Figures 2-2, 2-3). Relatively few *P. californica* were observed on the pipe and both M. pyrifera and Z. marina were almost absent. *Natural Habitat: Zostera marina* was the only plant growing on the sandy sea floor of the natural habitat (Table 2-14). It was dense at both the shallower and deeper sites (Figure 2-6). With the exception of *Z. marina* living on the natural habitat, we did not observe any strong seasonality in plant densities. Densities of *Z. marina* in both the shallower and deeper areas tended to increase over the course of the study.

Discussion

We began this study with the understanding that if a species is attracted to an EMF we would expect to find that species in disproportionately larger numbers or densities around the energized cables compared to the pipe or natural habitat. Similarly, if a taxa is repelled by that EMF we would expect that species to be present less often or in lower densities at the cables. However, the presence or absence of an EMF is not the only habitat parameter influencing how an organism chooses its habitat and we acknowledge that in this study to an extent the cables and pipe differed not only in the production of an EMF but also in the morphology of these habitats.

In particular, the pipe was a slightly more complex structure. First, the pipe's diameter (12") was somewhat greater than that of the two cables (8"). And while the cable was sometimes partially buried, the pipe was not. Thus for both reasons the pipe tended to present a somewhat higher profile. In addition, perhaps the greatest structural difference between the cables and pipe was the very high density, particularly on the shallower pipe, of *Cystoceira* sp., a brown algae that was essentially absent from the shallower cable. This alga forms a dense cover near the bottom and small fishes, particularly YOY rockfishes, will preferentially inhabit this complex substratum. Algae also grew on the cable, particularly *Macrocystis pyrifera* on the shallower area of Cable A, and *Laminaria* sp. on the deeper portion of both cables. However, M. pyrifera does not form luxuriant bottom structures and the *Laminaria* stands, while present, did not present as dense a cover as the *Cystoceira* on the pipe. The sandy natural habitat was the least complex of all three; it's two-dimensional aspect was only broken up by stands of *Z. marina*. At the start of the study *Z. marina* was only sporadically found and became more abundant over time.

Structural variability aside, the results of our study demonstrated that the fish and invertebrate assemblages of the three habitats were very similar. Although a few species statistically varied in abundance between the cables and pipe, in no instance was a fish or invertebrate species extremely abundant at one of these two habitats and extremely rare or absent from the other. And although fishes were statistically larger at the pipe than at the cable or natural habitat, we argue that this difference (of less than one-half centimeter between pipe and cable and two centimeters between pipe and natural habitat) is not biologically meaningful.

In particular, we saw no evidence that any species of fish or invertebrate was either preferentially attracted to, or repelled by, the EMF emitted by the cables. Any differences in the fish or invertebrate densities between cables, pipe, and natural habitat taxa are most likely due to the differences in the physical characteristics of these habitats. For instance, the higher densities of YOY rockfishes and black perch at the pipe are most likely due to greater densities of understory algae, specifically *Cystoseira* spp. By the same token, the lower-relief cables, which were closer to the sandy sea floor, were a better habitat for soft-bottom dwelling sanddabs. Contrary to the fish and invertebrate assemblages, the plant communities on cables, pipe, and natural habitat were clearly different from one another. However, if cable EMF were responsible for these differences, we would expect to see similarities in plant communities between energized cables A and B and this was not the case (Figure 2-16). Rather, it appears that plant communities were driven by site depth (particular among the algae) and habitat type (i.e., eelgrass).

We note that this study was not designed to directly determine the behavior of fishes and invertebrates when these organisms encounter an energized cable during, for instance, migrations. Rather, we observed the integration over time, that is the results, of myriads of such behaviors by many organisms. Understanding how individuals within a taxon relate to energized cables would have to involve either tracking (Westerberg and Lagenfelt 2008) or caging experiments (Love et al. 2015) or hybrids of the two (Gill et al. 2009).

In southern California, most along-shore migrations (as distinct from less synchronized movements) are conducted by such pelagic species as blue sharks (*Prionace glauca*) and Pacific sardines (*Sardinops sagax*). The more substrate-associated shallower species (exemplified by the taxa that dominated our survey) tend to be either resident (i.e., swell sharks, black perch), make seasonal shallower-deeper movements (rainbow perch), or locally disperse as they mature (YOY rockfishes, shiner perch). Given that the EMF emitted from the study cables is undetectable beginning at a distance of about one meter (Love et al. 2015, Love unpubl. data) it would be unlikely that pelagic and midwater species are affected by this field. In fact, the limited range of the EMF implies that only the movements of those species that live close to the bottom would be potentially impacted.

In our study area, some of the bottom-dwelling or bottom-oriented species most likely to respond to energized cables are the elasmobranchs: the sharks, skates, and rays. It is probable that all of these fishes can detect an EMF and this ability appears to be used for a number of behaviors including migration and food detection (Kalmijn 1971, Tricas 1982, Klimley et al. 2005). Moreover, while the actual sensitivity to an EMF is known for only a few elasmobranch species, we note that at least two Atlantic species, *Carcharhinus plumbeus* and *Sphyrna lewini*, are able to detect an EMF in the 25–100 µT range (Meyer et al. 2005); this is within the range generated by the current studies' energized cables.

The shallower habitats of southern California, and specifically this study site, harbor a rich diversity of elasmobranchs (Love 2011). These include both motile taxa (e.g., leopard sharks, *Triakis semifasciata* and smoothhounds, *Mustelus* spp.) and more sedentary species (shovelnose guitarfish, *Rhinobatos productus*, thornback, *Platyrhinoidis triseriata*, and Pacific angel shark, *Squatina californica*). Given this diversity, it is interesting to note that over the course of this study we observed only one elasmobranch individual, a swell shark near the pipe. It might be argued that the chances of seeing individuals of the more motile species would be small on any given day; although these chances would likely be increased if the animals were attracted to the cables. However, if the more sedentary species were similarly attracted, one might expect to have encountered them. And again, the absence of these animals from the cable is likely not because the EMF generated is below their sensory threshold. Rather, the data strongly imply that of the electro-sensitive species in the study area, at least the elasmobranchs are not attracted to the energized cables. Moreover, if these organisms were repelled by the EMF one might expect them to be more abundant at the pipe or natural habitat, and that was also not the case.

Our findings are particularly important because, worldwide, the small number of field or semi-field studies that have been conducted on how fishes respond to energized power cables have found either little or no response (Westerberg and Lagenfelt 2008, DONG Energy and Vattenfall A/S 2006, Love et al. 2015, present study) or, arguably, an equivocal one (Gill et al. 2009). One possible explanation is that marine organisms respond to human-made EMF differently from those produced in nature. Recent studies demonstrate that human-made EMF is inherently different from naturally produced EMF. Naturally produced EMF is polarized and consequently more biologically active (Panagopoulos et al. 2015). Thus, it is possible that electro-sensitive organisms are able to differentiate between the two types and therefore respond differently to each of these stimuli.

Regarding the specific objectives of this study:

1) *The differences among fish and invertebrate communities associated with energized and unenergized cable habitat and those communities in soft seafloor habitats lacking cables.*

We did not find any biologically significant differences among fish and invertebrate communities between energized cables, pipe, and natural habitat. In particular, only three species of fish showed statistically significant, but slight, differences in densities between the cables and pipe. Plant communities did differ among habitats and within habitats between depths. These differences were almost certainly structure and depth, rather than EMF, related.

2) *Whether electro-sensitive species that are regionally important, such as sharks and rays, respond (via either attraction or repulsion) to the EMFs of an in situ power transmission cable.*

We observed only one elasmobranch individual, a swell shark, during the course of this study. Thus, it would appear that the EMFs generated by these energized cables are either unimportant to these organisms or that at least other environmental factors take precedence.

3*) The strength, spatial extent, and variability of EMFs along both energized and unenergized cables.*

The strength of the EMF along the energized cable was relatively stable over time and along its length. The EMF produced by the energized cables diminishes to background levels about one meter away from the cable. Similarly, both the pipe and natural habitat sites had extremely small or undetectable EMFs.

4) *The potential effectiveness of the commonly proposed mitigation of cable burial.*

Given the rapidity with which the EMF produced by the energized cables diminishes and the lack of response to that EMF by the shallower fish and invertebrates, cable burial would not appear necessary strictly for biological reasons. In this and similar cases, cable burial, at sufficient depth, would be an adequate tool to prevent EMF emissions from being present at the seafloor.

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Figure 2-1. Schematic illustration of cables, pipe, and natural habitat surveyed by scuba, 1 February 2012–26 February 2014. Cables A and B were energized and were used in this study. Cable C1 was unenergized and was not used in this study as it was mostly buried in the sea floor. Distance between cables, pipe, and natural habitat not drawn to scale.

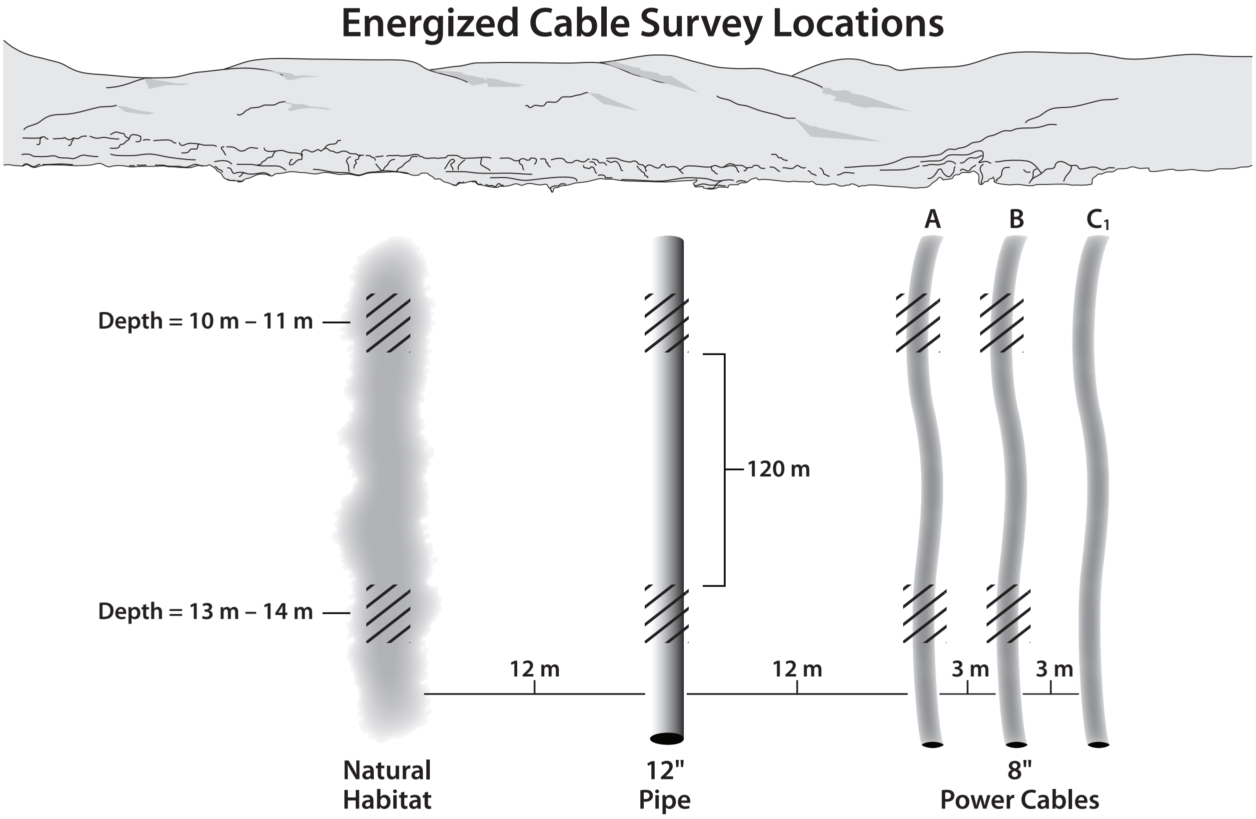

Figure 2-2. Number of *Cystoseira* spp. observed, by survey date, on cables, pipe, and natural habitat surveyed from 1 February 2012–26 February 2014.

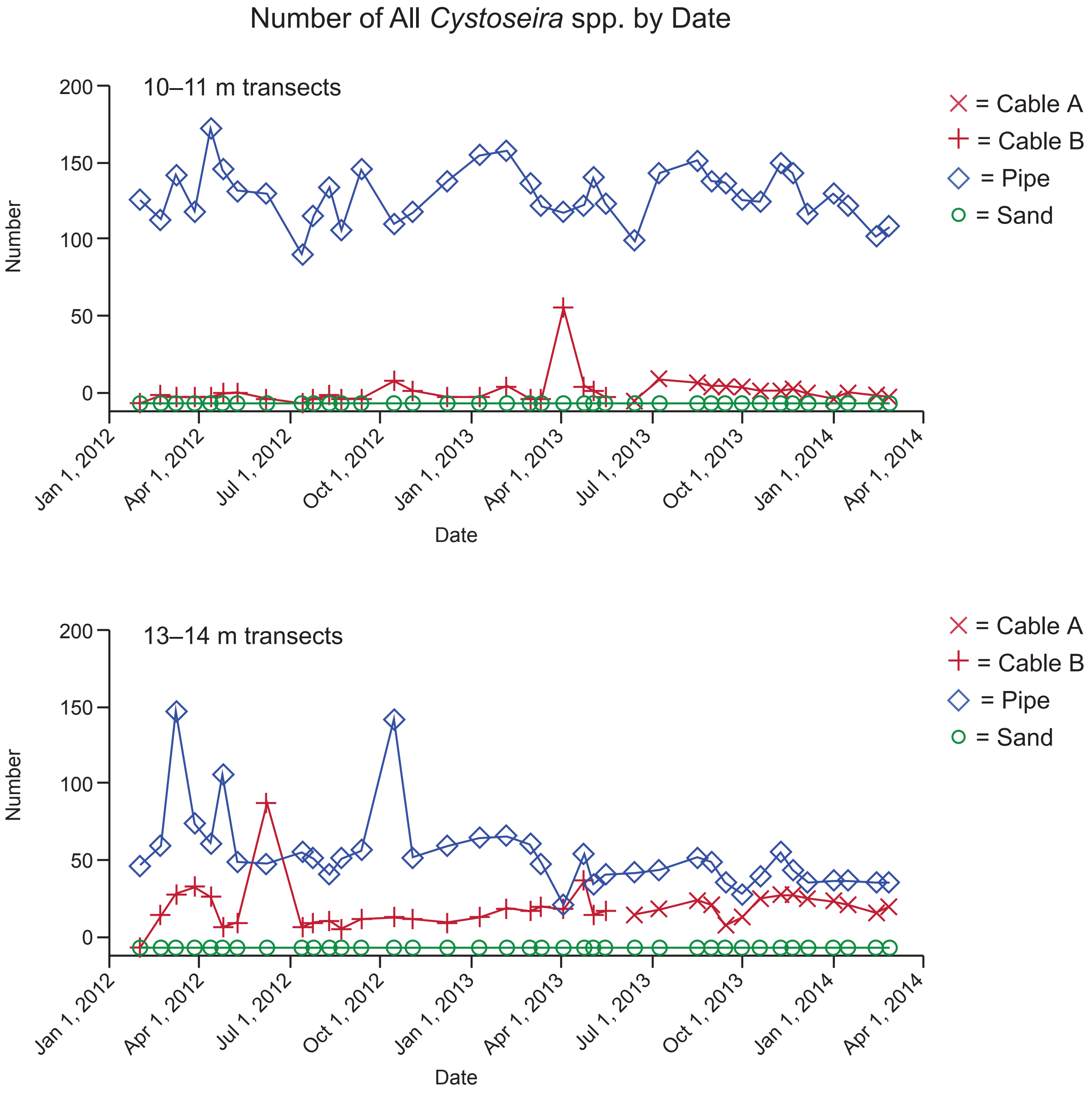

Figure 2-3. Number of *Laminaria* spp. observed, by survey date, on cables, pipe, and natural habitat surveyed from 1 February 2012–26 February 2014.

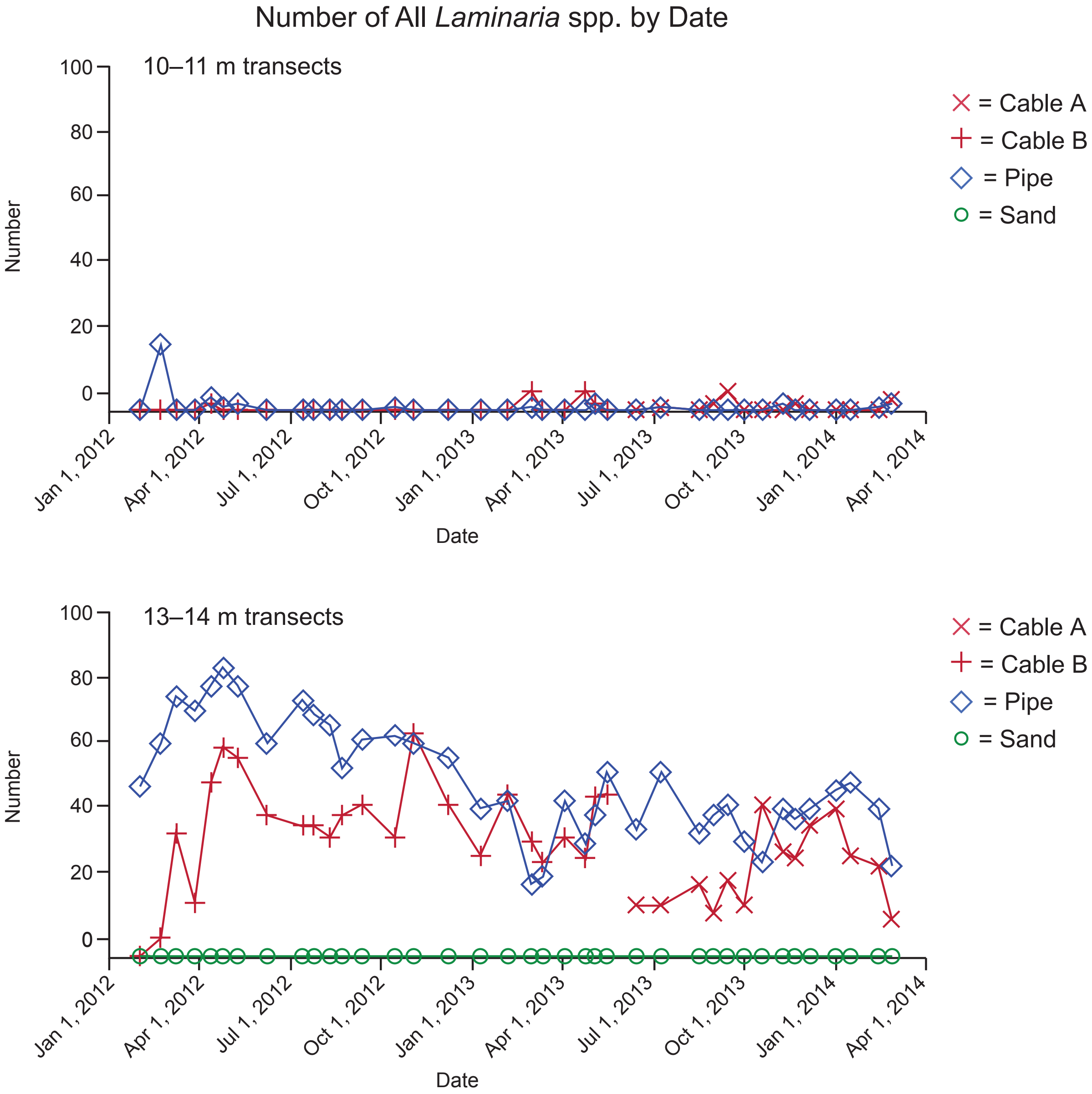

Figure 2-4. Number of *Pterygophora californica* spp. observed, by survey date, on tcables, pipe, and natural habitat surveyed from 1 February 2012–26 February 2014.

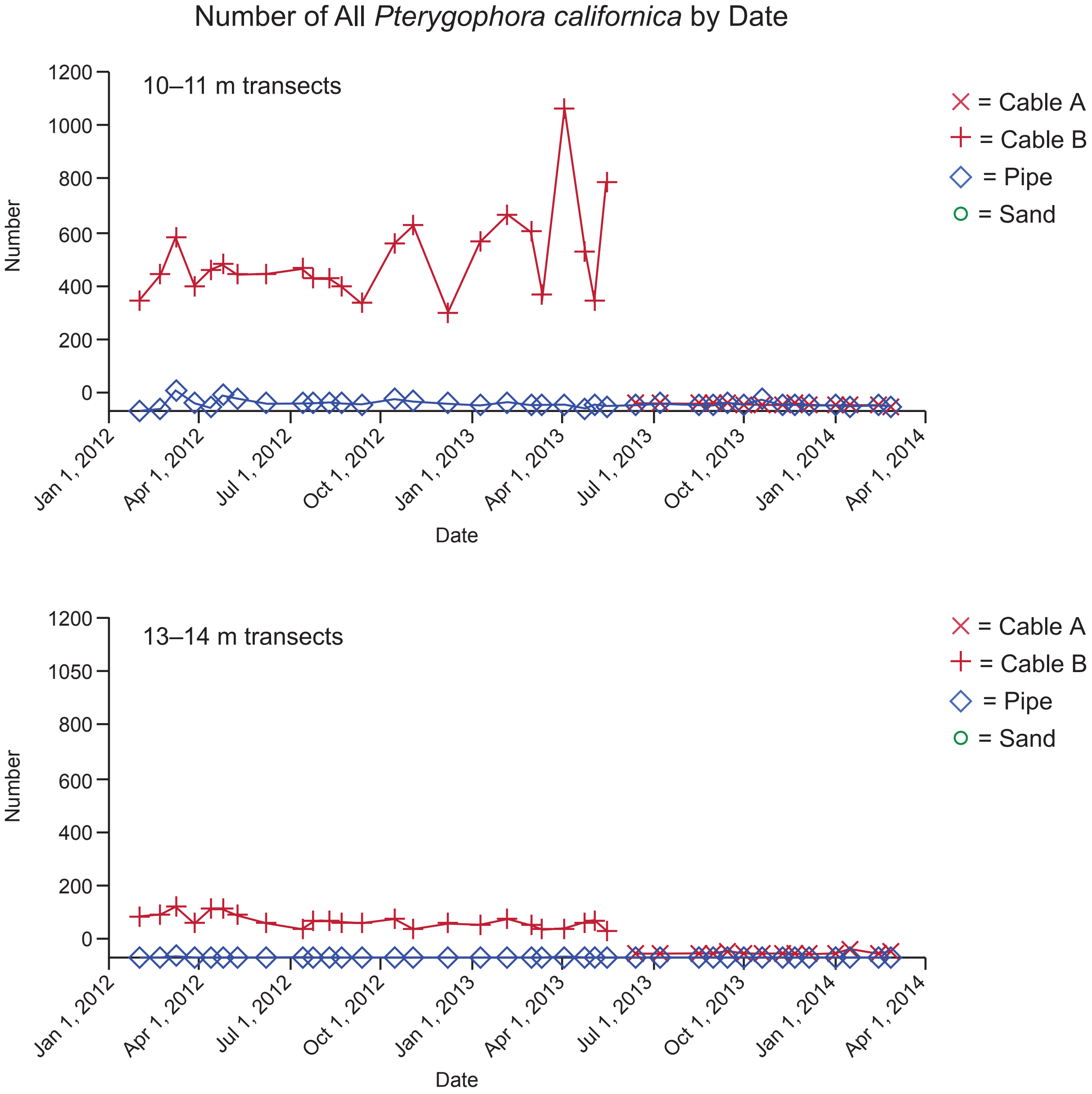

Figure 2-5. Number of *Macrocystis pyrifera* observed, by survey date, on cables, pipe, and natural habitat surveyed from 1 February 2012–26 February 2014.

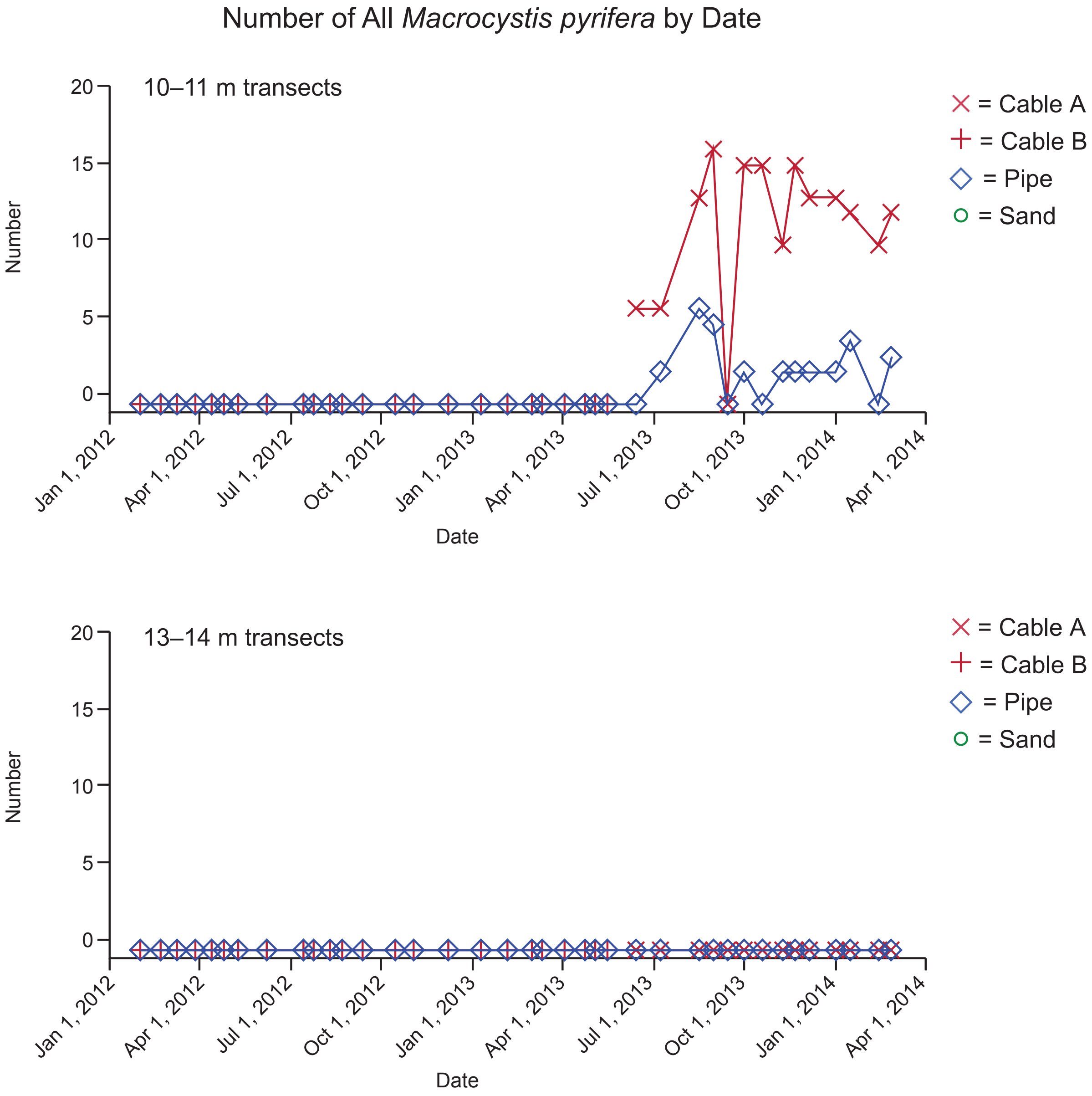

Figure 2-6. Number of *Zostera marina* observed, by survey date, on cables, pipe, and natural habitat surveyed from 1 February 2012–26 February 2014.

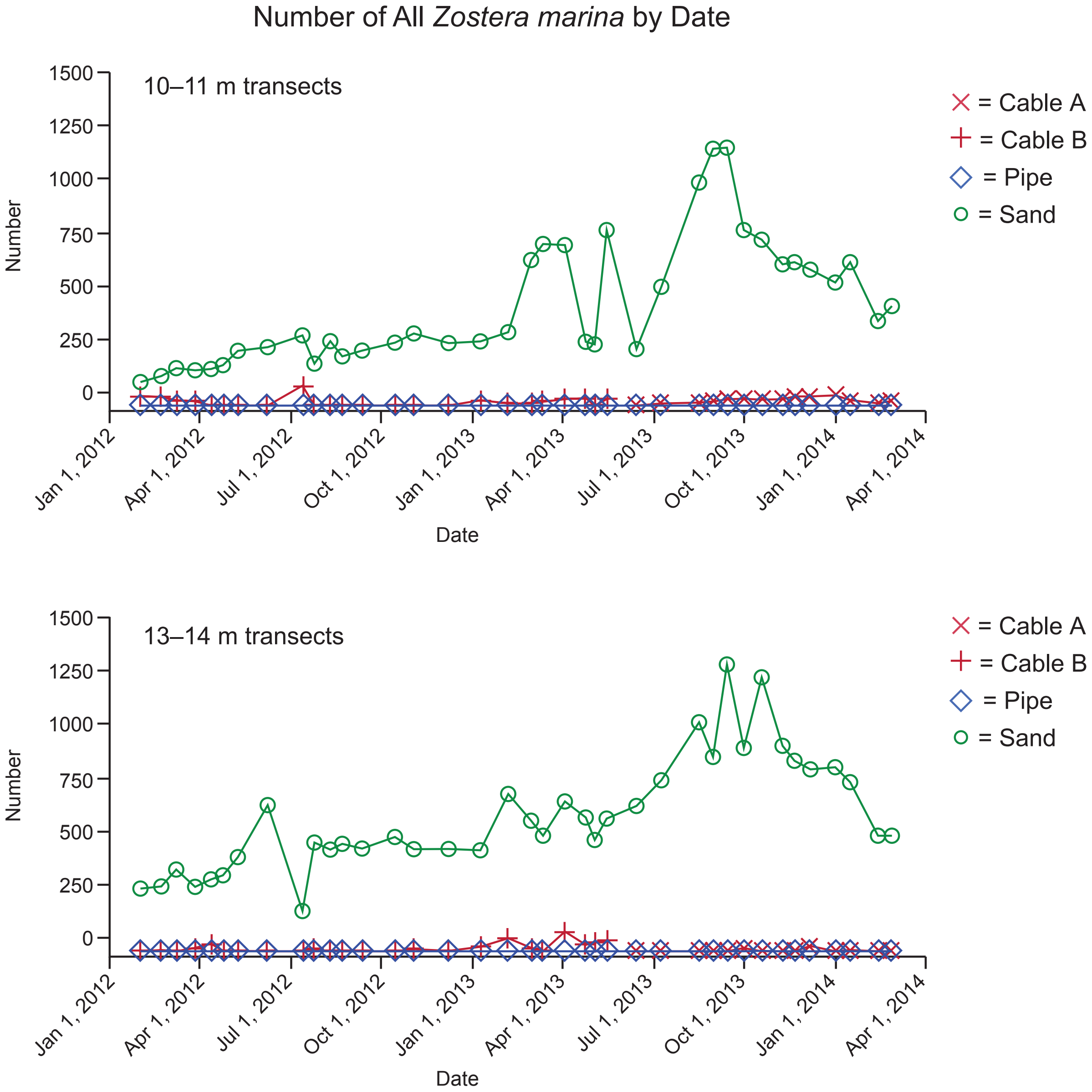

Figure 2-7. Electromagnetic field levels measured on cables, pipe, and natural habitat surveyed from 1 February 2012–26 February 2014. Vertical bars represent standard errors.

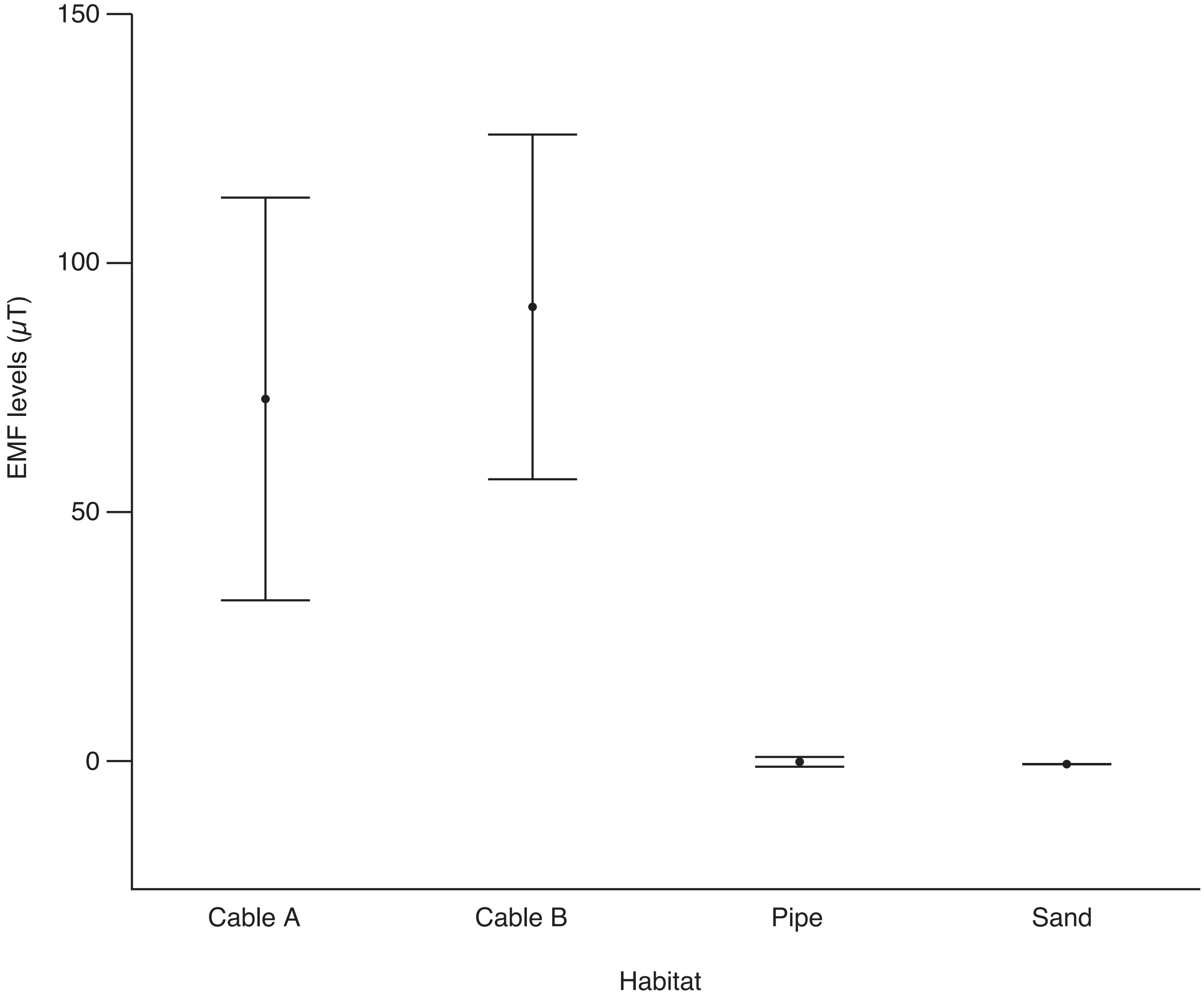

Figure 2-8. A 2-d multiple dimensional scaling model comparing the shallower and deeper fish assemblages on cables, pipe, and natural habitat surveyed from 1 February 2012–26 February 2014.

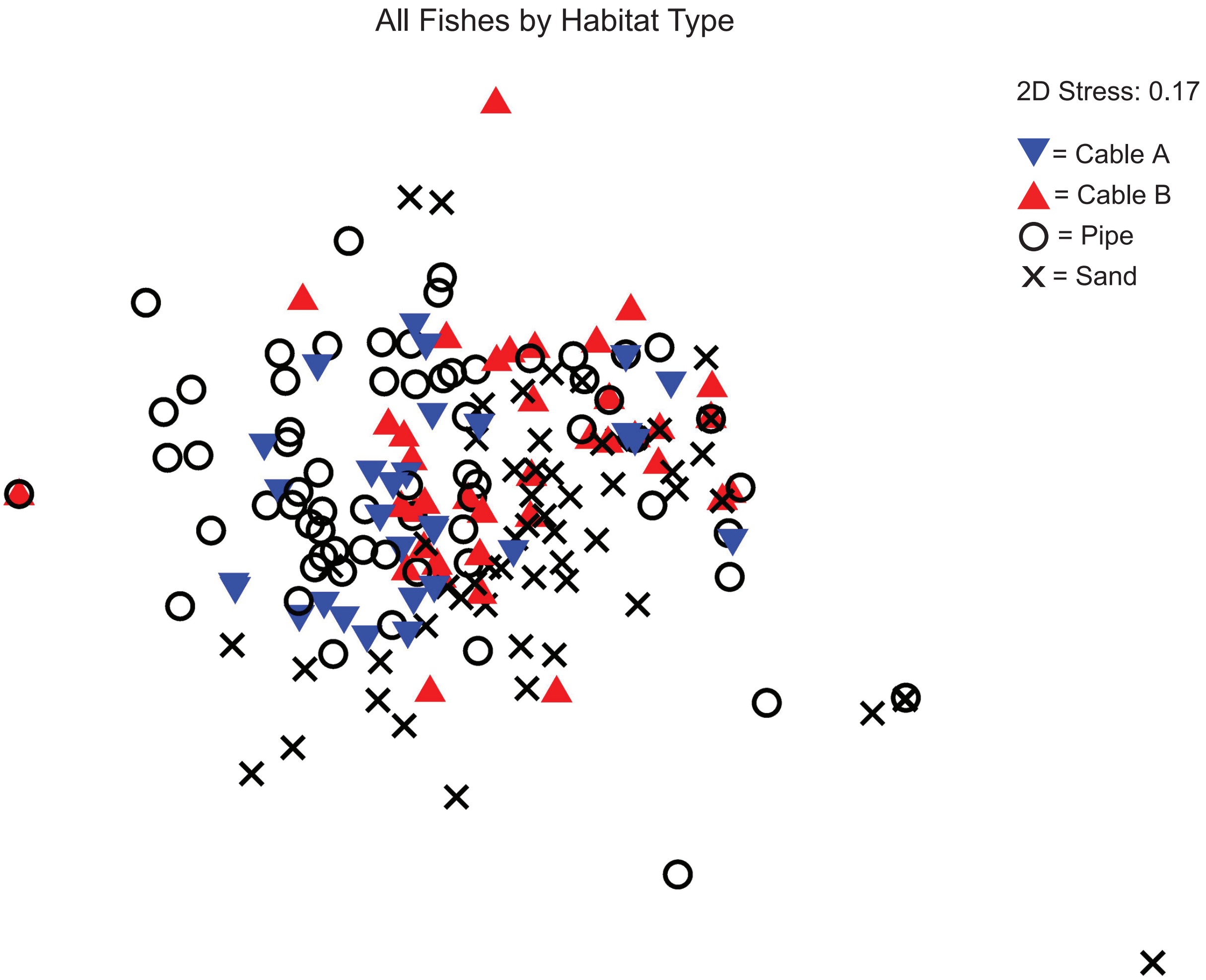

Figure 2-9. A 2-d multiple dimensional scaling model comparing the fish assemblages on cables, pipe, and natural habitat (shallower and deeper transects combined) surveyed from 1 February 2012–26 February 2014.

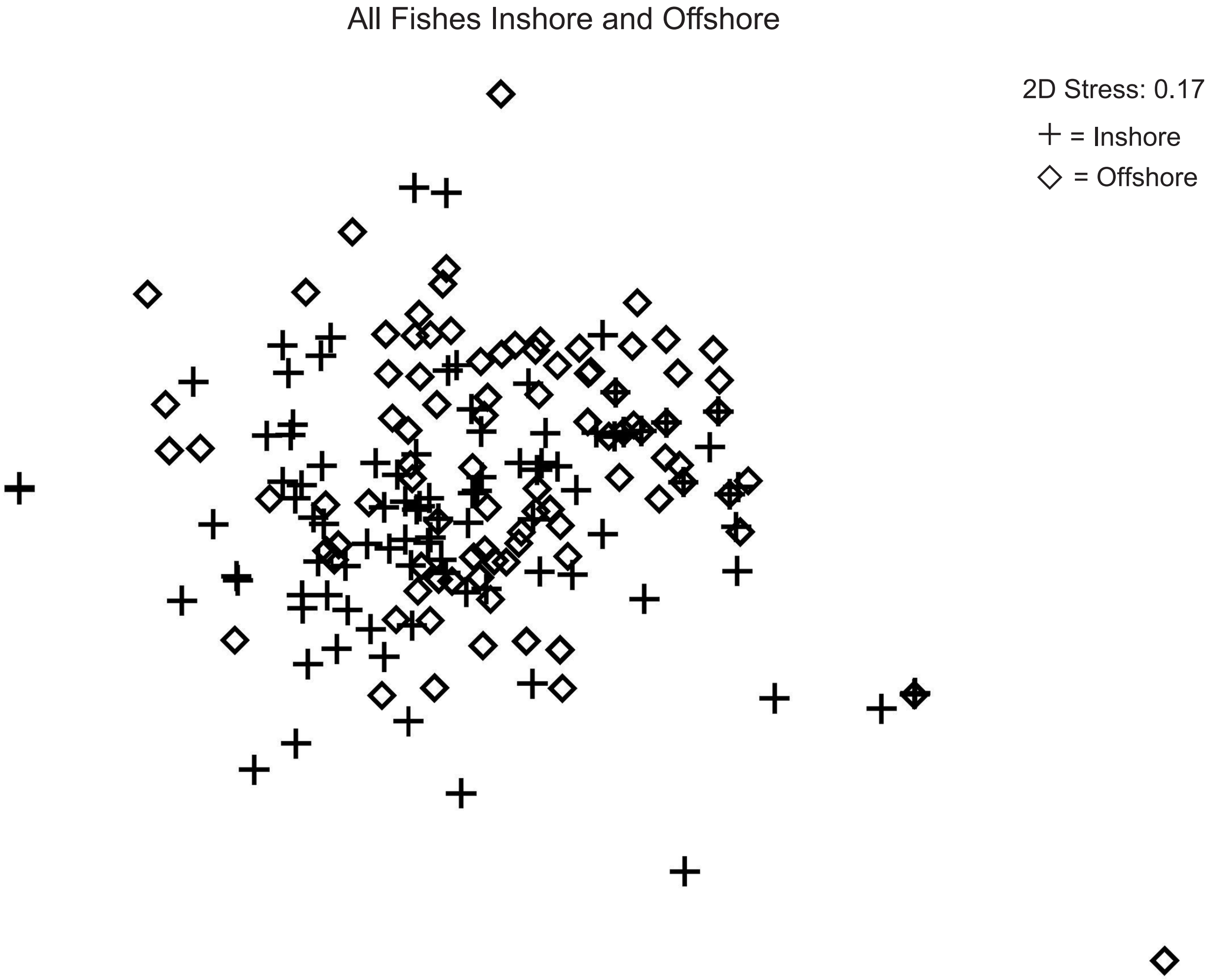

Figure 2-10. Length frequencies of all fishes observed on cables, pipe, and natural habitat surveyed from 1 February 2012–26 February 2014.

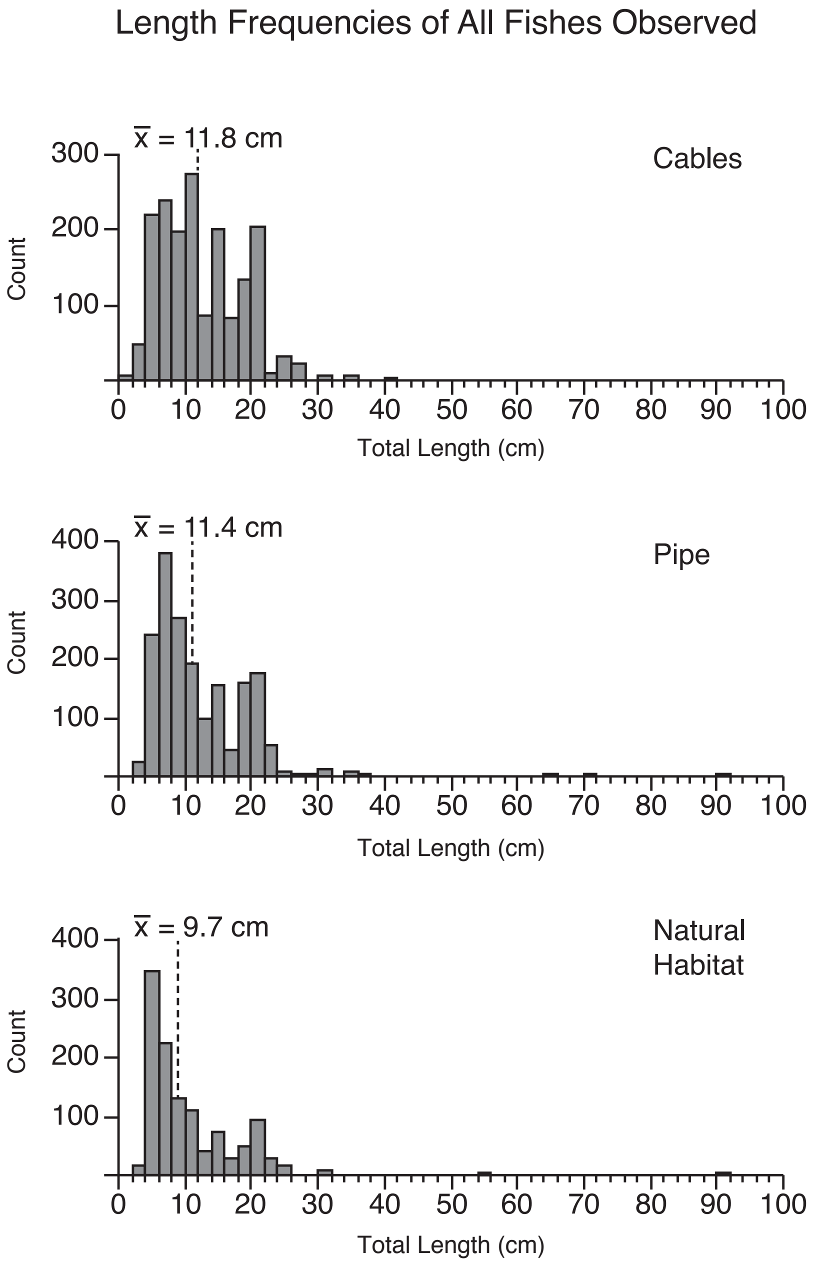

Figure 2-11. Densities of all fishes observed, by survey date, on cables, pipe, and natural habitat, 1 February 2012–26 February 2014.

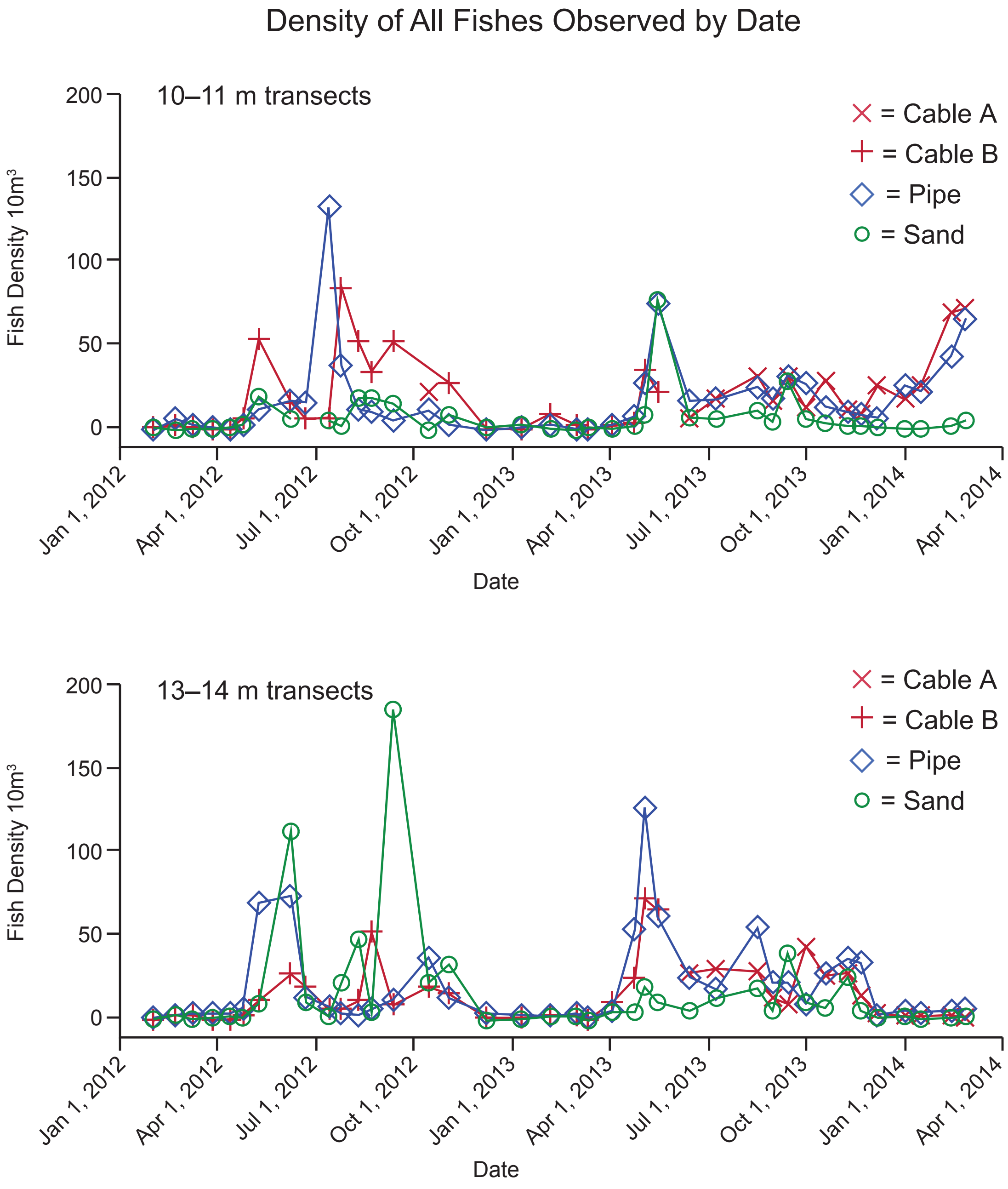

Figure 2-12. A 2-d multiple dimensional scaling model comparing the shallower and deeper invertebrate assemblages on cables, pipe, and natural habitat surveyed from 22 June 2012–26 February 2014.

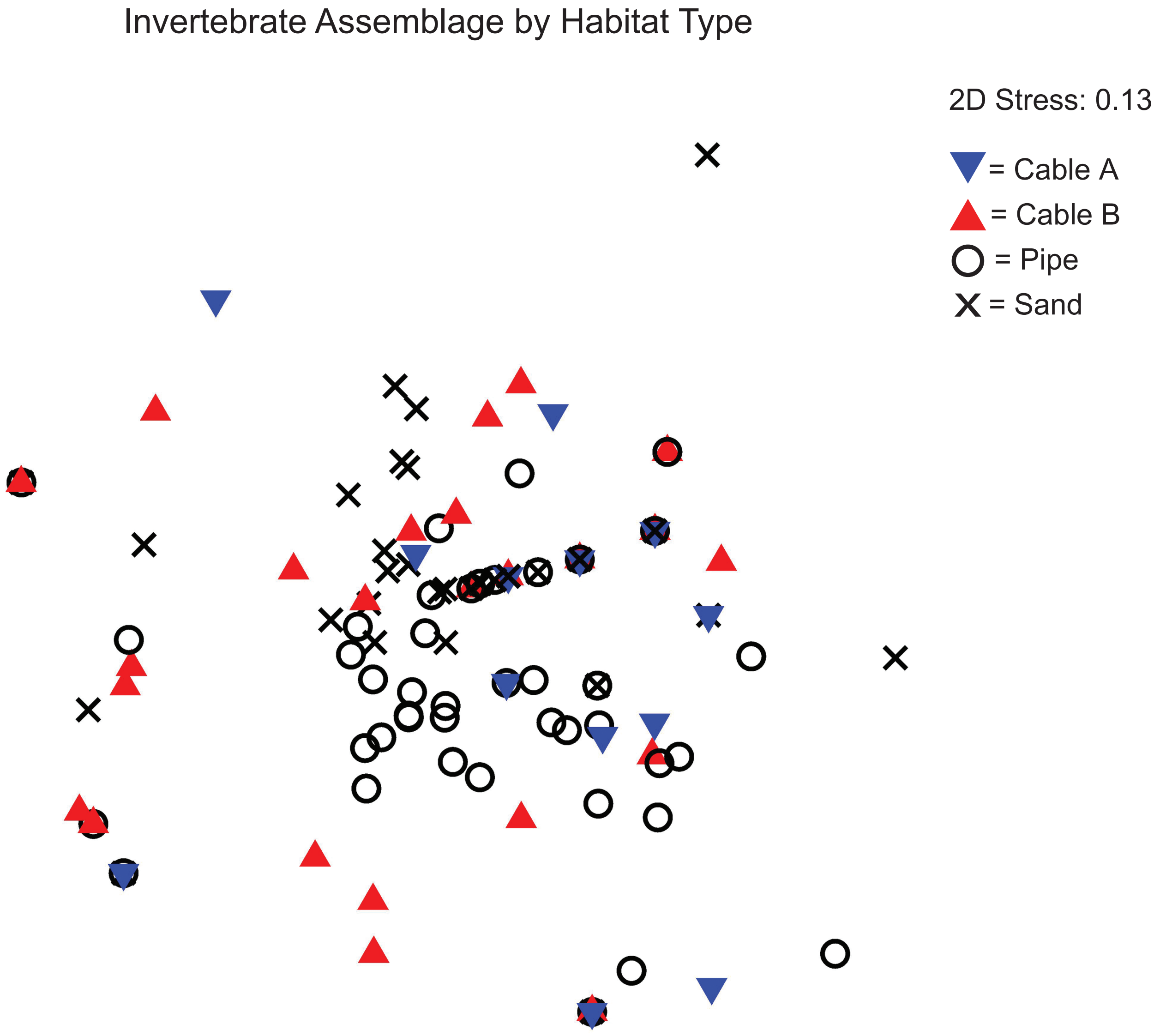

Figure 2-13. A 2-d multiple dimensional scaling model comparing the invertebrate assemblages on cables, pipe, and natural habitat (shallower and deeper transects combined) surveyed from 22 June 2012–26 February 2014.

Figure 2-14. Densities of all invertebrates observed, by survey date, on cables, pipe, and natural habitat, 22 June 2012–26 February 2014.

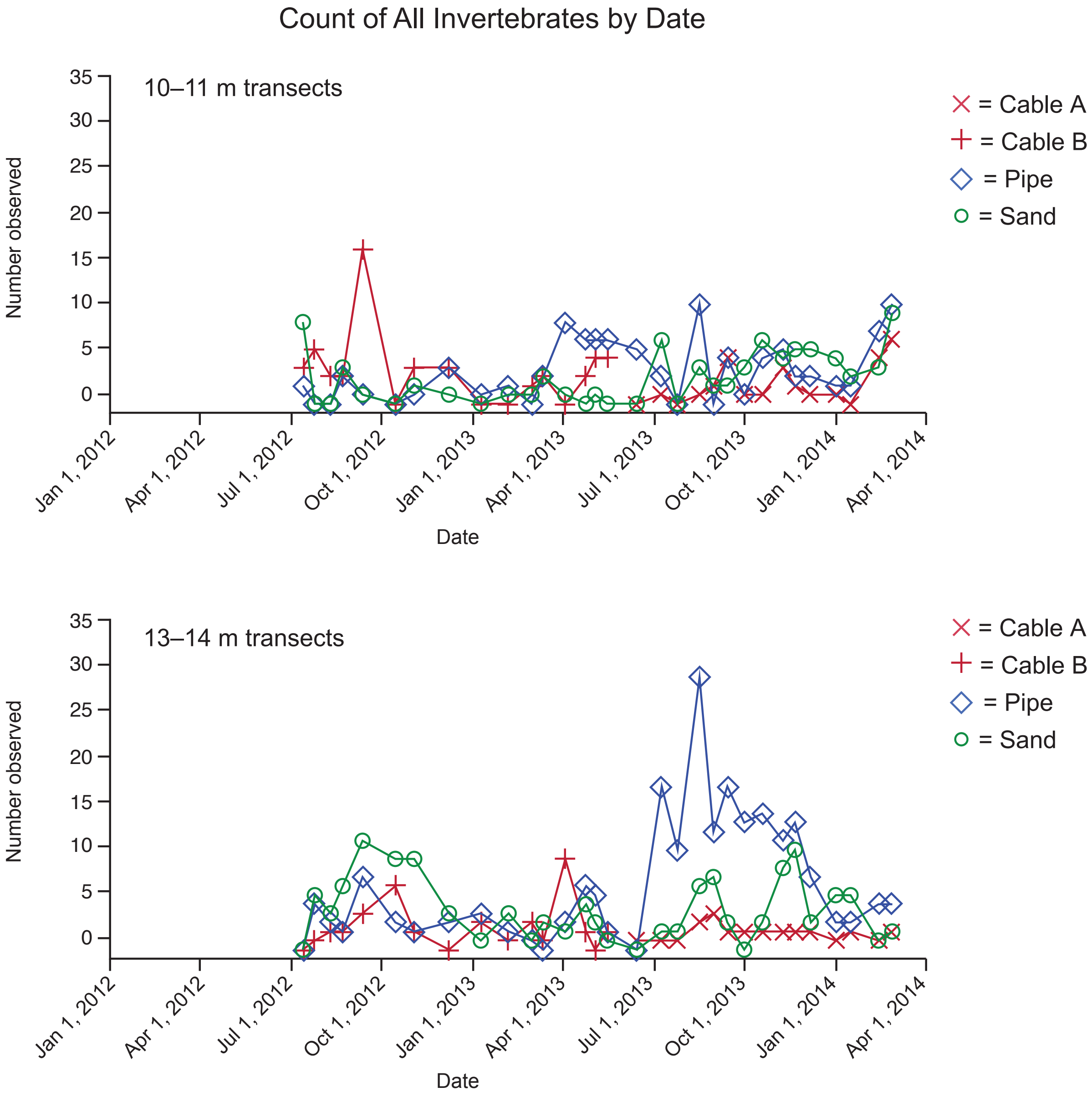

Figure 2-15. Densities of all sea stars observed, by survey date, on cables, pipe, and natural habitat, 22 June 2012–26 February 2014.

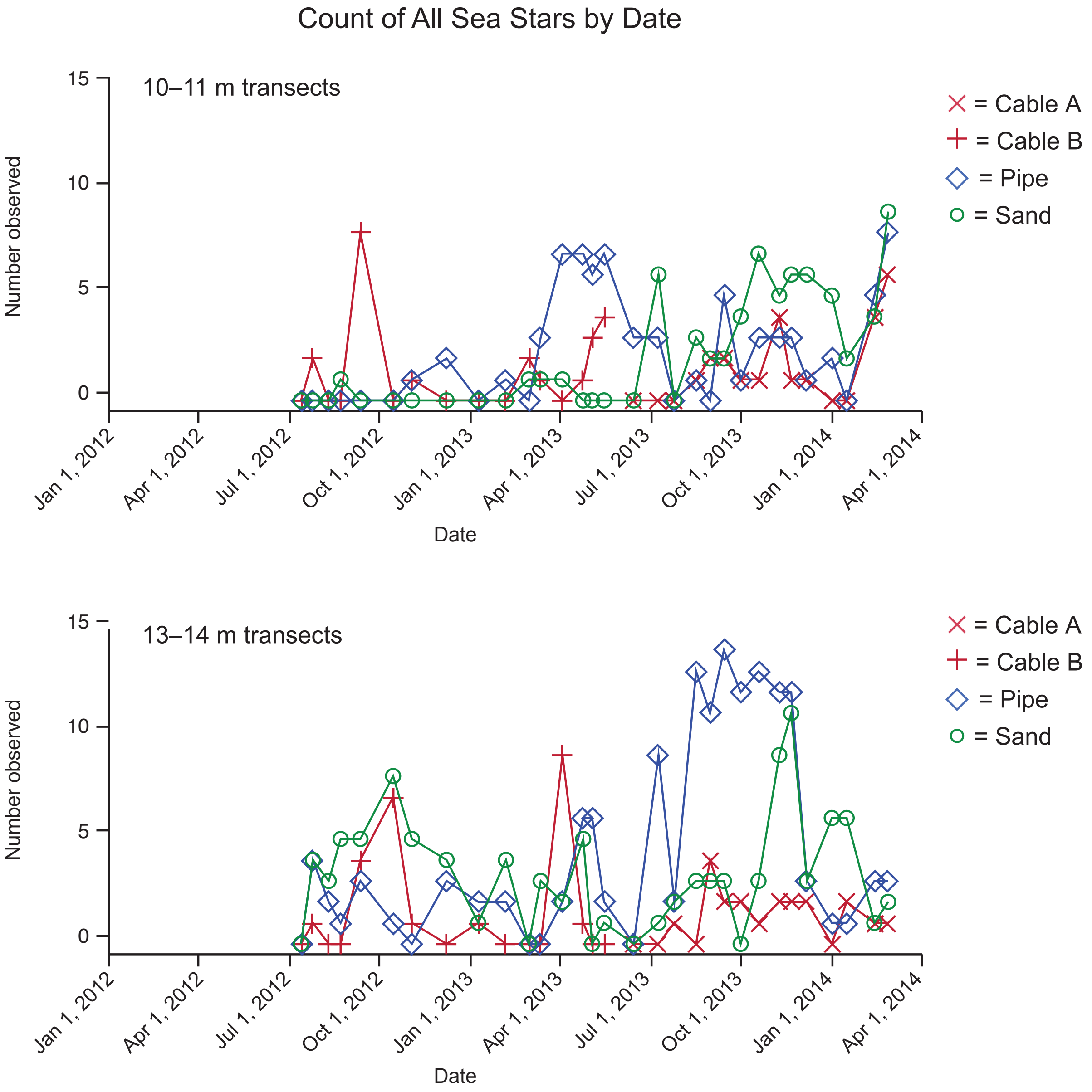

Figure 2-16. A 2-d multiple dimensional scaling model comparing the shallower and deeper plant assemblages on cables, pipe, and natural habitat surveyed from 1 February 2012–26 February 2014.

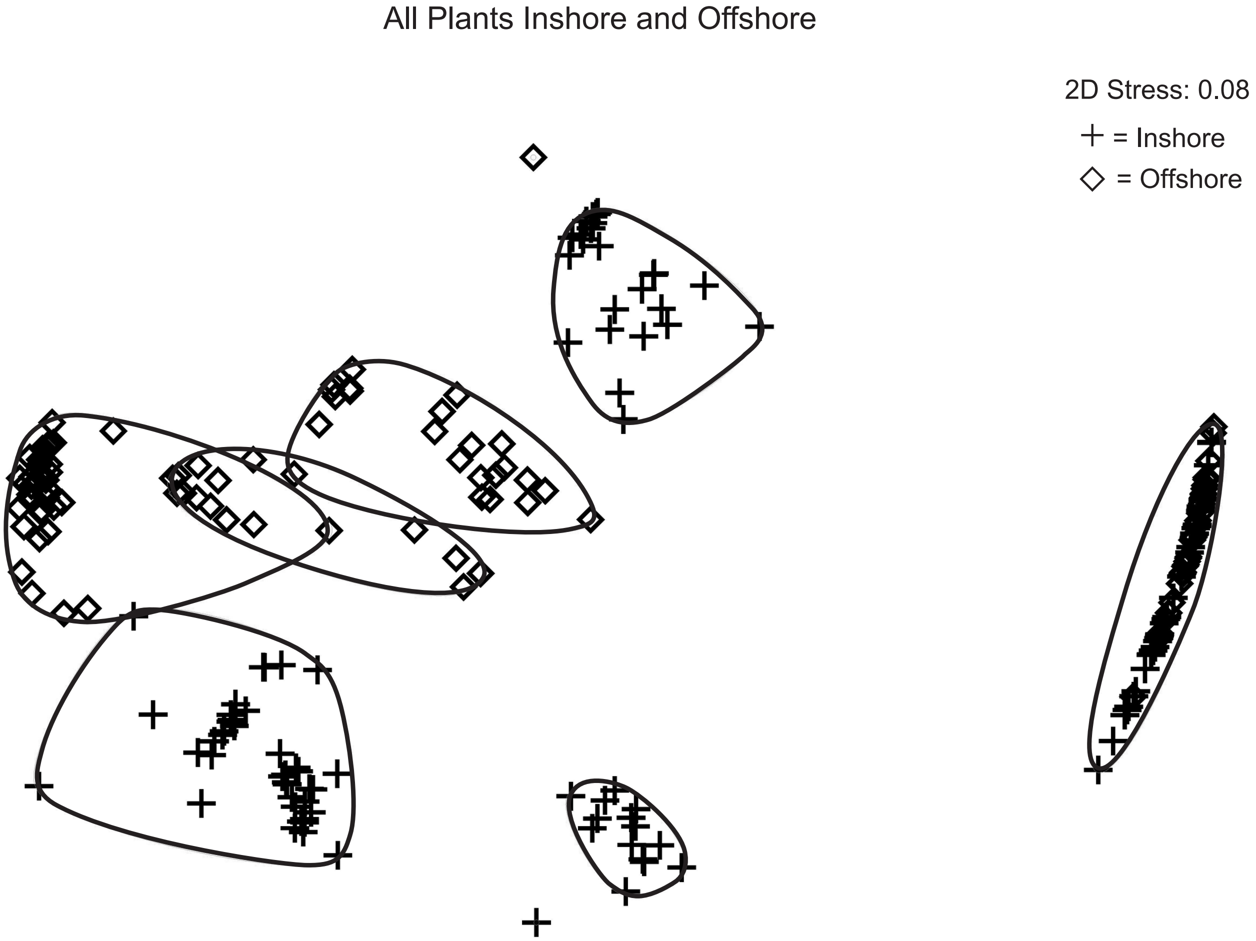

Figure 2-17. A 2-d multiple dimensional scaling model comparing the plant assemblages on cables, pipe, and natural habitat (shallower and deeper transects combined) surveyed from 1 February 2012–26 February 2014.

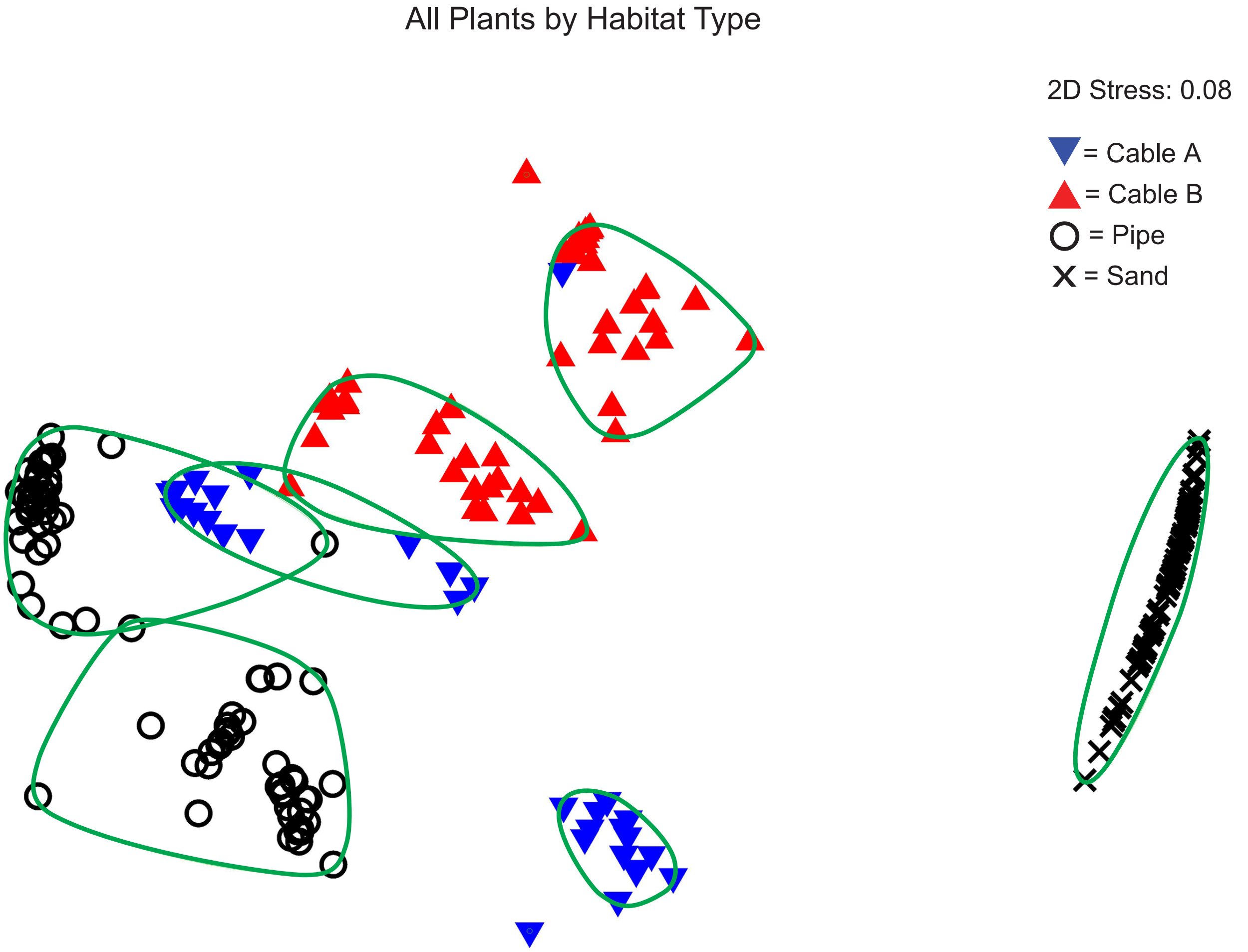

Table 2-1. All dates of surveys on energized cables, pipe, and soft sea floor. Fishes and plants were surveyed on all dates; invertebrates were surveyed from 22 June 2012 to 26 February 2014. Surveys were conducted on energized Cable B from 1 February 2012 to 3 May 2013 and on energized Cable A from 15 May 2013 to 26 February 2014.

2012									
1 Feb	22 Feb	8 Mar	27 Mar	12 Apr	24 Apr	9 May	8 Jun	22 Jun	
13 Jul	25 Jul	10 Aug	22 Aug	11 Sep	14 Oct	2 Nov	7 Dec		
2013									
8 Jan	5 Feb	28 Feb	12 Mar	3 Apr	24 Apr	3 May	15 May	14 Jun	
9 Jul	16 Aug	30 Aug	13 Sep	30 Sep	18 Oct	8 Nov	20 Nov	6 Dec	31 Dec
2014									
15 Jan	12 Feb	26 Feb							

Table 2-2. Wilcoxon test values comparing EMF field strengths of two energized cables, pipe, and natural habitat, 2012–2014. NH = natural habitat.

Site	Site	Mean Difference	Standard Error	Z	p-value
Cable B	Cable A	5.95	4.15	1.43	0.15
NH	Cable A	-32.46	4.40	-7.38	<.0001
Pipe	Cable A	-34.46	5.30	-6.50	<.0001
Pipe	Cable B	-36.39	5.30	-6.87	<.0001
NH	Cable B	-36.97	4.67	-7.92	<.0001
NH	Pipe	-43.74	5.34	-8.18	<.0001

Table 2-3. Common and scientific names of fishes observed by scuba at bottom depths of 10–11 m and 13–14 m over energized cables, pipe, and natural habitat in southern California, 2012–2014.

Barred sand bass	*Paralabrax nebulifer*
Bat ray	*Myliobatis californica*
Black perch	*Embiotoca jacksoni*
Blackeye goby	*Rhinogobius nicholsii*
Blue rockfish	*Sebastes mystinus*
Bocaccio[1]	*Sebastes paucispinis*
Brown rockfish	*Sebastes auriculatus*
Cabezon	*Scorpaenichthys marmoratu*
Calico rockfish	*Sebastes dalli*
California halibut	*Paralichthys californicus*
California lizardfish	*Synodus lucioceps*
C-O Sole	*Pleuronichthys coenosus*
Copper rockfish	*Sebastes caurinus*
Curlfin sole	*Pleuronichthys decurrens*
Giant kelpfish	*Heterostichus rostratus*
Gopher rockfish	*Sebastes carnatus*
Grass rockfish	*Sebastes rastrelliger*
Halfbanded rockfish	*Sebastes semicinctus*
Horn shark	*Heterodontus francisci*
Kelp bass	*Paralabrax clathratus*
Kelp greenling	*Hexagrammos decagrammus*
Kelp perch	*Brachyistius frenatus*
Kelp rockfish	*Sebastes atrovirens*
Lavender sculpin	*Leiocottus hirundo*
Lingcod	*Ophiodon elongatus*
Olive/yellowtail rockfish[2]	*Sebastes serranoides/S. flavidus*
Painted greenling	*Oxylebius pictus*
Pile perch	*Damalichthys vacca*
Rainbow seaperch	*Hypsurus caryi*
Rock wrasse	*Halichoeres semicinctus*
Round stingray	*Urobatis halleri*
Sarcastic fringehead	*Neoclinus blanchardi*
Senorita	*Oxyjulis californica*
Sharpnose seaperch	*Phanerodon atripes*
Shiner perch	*Cymatogaster aggregata*
Shortbelly rockfish[3]	*Sebastes jordani*
Striped kelpfish	*Gibbonsia metzi*
Swell shark	*Cephaloscyllium ventriosum*
Tubesnout	*Aulorhynchus flavidus*
Unidentified kelpfish	*Gibbonsia spp.*
Unidentified midshipman	*Porichthys sp.*
Unidentified perch	*Family Embiotocidae*
Unidentified pipefish	*Syngnathus spp.*
Unidentified rockfish YOY[4]	*Sebastes spp.*
Unidentified ronquil	*Rathbunella sp.*
Unidentified sanddab[5]	*Citharichthys spp.*
Unidentified sculpin	*Family Cottidae*
Vermilion rockfish[6]	*Sebastes miniatus*
White seaperch	*Phanerodon furcatus*

[1] Young-of-the-year.
[2] Young-of-the-year.
[3] Young-of-the-year.
[4] These were young-of-the-year rockfishes of the following species: Sebastes atrovirens, Sebastes carnatus, or Sebastes chrysomelas (black-and-yellow rockfish).
[5] Probably primarily speckled sanddab, Citharichthys stigmaeus.
[6] Young-of-the-year.

Table 2-4. All fishes observed at bottom depths of 10–11 m and 13–14 m over energized cables, pipe, and natural habitat in southern California, 2012–2014. FO = frequency of occurrence (of 38 surveys).

Species	Number	Abundance	FO
Senorita	976	20.9	26
Unidentified sanddabs1	647	13.9	38
White seaperch	352	7.5	24
Shiner perch	334	7.2	8
Unidentified rockfish YOY2	331	7.1	23
Kelp perch	278	6.0	25
Vermilion rockfish	255	5.5	17
Shortbelly rockfish	190	4.1	1
Black perch	187	4.0	23
Tubesnout	165	3.5	16
Rainbow seaperch	151	3.2	23
Pile perch	142	3.0	15
Copper rockfish	110	2.4	17
Bocaccio	99	2.1	13
Olive/yellowtail rockfish3	72	1.5	13
Giant kelpfish	53	1.1	19
Halfbanded rockfish	44	0.9	6
California lizardfish	27	0.6	3
Painted greenling	25	0.5	13
Blue rockfish	20	0.4	6
Brown rockfish	19	0.4	3
Cabezon	14	0.3	12
C-O Sole	12	0.3	10
Kelp greenling	12	0.3	7
Unidentified kelpfish	10	0.2	7
Calico rockfish	10	0.2	4
Lavender sculpin	8	0.2	6
Kelp bass	7	0.2	4
Unidentified sculpins	6	0.1	5
Blackeye goby	6	0.1	4
Sarcastic fringehead	5	0.1	5
California halibut	5	0.1	4
Lingcod	5	0.1	3
Kelp rockfish	4	0.1	4
Unidentified pipefish	3	0.1	2
Unidentified fish	3	0.1	2
Striped kelpfish	2	>0.1	2
Gopher rockfish	2	>0.1	2
Swell shark	1	>0.1	1
Rock wrasse	1	>0.1	1
Horn shark	1	>0.1	1
Bay ray	1	>0.1	1
Barred sand bass	1	>0.1	1
Sharpnose seaperch	1	>0.1	1
Curlfin sole	1	>0.1	1
Unidentified midshipman	1	>0.1	1
Unidentified ronquil	1	>0.1	1
Grass rockfish	1	>0.1	1
Unidentified perch	1	>0.1	1
Round stingray	1	>0.1	1
Total	4,603		

Table 2-5. Fishes observed at bottom depths of 10–11 m and 13–14 m over energized cables in southern California, 2012–2014. Density is in fish per 100 m^3. FO = frequency of occurrence (of 38 surveys).

Species	Number	Mean Density	Percent Abundance	FO
Senorita	393	4.3	22.8	23
Unidentified sanddabs	315	3.5	18.3	38
Kelp perch	192	2.1	11.2	19
White seaperch	156	1.7	9.1	18
Unidentified rockfish YOY	129	1.4	7.5	15
Black perch	67	0.7	3.9	20
Vermilion rockfish	62	0.7	3.6	11
Copper rockfish	55	0.6	3.2	11
Shiner perch	52	0.5	3.0	3
Rainbow seaperch	44	0.5	2.6	19
Giant kelpfish	35	0.4	2.0	15
Tubesnout	35	0.4	2.0	5
Bocaccio	28	0.3	1.6	10
California lizardfish	22	0.2	1.3	2
Shortbelly rockfish	20	0.2	1.2	1
Olive/yellowtail rockfish	18	0.2	1.0	10
Halfbanded rockfish	16	0.2	0.9	6
Painted greenling	12	0.1	0.7	9
Blue rockfish	10	0.1	0.6	4
Pile perch	9	0.1	0.5	6
C-O sole	6	0.1	0.3	5
Calico rockfish	6	0.1	0.3	3
Kelp bass	5	0.1	0.3	2
Sarcastic fringehead	3	>0.1	0.2	3
Cabezon	3	>0.1	0.2	3
Lavender sculpin	3	>0.1	0.2	2
Unidentified fishes	3	>0.1	0.2	2
Unidentified kelpfishes	2	>0.1	0.1	2
Kelp greenling	2	>0.1	0.1	2
Lingcod	2	>0.1	0.1	2
Kelp rockfish	2	>0.1	0.1	2
Rock wrasse	1	>0.1	0.1	1
Barred sand bass	1	>0.1	0.1	1
Brown rockfish	1	>0.1	0.1	1
Gopher rockfish	1	>0.1	0.1	1
Unidentified pipefish	1	>0.1	0.1	1
Round stingray	1	>0.1	0.1	1
Total	1,713	18.9		

Table 2-6. Fishes observed at bottom depths of 10–11 m and 13–14 m over a pipe in southern California, 2012–2014. Density is in fish per 100 m^3. FO = frequency of occurrence (of 38 surveys).

Species	Number	Mean Density	Percent Abundance	FO
Senorita	408	4.5	22.3	20
Unidentified rockfish YOY	195	2.1	10.7	21
Vermilion rockfish	164	1.8	9.0	12
Pile perch	130	1.4	7.1	11
Black perch	114	1.3	6.2	22
Unidentified sanddabs	110	1.2	6.0	31
Rainbow seaperch	87	1.0	4.8	21
White seaperch	86	0.9	4.7	16
Kelp perch	81	0.9	4.4	13
Bocaccio	67	0.7	3.7	5
Copper rockfish	52	0.6	2.8	16
Shortbelly rockfish	50	0.6	2.7	1
Olive/yellowtail rockfish	43	0.5	2.4	8
Halfbanded rockfish	28	0.3	1.5	5
Tubesnout	20	0.2	1.1	9
Brown rockfish	18	0.2	1.0	3
Giant kelpfish	16	0.2	0.9	10
Painted greenling	13	0.1	0.7	8
Shiner perch	12	0.1	0.7	3
Cabezon	10	0.1	0.5	9
Kelp greenling	10	0.1	0.5	6
Blue rockfish	10	0.1	0.5	3
Unidentified kelpfish	8	0.1	0.4	6
Unidentified sculpins	6	0.1	0.3	5
Blackeye goby	6	0.1	0.3	4
Lavender sculpin	4	>0.1	0.2	3
Calico rockfish	4	>0.1	0.2	2
Striped kelpfish	2	>0.1	0.1	2
Sarcastic fringehead	2	>0.1	0.1	2
Kelp bass	2	>0.1	0.1	2
California halibut	2	>0.1	0.1	2
C-O sole	2	>0.1	0.1	2
Kelp rockfish	2	>0.1	0.1	2
Swell shark	1	>0.1	0.1	1
Horn shark	1	>0.1	0.1	1
Unidentified midshipman	1	>0.1	0.1	1
Unidentified ronquil	1	>0.1	0.1	1
Gopher rockfish	1	>0.1	0.1	1
Grass rockfish	1	>0.1	0.1	1
Unidentified pipefish	1	>0.1	0.1	1
Total	1,771	20.1		

Table 2-7. Fishes observed at bottom depths of 10–11 m and 13–14 m over natural habitat in southern California, 2012–2014. Density is in fish per 100 m^3. FO = frequency of occurrence (of 38 surveys).

Species	Number	Mean Density	Percent Abundance	FO
Shiner perch	270	3.0	24.1	5
Unidentified sanddabs	222	2.4	19.8	37
Senorita	175	1.9	15.6	19
Shortbelly rockfish	120	1.3	10.7	1
White seaperch	110	1.2	9.8	17
Tubesnout	110	1.2	9.8	8
Vermilion rockfish	29	0.3	2.6	5
Rainbow seaperch	20	0.2	1.8	8
Olive/yellowtail rockfish	11	0.1	1.0	5
Unidentified rockfish YOY	7	0.1	0.6	7
Black perch	6	0.1	0.5	3
Kelp perch	5	0.1	0.4	3
California lizardfish	5	0.1	0.4	2
C-O sole	4	>0.1	0.4	3
Bocaccio	4	>0.1	0.4	2
Pile perch	3	>0.1	0.3	3
Copper rockfish	3	>0.1	0.3	3
Lingcod	3	>0.1	0.3	2
California halibut	3	>0.1	0.3	2
Giant kelpfish	2	>0.1	0.2	2
Lavender sculpin	1	>0.1	0.1	1
Bat ray	1	>0.1	0.1	1
Sharpnose seaperch	1	>0.1	0.1	1
Curlfin sole	1	>0.1	0.1	1
Cabezon	1	>0.1	0.1	1
Unidentified pipefish	1	>0.1	0.1	1
Unidentified perch	1	>0.1	0.1	1
Total	1,119	12.3		

Table 2- 8. Comparisons of the size frequency distributions of fishes observed at bottom depths of 10–11 m and 13–14 m over energized cables, pipe, and natural habitat in southern California, 2012–2014 using the Kolmogorov Smirnov Two-Sample Test.

Cables v Pipe		
N	KS	p
3,484	0.053	<0.0001*
Cables v Natural Habitat		
N	KS	p
2,832	0.147	<0.0001*
Pipe v Natural Habitat		
N	KS	P
2,890	0.117	<0.0001*
*Significant at p<.01		

Table 2-9. Abundance comparisons of the top 15 fish species among the three survey habitats. Analysis excludes survey dates when species or species groups were absent. All surveys included six transects: shallower and deeper transects along pipe, energized cables, and natural habitat. One-way ANOVA or t-test and Tukey HSD multiple comparison tests were used when data was homoscedastic. Welch's ANOVA or Mann-Whitney test and Wilcoxon method for multiple comparisons were used when variances were unequal. * = significance at 0.05 or less. NH = Natural Habitat.

Species	All Three Habitats	Pipe v Cable	NH v Cable	NH v Pipe
Senorita	0.03*	0.49	0.03*	0.20
Unidentified sanddabs	<0.01*	<0.01*	0.49	<0.01*
White seaperch	0.19			
Shiner perch	0.16			
Unidentified rockfish YOY	<0.01*	0.10*	<0.01*	<0.01*
Kelp perch	<0.01*	0.13	<0.01*	<0.01
Vermilion rockfish	-0.16			
Black perch	<0.01*	0.03*	<0.01*	<0.01*
Tubesnout	0.55			
Rainbow seaperch	<0.01*	0.11	0.01*	<0.01
Pile perch	0.02	0.06	0.27	<0.01
Bocaccio	0.03*	0.21	<0.01*	0.21
Olive/yellowtail rockfish	0.21			
Giant kelpfish	<0.01*	0.06	<0.01*	<0.01*
Copper rockfish	<0.01*	0.37	<0.02*	<0.01*

Table 2-10. Invertebrates observed at bottom depths of 10–11 m and 13–14 m over energized cables, pipe, and natural habitat in southern California, 2012–2014. Density is in fish per 100 m^3. FO = frequency of occurrence (of 30 surveys).

Common Name	Scientific Name	Number	Density	Percent Abundance	%FO
Bat star	*Patiria miniata*	244	1.1	29.7	50.6%
Pisaster sea stars	*Pisaster* spp.	167	0.8	20.3	34.4%
Purple urchin	*Strongylocentrotus purpuratus*	100	0.5	12.2	0.6%
California sea hare	*Aplysia californica*	63	0.3	7.7	18.3%
Comb sand star	*Astropecten armatus*	51	0.2	6.2	16.1%
Kellet's whelk	*Kelletia kelletii*	48	0.2	5.8	12.8%
Sea cucumbers	*Parastichopus* sp.	23	0.1	2.8	9.4%
Rock crabs	*Metacarcinus* sp. and *Cancer* sp.	22	0.1	2.7	8.3%
Kelp crab	*Pugettia* spp.	21	0.1	2.6	7.8%
California market squid eggs	*Loligo opalescens*	20	0.1	2.4	0.6%
Sheep or masking crabs	*Loxorhynchus* spp.	19	0.1	2.3	9.4%
Sand dollars	*Dendraster excentricus*	19	0.1	2.3	4.4%
Octopuses	*Octopus* spp.	12	0.1	1.5	5.6%
Graceful crab	*Metacarcinus gracilis*	5	<0.05	0.6	1.7%
Leather star	*Dermasterias imbricata*	4	<0.05	0.5	1.1%
Giant keyhole limpet	*Megathura crenulata*	2	<0.05	0.2	1.1%
California spiny lobster	*Panulirus interruptus*	1	<0.05	0.1	0.6%
Sunflower star	*Pycnopodia helianthoides*	1	<0.05	0.1	0.6%
Total		822	3.8		

Table 2-11. Invertebrates observed at bottom depths of 10–11 m and 13–14 m over energized cables, pipe, and natural habitat, by habitat, in southern California, 2012–2014. Density is in fish per 100 m^3. FO = frequency of occurrence (of 30 surveys).

	Bat start	*Pisaster* sea star	Purple urchin	California sea hare	Comb sand star	Kellet's whelk	Sea cucumber	Rock crabs	Kelp crabs	California market squid eggs	Sand dollar	Sheep or masking crab	Octopus	Graceful crab	Leather star	Giant keyhole limpet	California spiny lobster	Sunflower star	
CABLES																			
Number	37	39	0	18	8	12	1	16	9	0	3	4	3	2	3	0	1	1	
Density	0.51	0.54	0.00	0.25	0.11	0.17	0.01	0.22	0.13	0.00	0.04	0.06	0.04	0.03	0.04	0.00	0.01	0.01	
FO	35%	30%	0%	22%	12%	10%	2%	17%	10%	0%	3%	7%	3%	2%	2%	0%	2%	2%	
PIPE																			
Number	89	112	100	43	12	14	21	3	8	20	1	7	8	2	0	2	0	0	
Density	1.24	1.56	1.39	0.60	0.17	0.19	0.29	0.04	0.11	0.28	0.01	0.10	0.11	0.03	0.00	0.03	0.00	0.00	
FO	55%	53%	2%	30%	17%	8%	25%	5%	8%	2%	2%	12%	12%	2%	0%	3%	0%	0%	
NATURAL HABITAT																			
Number	118	16	0	2	31	22	1	3	4	0	15	8	1	1	1	0	0	0	
Density	1.64	0.22	0.00	0.03	0.43	0.31	0.01	0.04	0.06	0.00	0.21	0.11	0.01	0.01	0.01	0.00	0.00	0.00	
FO	62%	20%	0%	3%	20%	20%	2%	3%	5%	0%	8%	10%	2%	2%	2%	0%	0%	0%	

Table 2-12. Habitat comparisons for most common invertebrates observed at bottom depths of 10–11 m and 13–14 m over energized cables, pipe, and natural habitat in southern California, 2012–2014. One-way ANOVA or t-test and Tukey HSD multiple comparison tests were used when data was homoscedastic. Welch's ANOVA or Mann-Whitney test and Wilcoxon method for multiple comparisons were used when variances were unequal. NH = natural habitat.

Species	Number of Surveys	Number of Transects	Habitats	Pipe v Cable	NH v Cable	NH v Pipe
Pisaster sea stars	23	138	<0.0001*	0.0006*	0.1332	<0.0001*
Bat star	28	168	<0.0001*	0.0043*	0.0001*	0.2356
Comb sand star	12	72	0.0980			
California sea hare	21	126	<0.0001*	0.1822	0.0016*	<0.0001*
Kellet's whelk	12	72	0.2391			
Sea cucumbers	11	66	<0.0001*	<0.0001*	1.0000	<0.0001*
Rock crabs	12	72	0.0358*	0.0195*	0.0101*	0.6971

Table 2-13. All plants observed at bottom depths of 10–11 m and 13–14 m over energized cables, pipe, and natural habitat in southern California, 2012–2014. FO = frequency of occurrence (of 38 surveys).

Species	Number	%FO
Zostera marina	43,072	100
Pterygophora californica	18,175	100
Cystoseira spp.	8,456	100
Laminaria spp.	3,110	100
Macrocystis pyrifera	186	34
Total	72,999	

Table 2-14. Numbers and frequency of occurrence of plants observed, by habitat type, at bottom depths of 10–11 m and 13–14 m over energized cables, pipe, and natural habitat in southern California, 2012–2014. FO = frequency of occurrence (of 38 surveys).

Habitat	*Zostera marina*	*Pterygophora californica*	*Cystoseira* spp.	*Laminaria* spp.	*Macrocystis pyrifera*
Cables					
Number	1,182	17,193	1,232	1,220	156
FO	22	38	36	23	6
Pipe					
Number	2	982	7,224	1,890	30
FO	4	20	38	24	5
Natural Habitat					
Number	41,888	0	0	0	0
FO	38	0	0	0	0

CHAPTER 3. OFFSHORE SURVEY

Abstract

We conducted surveys of energized and unenergized cables and of the nearby sea floor during 2012 (6–9 October), 2013 (3–5 October) and 2014 (23–25 October) at depths between 76 and 213 m. During 2012, only the east side of each cable was surveyed, while in 2013 and 2014 we surveyed both sides of the cables at similar depths. All natural habitat surveys were conducted between 100 and about 500 m from the nearest cable.

In 2012, we measured the EMF levels at three distances from energized Cable A. These measurements were taken at four locations along the cable (at bottom depths of 108 m, 112 m, 135 m, and 158 m). At all four locations, EMF levels dropped off precipitously with distance from the cable and, at one meter from the cable, approached background levels at three of the four locations.

With one exception (Cable C1 was not measured in 2013), in each year we measured the EMF levels at each cable (A, B, C, and C1) and at the sea floor away from these cables. In all years, Cable A was energized and this cable formed the basis of our energized cable surveys. In all years Cable C was unenergized and Cable B was energized in 2012 and 2014, but unenergized in 2013. Cable C1 was unenergized in 2012 and energized in 2014. In general, field strengths on the energized cables were around 100 μT, while those on the unenergized cables were very low and near background (sea floor) levels.

Fishes

We found that fish species communities were structured by depth more so than by habitat type (Global R=0.176, p=0.001). There was no statistical difference between the fish assemblages along the energized and unenergized cables. The natural habitat community statistically differed from both the energized cable and unenergized cable communities. Within species (or in several cases species-groups) that formed at least one percent of the fishes observed, we found no differences in densities between energized and unenergized cables. We did find differences based on cable side (shortspine combfish densities were higher on the west side of cables), depth strata (stripetail rockfish, unidentified poachers, shortspine combfish, greenstriped rockfish, lingcod, and unidentified eelpouts), and year (halfbanded rockfish, stripetail rockfish, and lingcod).

Total fish densities were significantly higher around the cables than over the natural habitat. Among the more important species, densities of halfbanded, stripetail, and greenstriped rockfishes, shortspine combfish, and lingcod were higher at the cables and eelpouts were found at higher densities over natural habitat. There were no significant differences in the densities of unidentified sanddabs and unidentified poachers. There were very slight, but statistically significant, differences in both mean lengths and size distributions of fishes among the three study habitats as fishes at the unenergized cables tended to be slightly larger (mean = 14.8 cm) than those at both natural habitats (mean = 13.7 cm) and energized cables (mean = 13.0 cm).

Over all habitats we observed 9,675 individuals of at least 41 species. Dominant species included halfbanded, stripetail, and greenstriped rockfishes, and lingcod, and unidentified flatfishes, poachers, and combfishes. *Energized cables:* In the vicinity of the energized cables, we observed at least 33 species of fishes, comprising 4,455 individuals. Halfbanded rockfish dominated this habitat, comprising 56% of all fishes observed and present during 82.3% of the transects. Other important species or species groups included unidentified flatfishes and poachers, stripetail and shortspine combfish. *Unenergized cables*: Similar to the fish assemblage found around energized cables, there were at least 35 fish species in proximity to the unenergized cables and 3,691 individuals. As with the energized cables, halfbanded rockfish were by far the most abundant

species, comprising 37.4% of all fish observed. Other important species included stripetail and greenstriped rockfishes and unidentified flatfishes, poachers, and combfishes. Natural habitats: Fewest species (at least 23) and fishes (1,529) were observed on the natural habitats. Here, unidentified flatfishes, eelpouts, poachers, combfishes, sanddabs and halfbanded rockfish predominated.

Invertebrates

The structure of the invertebrate communities living around energized and unenergized cables and natural habitats was similar to that of fishes. We found that invertebrate communities were structured by habitat type and depth. Similar to the fishes, there was no statistical difference between the invertebrate assemblages along the energized and unenergized cables. The natural habitat community of invertebrates strongly differed from the energized cable and unenergized cable communities.

To determine if there were significant differences in species densities between energized and unenergized cables, we compared the densities of those important species that comprised at least 1% of individuals observed in this study in the same way as for fishes. We did note slight but statistically significant differences in densities for only two of nine of the most abundant species. Sand star and black crinoid densities differed between unenergized and energized cables [sand star greater at unenergized cables, 4/1/m^3 v 2.7 m^3, and black crinoid at energized cables, 1.7/m^3 v 0.3/m^3]. Three species, thin sea pen, red octopus, and white sea urchin differed between cable sides. Seven species, white-plumed anemone, spot prawn, thin sea pen, California sea cucumber, red octopus, unidentified *Urticina* anemone, and black crinoid exhibited bottom depth differences. Densities of two species, thin sea pen and sand star, varied among years.

A number of species were more abundant around the cables than over the natural habitats. Important species that were more abundant around cables were white-plumed anemone, spot prawn, thin sea pens, California sea cucumber, sand star, and unidentified *Urticina* anemone. Red octopus and white sea urchin were denser over natural habitats and densities of black crinoid did not differ between the two habitats.

Over all habitats, we observed a total of 30,523 invertebrates of at least 43 invertebrate species. The white-plumed anemone was by far the most abundant animal and comprised 43.4% of all invertebrates recorded. Spot prawns, thin sea pens, California sea cucumbers, sand stars, and the red octopuses were also found at relatively high densities. *Energized cables*: We observed 13,388 individuals, of at least 36 species, living on or near the energized cables. White-plumed anemones, thin sea pens and spot prawns were the species found in highest densities, forming in aggregate 79.7% of all invertebrates observed. California sea cucumbers, sand stars, red octopuses, black crinoids, and *Urticina* anemones were also common. *Unenergized cables*: At least 35 species and 14,619 individuals were observed along the unenergized cables. Three species, white-plumed anemones, spot prawns, and thin sea pens, were by far the most dense, in aggregate forming 79.2% of all invertebrates surveyed. California sea cucumbers, sand stars, red octopus, unidentified *Urticina* anemones, and serpulid worms were also characteristic of this habitat. Natural habitats: We observed the fewest number of species (a minimum of 27) and individuals (2,516) over the natural habitat. Thin sea pens, red octopuses, white sea urchins and sand stars dominated this habitat, along with smaller numbers of white-plumed anemones, fragile pink urchins, California sea cucumbers, and sea slugs.

Regarding the specific objectives of this study:

1) *The differences among fish and invertebrate communities associated with energized and unenergized cable habitat and those communities in soft seafloor habitats lacking cables.*

We did not observe any significant differences in the fish communities living around energized and unenergized cables and natural habitats. A very slight, and likely biologically insignificant, difference in mean sizes was observed as fishes at unenergized cables were marginally larger than those around energized ones. Overall species diversity and the densities of the most important fish species (define as comprising at least 1% of all fishes observed) were higher at the cables than at the natural habitats. This is likely reflective of the more complex habitats afforded by the cables than the primarily soft substrata natural habitats.

Similar to the fish communities, the invertebrate assemblages living around energized and unenergized cables and natural habitats were similar to one another and variability between these communities was primarily driven by sea floor depth. Among the three habitat types, there were some statistically significant differences in densities for all nine of the most abundant species. These differences included: 1) two species, sand star and black crinoid, whose densities differed between energized and unenergized cables, 2) three species, thin sea pen, red octopus, and white sea urchin which differed between cable sides, 3) seven species, white-plumed anemone, spot prawn, thin sea pen, California sea cucumber, red octopus, unidentified *Urticina* anemone, and black crinoid that exhibited bottom depth differences, and 4) two species, thin sea pen and sand star, whose densities varied among years. Sand star densities were greater at unenergized cables, 4/1/m^3 v 2.7 m^3, and black crinoid densities were greater at energized cables, 1.7/m^3 v 0.3/m^3.

2) Whether electro-sensitive species that are regionally important, such as sharks and rays, respond (via either attraction or repulsion) to the EMFs of an in situ power transmission cable.

We observed very few individuals of electro-sensitive species on the energized or unenergized cables or on the natural habitats. Only five ratfish (three at the energized cables and two on the unenergized ones) and one California skate (at the unenergized cable) were noted. Thus, we found no compelling evidence that the EMF produced by the energized power cables in this study were either attracting or repelling these fishes.

3) The strength, spatial extent, and variability of EMFs along both energized and unenergized cables.

The EMFs produced by the energized cables were similar both over the three years of the study and along the cables. EMF strength dissipated relatively quickly with distance from the cable and approached background levels at about one meter from the cable. The EMF at unenergized cables was similar to that found at the natural habitats.

4) The potential effectiveness of the commonly proposed mitigation of cable burial.

Given the rapidity with which the EMF produced by the energized cables diminishes and the lack of response to that EMF by the fishes and invertebrates in this study, cable burial would not appear necessary strictly for biological reasons. In this and similar cases, cable burial, at sufficient depth, would be an adequate tool to prevent EMF emissions from being present at the seafloor.

Methods

Our surveys of the offshore marine communities were conducted off the coast of Las Flores Canyon, southern California (34°27.6´N, 120°02.7´W) (Figure 3-1). At this site there are four, variously energized and unenergized, 8" diameter submarine power cables providing power to three offshore oil platforms. Surveys were conducted aboard the research submersibles *Dual DeepWorker* (2012 and 2014) and *DeepWorker* (2013). These submarines are 7.2 m in length and have a maximum operating depth of 610 m. The *DeepWorker* accommodates a pilot and the *Dual DeepWorker* accommodates both a pilot and an observer. Dives were made in September and October, during daylight hours.

We conducted belt transects along cables and on the nearby sea floor. These were documented with an externally mounted high-definition video camera positioned on the starboard bow of the submersible. All transects were 2-m wide and a set of lasers was used to measure transect width. A green and a red laser were set at an angle such that they intersected one another at a distance 2 m away from the submersible. The submersible followed a path parallel to the cable such that the intersection of the lasers landed on the cable. For off-cable (natural sea floor) transects, the crossing lasers were used to delineate the outside edge of each transect with the submarine continuing along a straight path along a compass heading for the duration of that transect.

During 2012 and 2014, and while in the submersible, the observer recorded into the microphone of a video recorder the species (to lowest possible taxon) of every fish observed within the transect boundary. The observer also estimated the total length (cm) of these fishes using reference light points from two parallel lasers installed 20 cm apart on either side of the external video camera. Comments were also made regarding general habitat and notable invertebrates. In 2013, when there was only a pilot aboard the submersible, we took data on fishes from the high definition video after returning to the laboratory.

In the laboratory, each video-recorded transect was reviewed and each fish again identified to the lowest possible taxa and its total length (estimated to the nearest 5 cm) recorded in an Access database. In a separate viewing of these videos, large invertebrates within the dimensions of the transect were surveyed. Any bottom-dwelling individual invertebrate with at least one dimension of ≥5 cm was included. The minimum dimension of 5 cm was selected because it was the size that could reliably be seen and identified. A few invertebrates, such as brittle stars, which were mostly buried could not be distinguished as individuals and were not counted. Invertebrates were identified to the lowest possible taxon. Transect length for the cable surveys was measured using an existing map of the cables and positions from a Ultra-Short Baseline (USBL) tracking system on the submersible. Navigation fixes were received from a Thales GeoPacific Winfrog ORE Trackpoint 2 USBL system at two-second intervals. Using the start and end points, and general path of the submarine from the USBL tracking system, the length of the submersible's path along the cable was measured using a straight-line ruler tool in ArcGIS. For the off-cable (natural sea floor) sites, the tracking system points were smoothed using a 9-point moving boxcar average and then plotted. Then the end-to-end straight-line distance was measured using a ruler tool in ArcGIS for each straight segment of a transect and segment lengths were totaled to obtain transect length. Most transects were only one straight segment. This method was found to be more accurate than calculating the distance between smoothed points, as the two methods were compared using the data from the cable surveys along a known path.

Measuring the Electromagnetic Field

We measured the electromagnetic field (EMF) emitted by the cables and the natural sea floor sites. In 2012, EMF readings were taken at distances of 1 m, 0.5 m, and 0 m from each cable. A Y-shaped measuring stick was attached to the EMF reader on the submersible's mechanical arm in order to ensure a perpendicular measurement from the cable (Figure 3-2). For each reading, the device was held in position until the readings stabilized (within approximately 1% of one another) and then the next three readings were taken and averaged. For natural habitat sites, readings were taken in a similar manner, but in a single position with the device touching the bottom. In 2013 and 2014 readings were taken on all cables, and on mud, but only at the 0 m distance.

Statistical Analysis

We used Primer v6.1.13 (Primer-E Ltd, 2009) to examine the biological assemblage data in relation to the type of habitat (energized cable, unenergized cable, and seafloor without cable) and bottom depth. Density was transformed to log[(number per 100m^3)+1] for the multivariate analyses. Bray-Curtis similarity coefficients were calculated to quantify the resemblance between transect samples and similarity matrices were generated for fish and invertebrates, separately. Natural groupings of samples were examined using hierarchical clustering with the group average linkage option and multidimensional scaling (MDS) ordination.

To test the null hypothesis that there are no assemblage differences among the two cable states and natural habitats (factor A) and depth (factor B) we used a two-way crossed analysis of similarity (ANOSIM), a nonparametric permutation procedure that operates on the resemblance matrix (Primer-E Ltd, 2009; Clarke and Gorley, 2006). Transects were divided into four depth stratum groups based on the clustering and MDS representations. The ANOSIM test statistic R ranges between 0 (approximately) and 1 and is very close to 0 if the null hypothesis is true with similarities between and within groups the same on average. The R statistic is a useful comparative measure of the degree of separation between groups. R values close to 1 are indicative of complete separation between groups. The global ANOSIM test indicates an overall difference among groups, and pairwise comparison tests using ANOSIM identifies the groups that differ from one another ($p<0.05$).

We used a generalized linear model (GLM) approach to test if cable state (energized v unenergized), controlling for other factors, affected the abundance of individual taxa of fishes and invertebrates. The GLM, with a normal distribution response and identity link function, included four factors: cable state, side of cable (west and east nested in cable state), bottom depth (stratum groups 1, 2, 3, and 4), and year (2012, 2013, 2014). The model, analogous to a multiple linear regression, was fit to transformed density data, log[(number per 100m^3)+1], by the Firth bias-adjusted maximum likelihood estimation method. A likelihood-ratio Chi-square test evaluated the hypothesis that all the model parameters in the whole model were zero. If the whole model was statistically different from the intercept model ($p<0.05$), then effect tests were used to identify which of the four factors had a significant effect on a taxon's abundance ($p<0.05$). Analyses were performed in JMP (SAS, 2015; Fox, 2014).

The same GLM approach was used to test if habitat type (cable v natural) affected the abundance of individual taxa controlling for the effects of bottom depth and year. In order to avoid including transects from both the west and east side of the cable within any given depth level and year in a single model, we used transects on the east side of the cable or on the west side if the east side was not surveyed. If side of cable had a significant effect on abundance, then we would evaluate models using transects from each side of the cable separately.

Results

We conducted surveys of energized and unenergized cables and of the nearby sea floor during 2012 (6–9 October), 2013 (3–5 October) and 2014 (23–25 October) (Table 3-1, Figures 3-3, 3-4, 3-5) at depths between 76 and 213 m (Table 3-1). During 2012, only the east side of each cable was surveyed. However, out of concern that there might be differences in species assemblages between the sides of cables, in 2013 and 2014 we surveyed both sides of the cables at similar depths. All natural habitat surveys were conducted between 100 and about 500 m from the nearest cable.

Note that for some analyses we divided the transect depths into four strata based on species groupings determined by MDS analyses of fish and invertebrate communities. These are defined as: Stratum 1 (transect categories1–8 = 76–107 m), Stratum 2 (transect categories 9–10 = 104–144 m), Stratum 3 (transect categories 11–13 = 137–180 m) and Stratum 4 (14–17 = 175–213 m) (Table 3-1).

EMF Levels

On 6 October 2012, we measured the EMF levels at three distances from energized Cable A. These measurements were taken at four locations along the cable (at bottom depths of 108 m, 112 m, 135 m, and 158 m). At all four locations, EMF levels dropped off precipitously with distance from the cable and, at one meter from the cable, approached background levels at three of the four locations (Table 3-2). This sharp drop-off was similar to that found in the nearshore part of this cable (Love et al. 2015).

With one exception (Cable C1 was not measured in 2013), in each year we measured the EMF levels at each cable (A, B, C, and C1) and at the sea floor away from these cables (Table 3-3). In all years, Cable A was energized and this cable formed the basis of our energized cable surveys. In all years Cable C was unenergized and Cable B was energized in 2012 and 2014, but unenergized in 2013. Cable C1 was unenergized in 2012 and energized in 2014. In general, field strengths on the energized cables were around 100 µT, while those on the unenergized cables were very low and near background (sea floor) levels (Table 3-3).

Fishes

We found that fish species communities were structured by depth (Global R=0.553, p=0.001) more so than by habitat type (Global R=0.176, p=0.001) (Figure 3-6). There was no statistical difference between the fish assemblages along the energized and unenergized cables (R=-0.055, p=0.87). The natural habitat community statistically differed from the energized cable (R=0.304, p=0.003) and unenergized cable communities (R=0.341, p=0.001).

We used a GLM approach to test for the effects on fish density of 1) cable state (energized or unenergized), 2) side of cable (nested in cable type), 3) depth strata, and 4) year (Table 3-4). Within species (or in several cases species-groups) that formed at least one percent of the fishes observed, we found no differences in densities between energized and unenergized cables. We did find differences based on cable side (shortspine combfish densities were higher on the west side of cables, two-tail t test, t=2,582, df 61, p=0.012), depth strata (stripetail rockfish, unidentified poachers, shortspine combfish, greenstriped rockfish, lingcod, and unidentified eelpouts), and year (halfbanded rockfish, stripetail rockfish, and lingcod).

Total fish densities were significantly higher around the cables than over the natural habitat (Figure 3-7). Among the more important species, densities of halfbanded, stripetail, and greenstriped rockfishes, shortspine combfish, and lingcod were higher at the cables and eelpouts were found at higher densities over natural habitat (Figure 3-8). There were no significant differences in the densities of unidentified sanddabs and unidentified poachers. There were very slight, but statistically significant, differences in both mean lengths and size distributions of fishes among the three study habitats (Table 3-5, Figure 3-9) as fishes at the unenergized cables tended to be slightly larger (mean = 14.8 cm) than those at both natural habitats (mean = 13.7 cm) and energized cables (mean = 13.0 cm).

Over all habitats we observed 9,675 individuals of at least 41 species (Tables 3-6, 3-7). Dominant species included halfbanded, stripetail, and greenstriped rockfishes, and lingcod, and unidentified flatfishes, poachers, and combfishes. *Energized cables:* In the vicinity of the energized cables, we observed at least 33 species of fishes, comprising 4,455 individuals (Table 3-8). Halfbanded rockfish dominated this habitat, comprising 56% of all fishes observed and present during 82.3% of the transects. Other important species or species groups included unidentified flatfishes and poachers, stripetail and shortspine combfish. *Unenergized cables*: Similar to the fish assemblage found around energized cables, there were at least 35 fish species in proximity to the unenergized cables (Table 3-9) and 3,691 individuals. As with the energized cables, halfbanded rockfish were by far the most abundant species, comprising 37.4% of all fish observed. Other important species included stripetail and greenstriped rockfishes and unidentified flatfishes, poachers, and combfishes. Natural habitats: Fewest species (at least 23) and fishes (1,529) were observed on the natural habitats (Table 3-10). Here, unidentified flatfishes, eelpouts, poachers, combfishes, sanddabs and halfbanded rockfish predominated.

Invertebrates

The structure of the invertebrate communities living around energized and unenergized cables and natural habitats was similar to that of fishes (Figure 3-10). We found that invertebrate communities were structured by habitat type (Global R=0.596, p=0.001) and depth (Global R=0.481, p=0.001). Similar to the fishes, there was no statistical difference between the invertebrate assemblages along the energized and unenergized cables (R=0.039, p=0.218). The natural habitat community of invertebrates strongly differed from the energized cable (R=0.846, p=0.001) and unenergized cable communities (R=0.751, p=0.001).

To determine if there were significant differences in species densities between energized and unenergized cables, we compared the densities of those important species that comprised at least 1% of individuals observed in this study in the same way as for fishes. We did note slight but statistically significant differences in densities for only two of nine of the most abundant species (Table 3-11). Sand star and black crinoid densities differed between unenergized and energized cables [sand star greater at unenergized cables, 4/1/m^3 v 2.7 m^3, and black crinoid at energized cables, 1.7/m^3 v 0.3/m^3]. Three species, thin sea pen, red octopus, and white sea urchin differed between cable sides. Seven species, white-plumed anemone, spot prawn, thin sea pen, California sea cucumber, red octopus, unidentified *Urticina* anemone, and black crinoid exhibited bottom depth differences. Densities of two species, thin sea pen and sand star, varied among years.

A number of species were more abundant around the cables than over the natural habitats. Important species that were more abundant around cables were white-plumed anemone, spot prawn, thin sea pens, California sea cucumber, sand star, and unidentified *Urticina* anemone. Red octopus and white sea urchin were denser over natural habitats and densities of black crinoid did not differ between the two habitats (Figure 3-11).

Over all habitats, we observed a total of 30,523 invertebrates of at least 43 invertebrate species (Tables 3-12, 3-13). The white-plumed anemone was by far the most abundant animal and comprised 43.4% of all invertebrates recorded. Spot prawns, thin sea pens, California sea cucumbers, sand stars, and the red octopuses were also found at relatively high densities. *Energized cables:* We observed 13,388 individuals, of at least 36 species, living on or near the energized cables (Table 3-14). White-plumed anemones, thin sea pens and spot prawns were the species found in highest densities, forming in aggregate 79.7% of all invertebrates observed. California sea cucumbers, sand stars, red octopuses, black crinoids, and *Urticina* anemones were also common. *Unenergized cables*: At least 35 species and 14,619 individuals were observed along the unenergized cables (Table 3-15). Three species, white-plumed anemones, spot prawns, and thin sea pens, were by far the most dense, in aggregate forming 79.2% of all invertebrates surveyed. California sea cucumbers, sand stars, red octopus, unidentified *Urticina* anemones, and serpulid worms were also characteristic of this habitat. Natural habitats: We observed the fewest number of species (a minimum of 27) and individuals (2,516) over the natural habitat (Table 3-16). Thin sea pens, red octopuses, white sea urchins and sand stars dominated this habitat, along with smaller numbers of white-plumed anemones, fragile pink urchins, California sea cucumbers, and sea slugs.

Discussion

The fish communities living around the cables and adjacent natural habitats in this study are typical of those found throughout central and southern California on 1) soft substrata, 2) cobble-strewn edges of rocky reefs, 3) the low-relief shell mounds around oil and gas platforms, and 4) adjacent to the low-relief oil and gas pipelines of southern California (Love et al. 1999, Love and York 2005, Anderson and Yoklavich 2007). A number of species of rockfishes, in particular, but also flatfishes, combfishes, and eelpouts are representative of these habitats. These fishes tend to be solitary rather than schooling (halfbanded rockfish are an exception) and benthic rather than water column dwelling. They also tend to reach relatively small maximum size. All of these characteristics reflect living in an environment that has no large structures that would allow for refuges or point of orientation.

Although we found no evidence that there were differences in fish communities between energized and unenergized cables, the abundances of some fishes did vary between cable sides (regardless of whether they were energized or not), with depth, and among years. It might be expected that abundances would vary with depth, reflective of depth preferences among species, and year, reflecting the patchiness of many species' small-scale distributions. However, the greater abundance of shortspine combfish on the west side of cables was unexpected and we have no definitive explanation for it. We have noted that, at times, mud will pile up on one side of the cable compared to the other, reflective of bottom current patterns. When this occurs it might be argued that sediment grain size differs between the two sides and that combfish are reacting to this – perhaps finding higher densities of benthic invertebrate prey on one side over the other. However, when we examined those patches where shortspine combfish were most abundant we did not see any obvious differences between the sides.

Electro-sensitive fishes were not abundant in the study area; only five ratfish (three at the energized cables and two on the unenergized ones) and one California skate (at the unenergized cable) were observed. It is important to note that, in the depth ranges we surveyed, both benthic elasmobranchs (sharks, skates, and rays) and chimaerids (ratfishes) are common in southern California waters (Love et al. 2009, Love 2012). However, with the exception of the schooling Pacific dogfish (*Squalus suckleyi*) and soupfin shark (*Galeorhinus zyopterus*), most of these species live solitary existences and thus it would be unlikely that we would have observed large numbers of any of these species (again with the possible exceptions of Pacific dogfish and soupfin shark) unless these habitats were somehow attracting these fishes. Thus, specifically, because we did not observe high densities of electro-sensitive fishes around energized cables or, on the contrary, around the unenergized ones, it might be argued these taxa are neither attracted to, nor repelled by, the EMF emitted.

Similar to the fish communities, we observed almost no differences in the abundances of important invertebrate species between energized and unenergized cables.
In particular, at these structures we found that the six invertebrate species that were most abundant at energized cables (white-plumed anemone, spot prawn, thin sea pen, California sea cucumber, sand star, and red octopus) were the most abundant taxa at unenergized cables. Again, as with the fish communities, bottom depth was a major driver of variability in the invertebrate communities. And again like the fishes we observed, these invertebrate species are very typical of both low-relief and soft substrata sea floors in southern and central California (Goddard and Love 2010, Kuhnz et al. 2015).

The cable habitat harbored many more invertebrate species and numbers than did the natural habitat. It is likely that this was due to the cables (hard, although relatively low structures) creating a more complex environment than that of the mud that formed most of the natural sea floor. In our cable surveys, we included not only the cable but also the sea floor within 2 m of the cable. This methodology allowed us to include not only organisms that might preferentially live on hard structure, such as white-plumed anemones, but also those dwelling on soft sea floor, such as sea pens.

As with the fishes, there were invertebrate taxa whose densities were greater on one side of the cable; these were red octopus and thin sea pen (Table 3-17). In two taxa, red octopus and thin sea pen, densities were significantly higher on the east side of the cables. Densities of red octopus were about twice as high on the east side and about nine times higher for thin sea pen. While we do not know why these patterns occurred, in the case of sea pens it is known that at least some species are highly sensitive to substratum grain size. For instance several species of sea pens in Scottish marine waters are abundant in mud and become rare or, ultimately, absent as the amount of gravel increases (Greathead et al. 2015). As noted before, it is possible that currents, playing over the cables, can distribute sediments based on grain size, thus leading to coarser sediments on one side and finer on the other. Similarly, it is possible that octopus prey were more abundant on one side of the cable compared to the other.

Data from the few field studies on the behavior of fishes in the presence of human-induced EMF in submarine power cables are, at best, equivocal. Westerberg and Lagenfelt (2008) observed the swimming speed of European eel, *Anguilla anguilla*, passing over a 130 kV AC power cable in the Baltic Sea. They found a small effect with eels slowing their swimming speed both when approaching and exiting from the cable region. However, there was no statistically significant relationship between the amperage in various parts of the cable and swimming speed. Gill et al. (2009) characterized the movements of three species of electro-sensitive elasmobranchs, thornback ray (*Raja clavata*), spurdog (*Squalus acanthias*), and small-spotted catshark (*Scyliorhinus canicula*), in enclosed mesocosms off Scotland containing either energized or unenergized cables. They found that one of the three species (spotted catshark) tended to be attracted to the energized cable compared to the unenergized one while the other two species did not show any differences in their responses. Lastly, DONG Energy and Vattenfall (2006) looked at the distribution of fishes in a nearshore area of the North Sea before and after the energizing of a submarine power cable transmitting energy from an offshore wind farm. They found evidence that the migrations of four species Baltic herring (*Clupea harengus*), European eel, Atlantic cod (*Gadus morhua*), and flounder (*Platichthys flesus*) appeared to be somewhat hindered by an energized cable.

The most apt comparisons between our findings and those of others are the surveys of fishes and invertebrates conducted in Monterey Bay, central California (Kogan et al. 2003, Kuhnz et al. 2011, 2015) on and near a power cable extending from land to the Pioneer Seamount, located about 51 km offshore. Note that this cable was smaller than the cables we studied (3.2 cm versus 20 cm diameter) and carried lower voltages (10 Kv versus 35 Kv) and the EMF emitted by the MBARI cable was not measured.

Using an ROV, the MBARI researchers surveyed the organisms living near or on the cable and those living on natural habitat control sites 50 m away using 100 m-long transects positioned every 5 km. Surveys were first conducted before the cable was first energized in 2008 (Kogan et al. 2003, Kuhnz et al. 2011), with subsequent post-energized surveys in 2010 (Kuhnz et al. 2011) and again in 2014–2015 (Kuhnz et al. (2015). The major findings of the latest study (that also summarize the 2010 surveys) (Kuhnz et al. 2015) were that:

1) The abundances of most animals observed did not differ between the area over the cable route and 50 m away.
2) The overall faunal communities did not differ between the cable and control site. Thus, the cable had little or no detectable effect on the distribution and abundance of either faunal assemblages.
3) The faunal communities did not differ between sampling years.
4) Faunal assemblages did vary with depth.
5) The abundance and distribution of fauna appears to be most closely linked to natural variation rather than to either the presence of the cable or whether it is energized.
6) Although electro-receptive species, such as skates and ratfishes, were observed the densities of these animals were no higher near the energized cable than at the control site.

Overall, cnidarians (sea pens and anemones) were most important and comprised 47% of all individuals observed and echinoderms (sea stars and urchins primarily) were second-most important at 42%. Among fishes, flatfishes and rockfishes were the dominant groups.

In several ways, our findings mirror those of Kuhnz et al. (2015). First, and most importantly, we also found little evidence that energized cables either attract or repel the marine organisms living in their vicinity. This is particularly striking as the cables in our study were both physically larger in diameter and carried more voltage (and thus likely also created greater EMF). In addition, the same group of fishes and invertebrates that were characteristic of the Kuhnz et al. study, also dominated the habitats in ours. Among fishes, rockfishes and flatfishes also dominated our sites as did, among invertebrates, cnidarians and echinoderms. And among the more striking similarities, white-plumed anemones were about 40 times more abundant on the cables than the natural habitat in Monterey Bay and 23 times more abundant in our study. The greatest difference between the studies was that spot prawns were quite abundant around our study cables and almost absent from the Monterey sites (L. Kuhnz, pers. comm. to M. L.).

We note that an observation by Kuhnz et al. (2011) demonstrates the complexities in distinguishing between human-induced and naturally occurring behaviors. In 2008, *before* the MBARI cable was energized, Kuhnz et al. (2011) reported a dense aggregation of longnose skate (*Raja rhina*) lying on the sea floor primarily within 5–10 m of the cable at a bottom depth of 300 m. The unenergized cable at this location was lying on rocks and suspended slightly above the sea floor. The authors speculated that "The suspended MARS cable very likely produced a weak electromagnetic field as local ocean currents flow through the Earth's magnetic field and around the cable...This is possible even though the cable was not energized during the 2008 video survey. We noted that while the cable was taut and 2–10 cm off the seafloor in other areas with topographic highs and lows, no other skate aggregations were seen. The combination of topography (small scarps and sediment depressions unique to this area), natural distribution of the animals, and a mild electrical field may have contributed to the aggregation." It is important to note that after the cable was energized subsequent surveys of this location found no aggregations of skates and no aggregations of skates were noted anywhere along the energized cable or in the control sites in these subsequent surveys (Kuhnz et al. 2011, 2015). At the very least, this presents a cautionary note regarding the interpretation of short-term or one-time surveys.

Kuhnz et al. (2015) also note that "While there were significant results [differences between cable and control site] for Ophiuroids (brittlestars) at the Shelf region, and for Pleuronectiformes (flatfishes) at the Neck region, we know that from our general [not affiliated with these surveys] benthic studies that both of these groups of animals are highly mobile and form ephemeral aggregations; these results may represent natural variability." We posit that many or perhaps all of the few significant differences we observed between taxa at energized and unenergized cables, such as in mean sizes of fishes or densities of several invertebrates, may represent natural variability. In any case, we believe it is quite possible that none of these differences are biologically significant.

There is a substantial body of research that demonstrates that a number of marine organisms can detect naturally occurring EMFs and perhaps utilize this ability for navigation, prey detection, and other functions (Normandeau et al. 2011). If this is the case, what, then might explain the lack of response to the human-induced EMF produced by the submarine power cables in our study? One possible explanation is that marine organisms may respond to human-induced EMF differently from those produced in nature. Recent studies demonstrate that human-made EMF is inherently different from naturally produced EMF; it is polarized and thus more biologically active (Panagopoulos et al. 2015). Thus, it is possible that electro-sensitive organisms are able to differentiate between the two types and therefore respond differently to each of these stimuli.

Regarding the specific objectives of this study:

1) The differences among fish and invertebrate communities associated with energized and unenergized cable habitat and those communities in soft seafloor habitats lacking cables.

We did not observe any significant differences in the fish communities living around energized and unenergized cables and natural habitats. A very slight, and likely biologically insignificant, difference in mean sizes was observed as fishes at unenergized cables were marginally larger than those around energized ones. Overall species diversity and the densities of the most important fish species (define as comprising at least 1% of all fishes observed) were higher at the cables than at the natural habitats. This is likely reflective of the more complex habitats afforded by the cables than the primarily soft substrata natural habitats.

Similar to the fish communities, the invertebrate assemblages living around energized and unenergized cables and natural habitats were similar to one another and variability between these communities was primarily driven by sea floor depth.

Among the three habitat types, there were some statistically significant differences in densities for all nine of the most abundant species. These differences included: 1) two species, sand star and black crinoid, whose densities differed between energized and unenergized cables, 2) three species, thin sea pen, red octopus, and white sea urchin which differed between cable sides, 3) seven species, white-plumed anemone, spot prawn, thin sea pen, California sea cucumber, red octopus, unidentified *Urticina* anemone, and black crinoid that exhibited bottom depth differences, and 4) two species, thin sea pen and sand star, whose densities varied among years. Sand star densities were greater at unenergized cables, 4/1/m^3 v 2.7 m^3, and black crinoid densities were greater at energized cables, 1.7/m^3 v 0.3/m^3.

2) Whether electro-sensitive species that are regionally important, such as sharks and rays, respond (via either attraction or repulsion) to the EMFs of an in situ power transmission cable.

We observed very few individuals of electro-sensitive species on the energized or unenergized cables or on the natural habitats. Only five ratfish (three at the energized cables and two on the unenergized ones) and one California skate (at the unenergized cable) were noted. Thus, we found no compelling evidence that the EMF produced by the energized power cables in this study were either attracting or repelling these fishes.

3) The strength, spatial extent, and variability of EMFs along both energized and unenergized cables.

The EMFs produced by the energized cables were similar both over the three years of the study and along the cables. EMF strength dissipated relatively quickly with distance from the cable and approached background levels at about one meter from the cable. The EMF at unenergized cables was similar to that found at the natural habitats.

4) The potential effectiveness of the commonly proposed mitigation of cable burial.

Given the rapidity with which the EMF produced by the energized cables diminishes and the lack of response to that EMF by the fishes and invertebrates in this study, cable burial would not appear necessary strictly for biological reasons. In this and similar cases, cable burial, at sufficient depth, would be an adequate tool to prevent EMF emissions from being present at the seafloor.

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Figure 3-1. Location of the offshore energized and unenergized submarine power cables surveyed in this study.

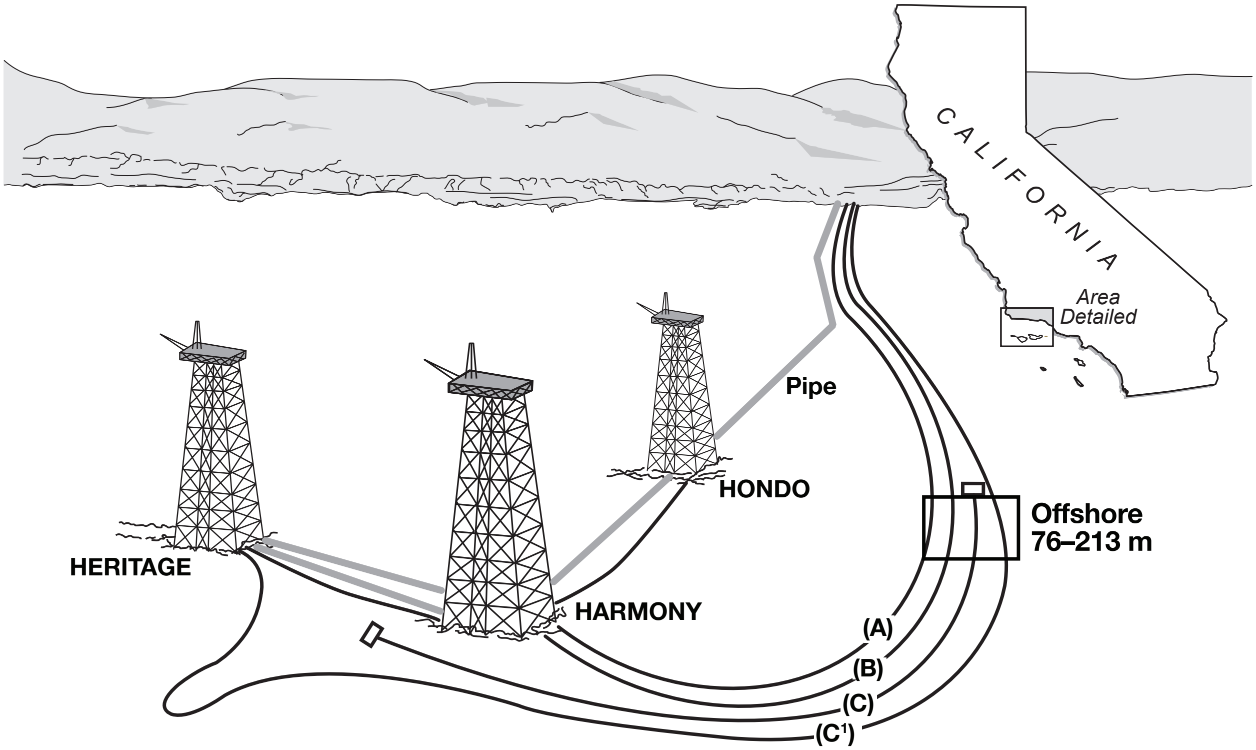


Figure 3-2. A photograph of the method used to assess the electromagnetic fields occurring around energized and unenergized submarine power cables and natural habitats.

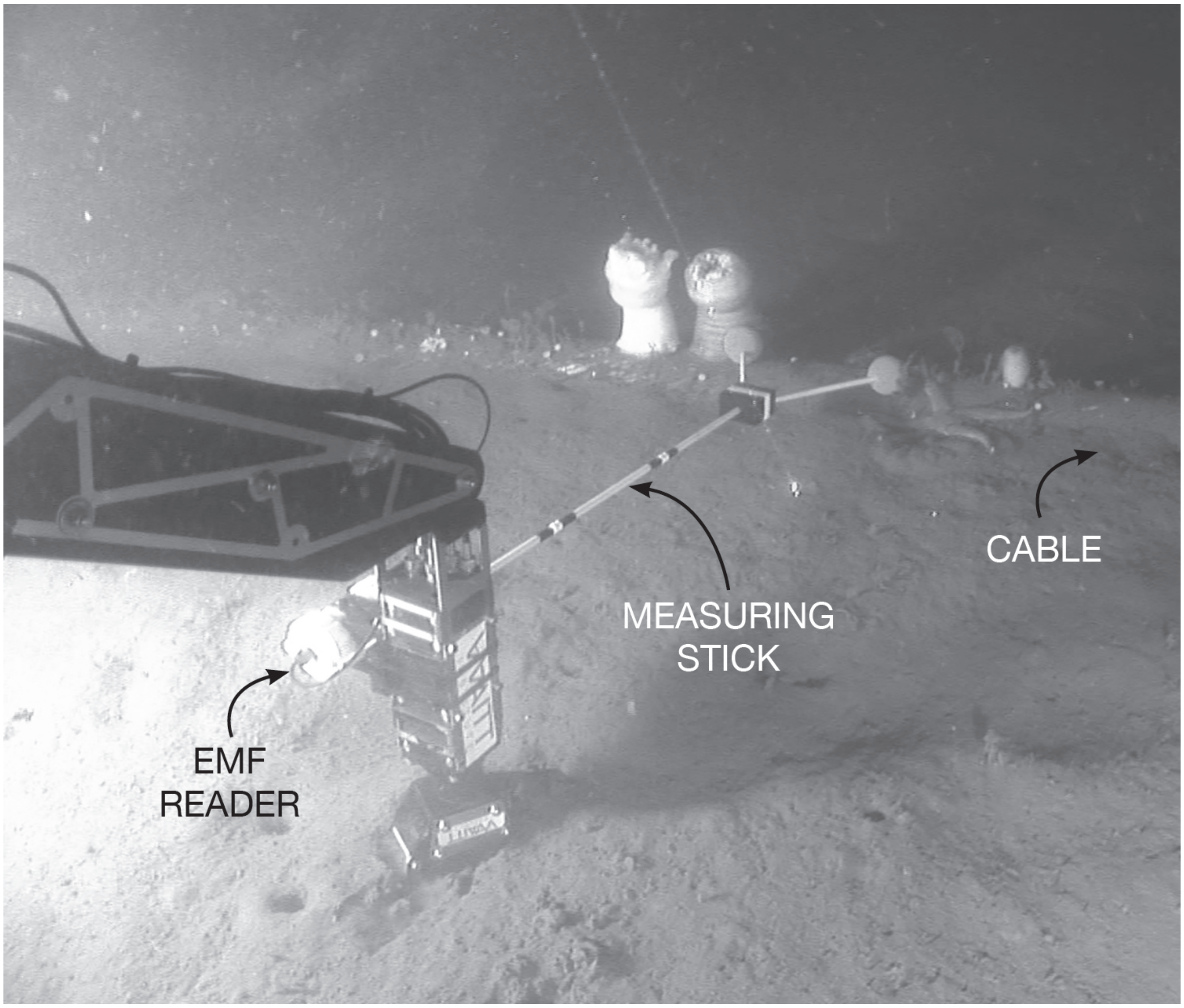


Figure 3-3. Locations of transects conducted over energized and unenergized cables and natural habitats, 2012. During this year cables A and B were energized and cables C and C1 were unenergized.

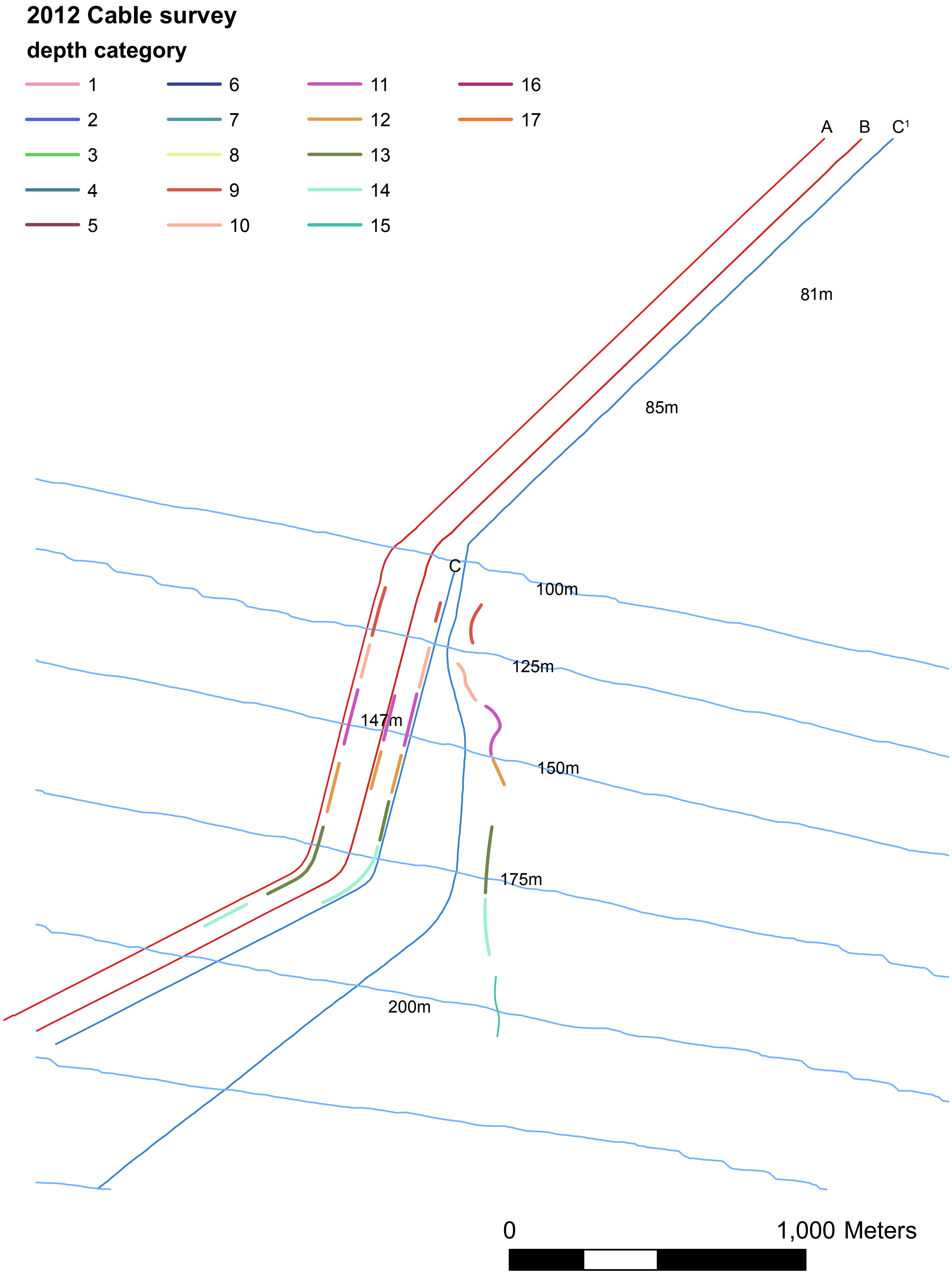


Figure 3-4. Locations of transects conducted over energized and unenergized cables and natural habitats, 2013. During this year cable A was energized, cables B and C were unenergized and C1 were neither surveyed nor was the electromagnetic field measured.

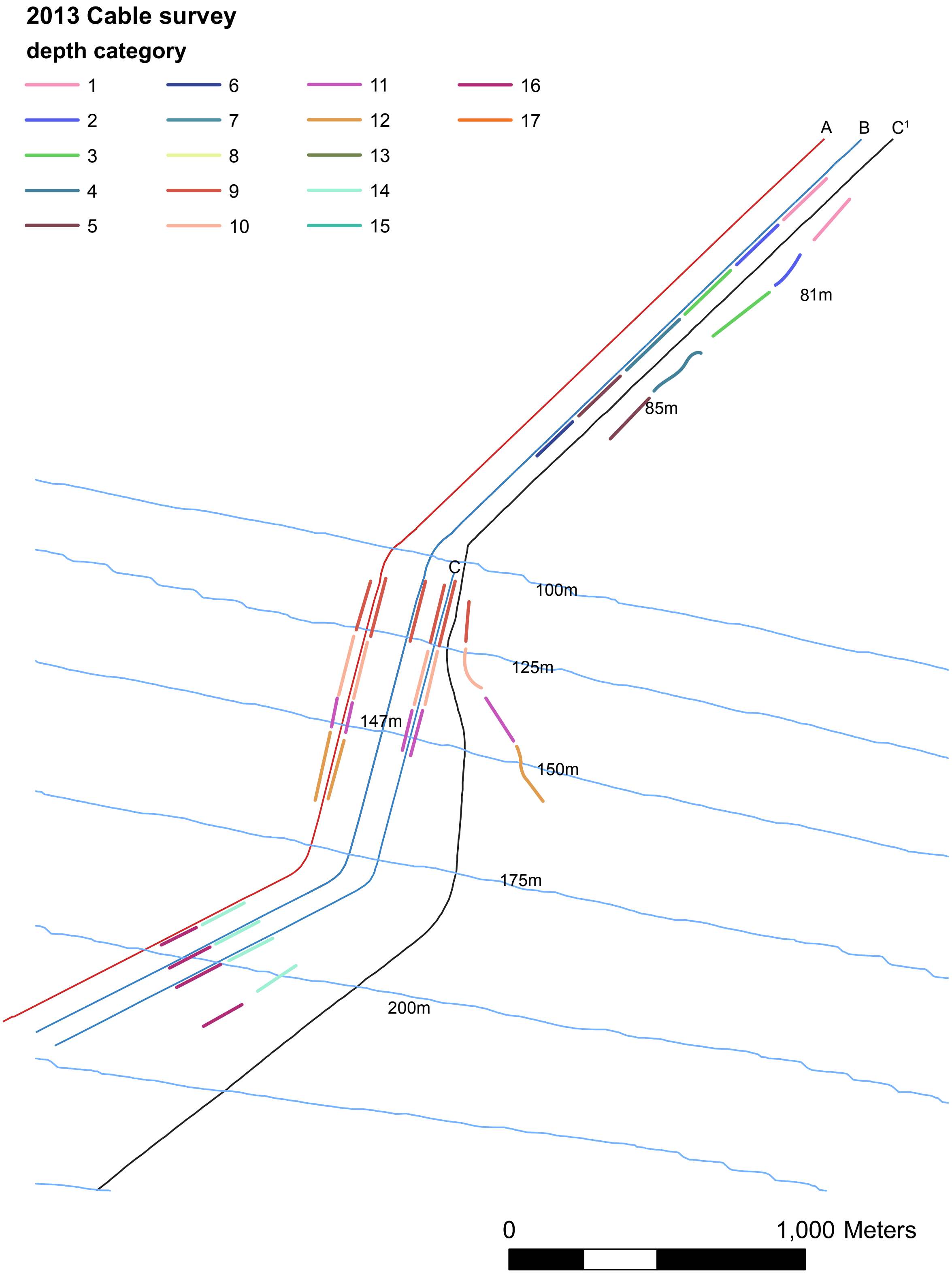


Figure 3-5. Locations of transects conducted over energized and unenergized cables and natural habitats, 2014. During this year cables A and B were energized and cables C and C1 were unenergized.

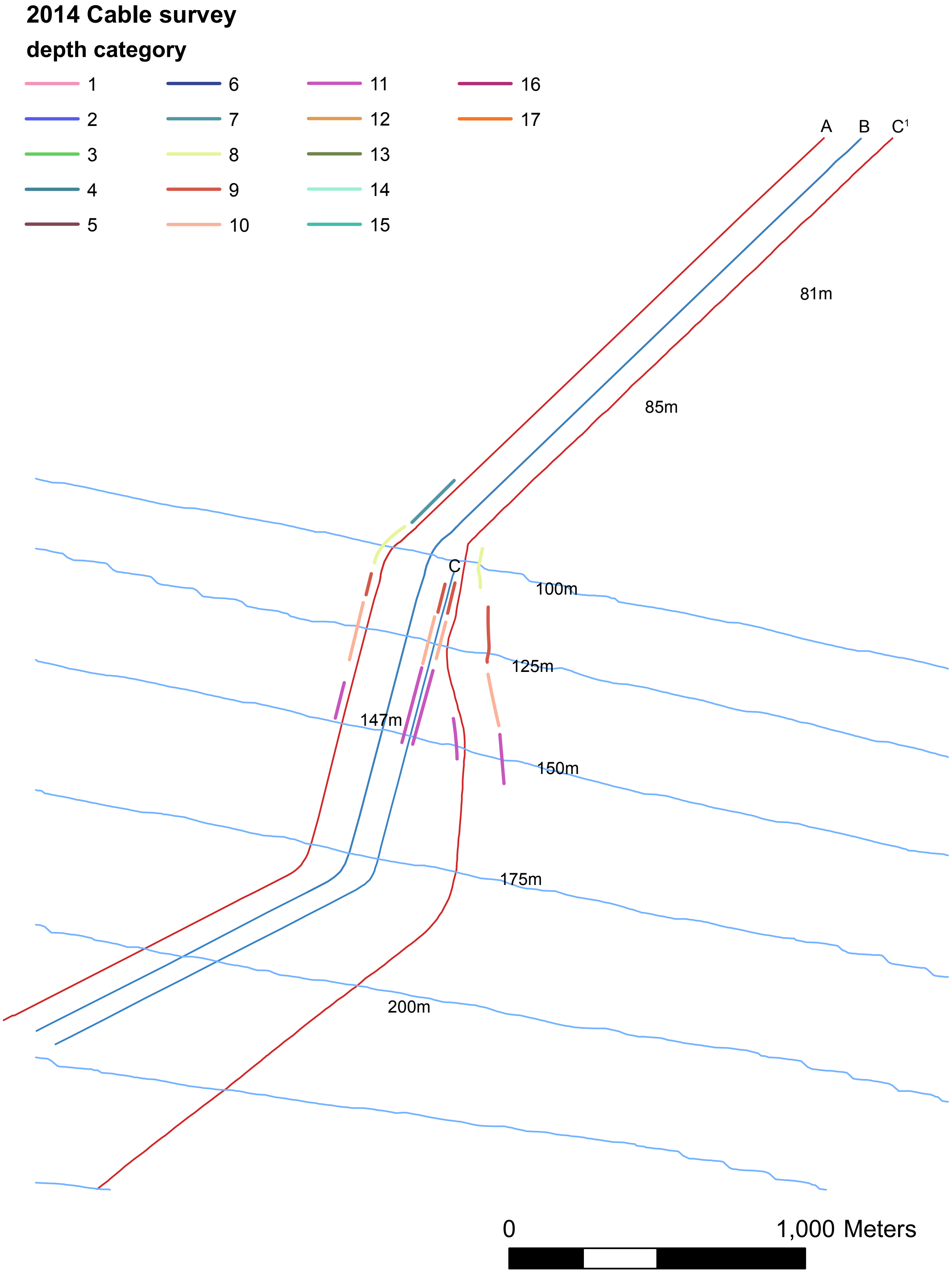
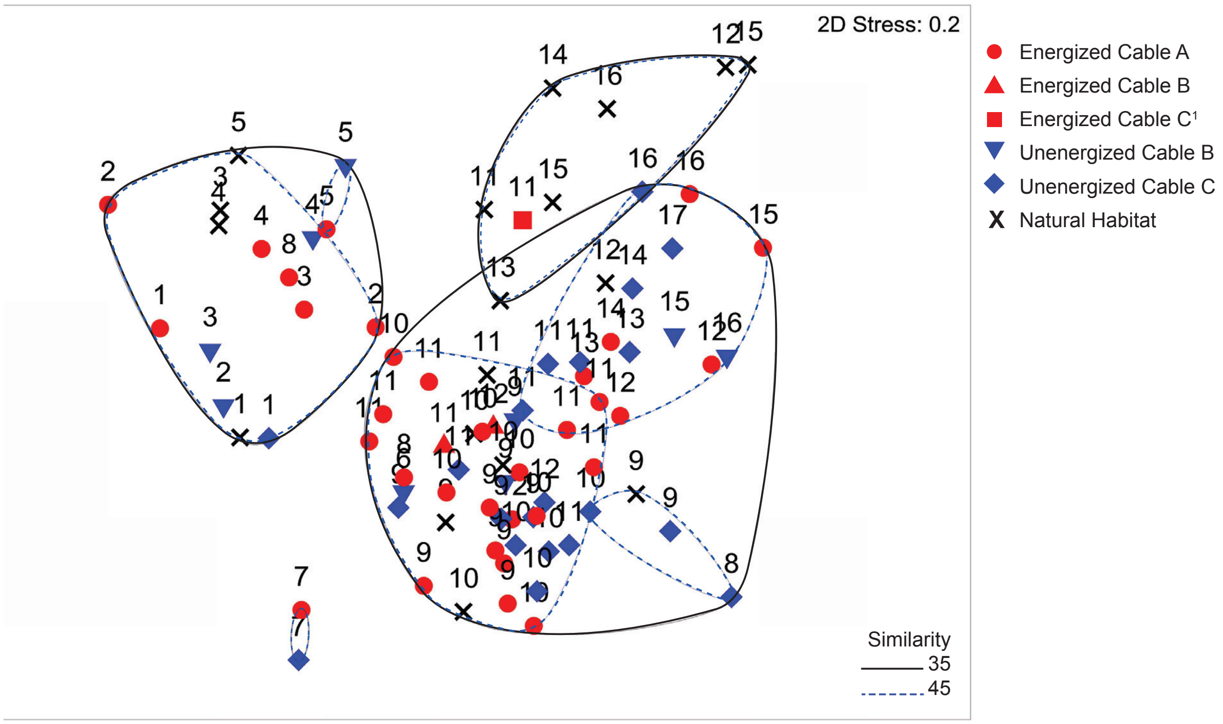


Figure 3-6. A 2-d multiple dimensional scaling model comparing the fish assemblages observed over energized and unenergized cables and natural habitats surveyed during 2012–2014. Numbers near symbols refer to the depth category of that transect. The higher the number the deeper the transect. Depth ranges of the depth categories are given in Table 3-1.



Fish Assemblage by Habitat Type

Figure 3-7. Densities of all fishes between all cables (energized and unenergized) combined and natural habitats of major species or species groups. Densities are in fishes per 100 m^3 and means and standard deviations are provided.

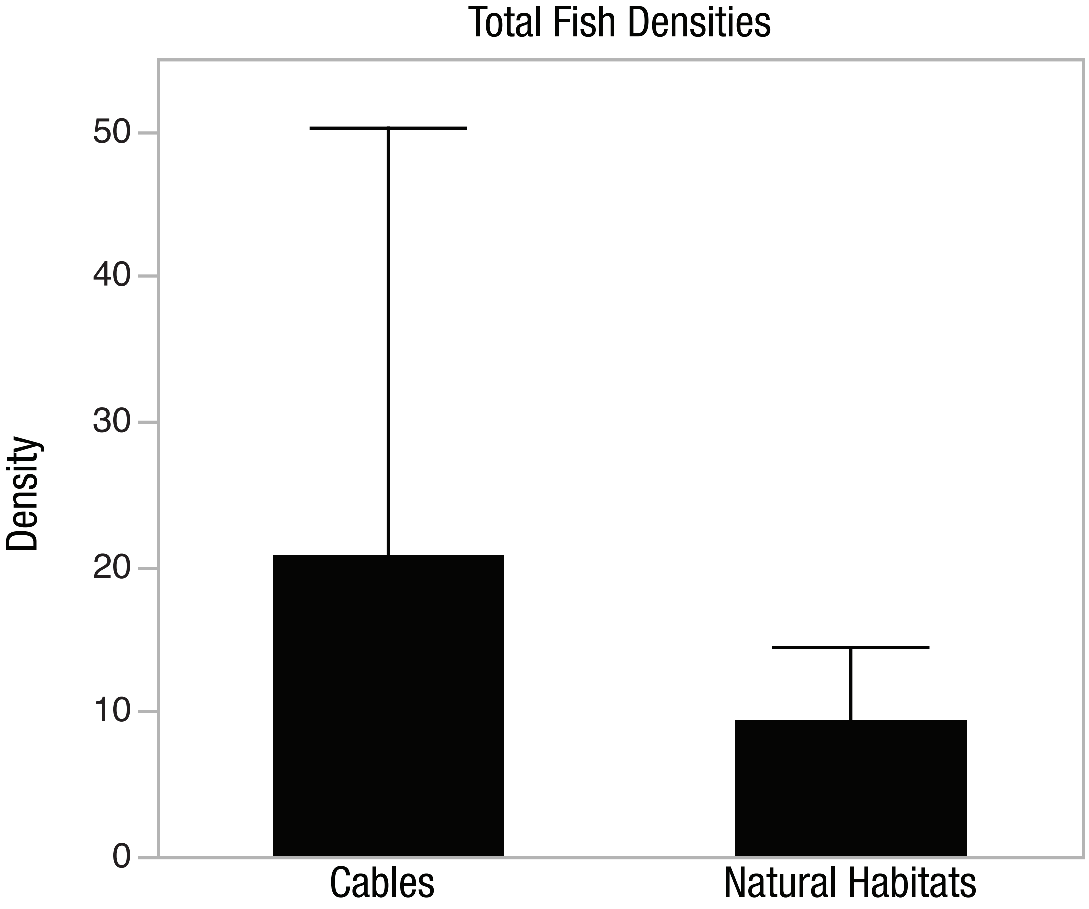


Figure 3-8. Densities of important fish species (defined as comprising at least 1% of all fishes observed), comparing 1) energized and unenergized cables and 2) natural habitats. Densities are in fish per 100 m^3 and means and standard deviations are provided.

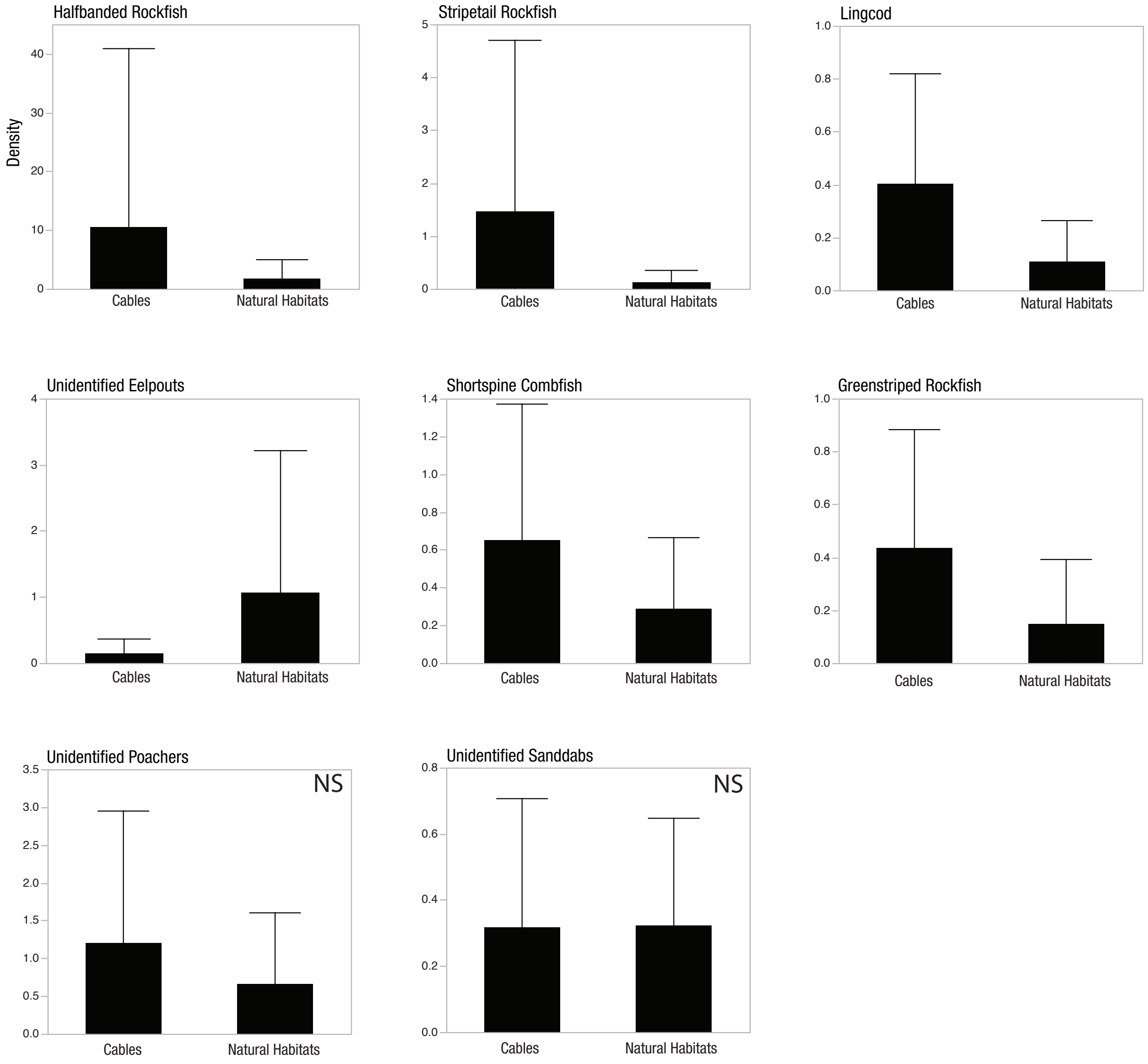


Figure 3-9. Length frequencies of all fishes observed on energized and unenergized cables and natural habitats, 2012–2014.

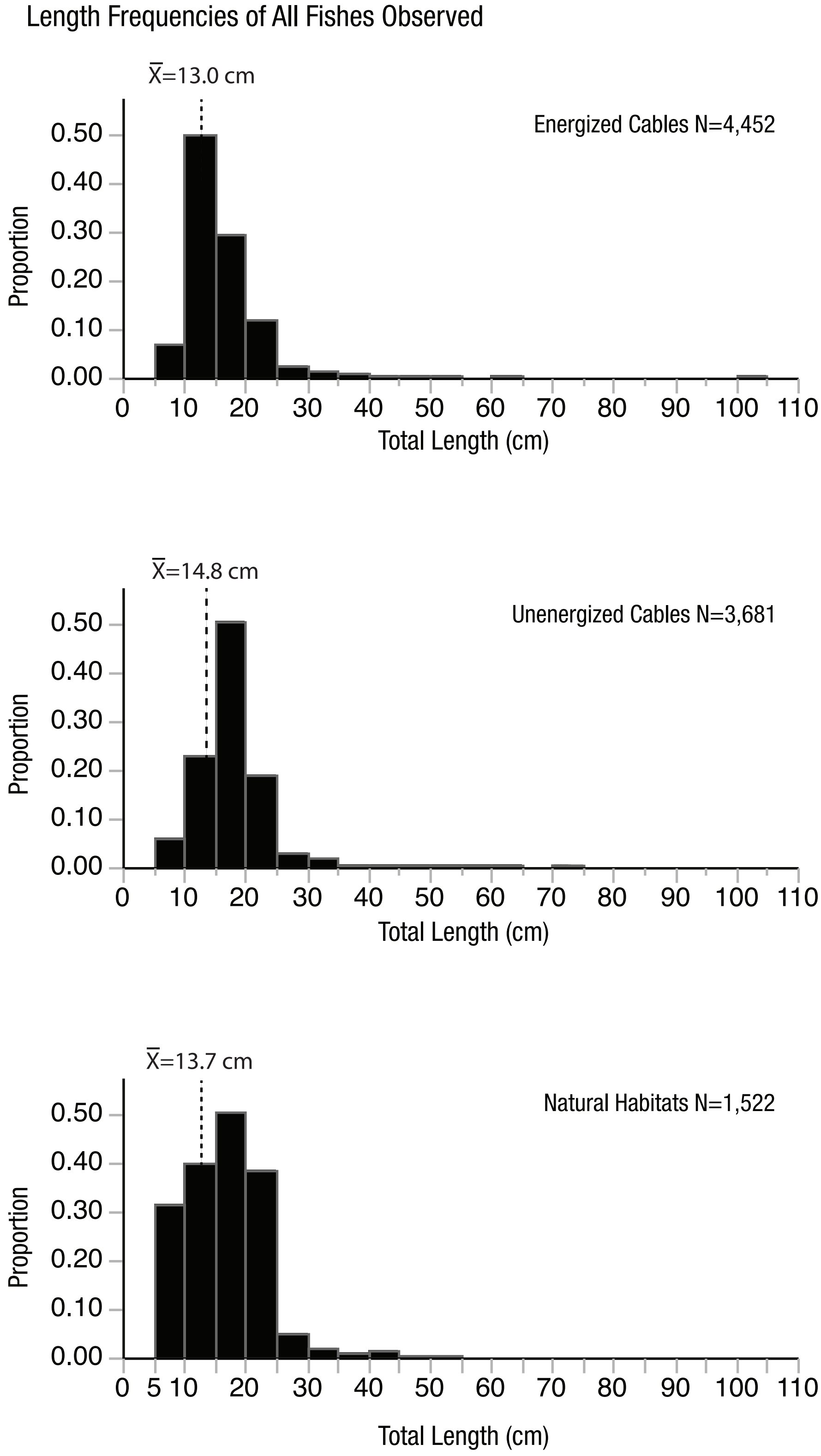


Figure 3-10. A 2-d multiple dimensional scaling model comparing the invertebrate assemblages observed over energized and unenergized cables and natural habitats surveyed during 2012–2014. Numbers near symbols refer to the depth category of that transect. The higher the number the deeper the transect. Depth ranges of the depth categories are given in Table 3-1.

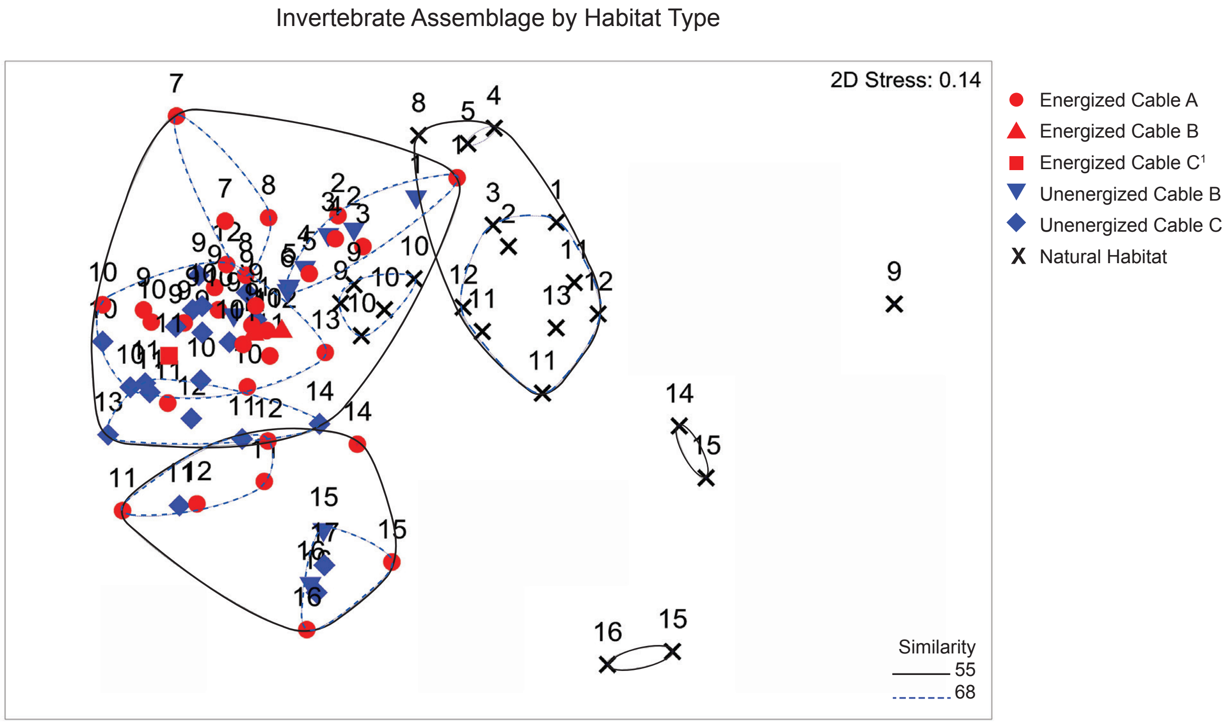


Figure 3-11. Densities of important invertebrate species (defined as comprising at least 1% of all invertebrates observed) between all cables (energized and unenergized) combined and natural habitats of major species or species groups. Densities are in invertebrates per 100 m^3 and means and standard deviations are provided

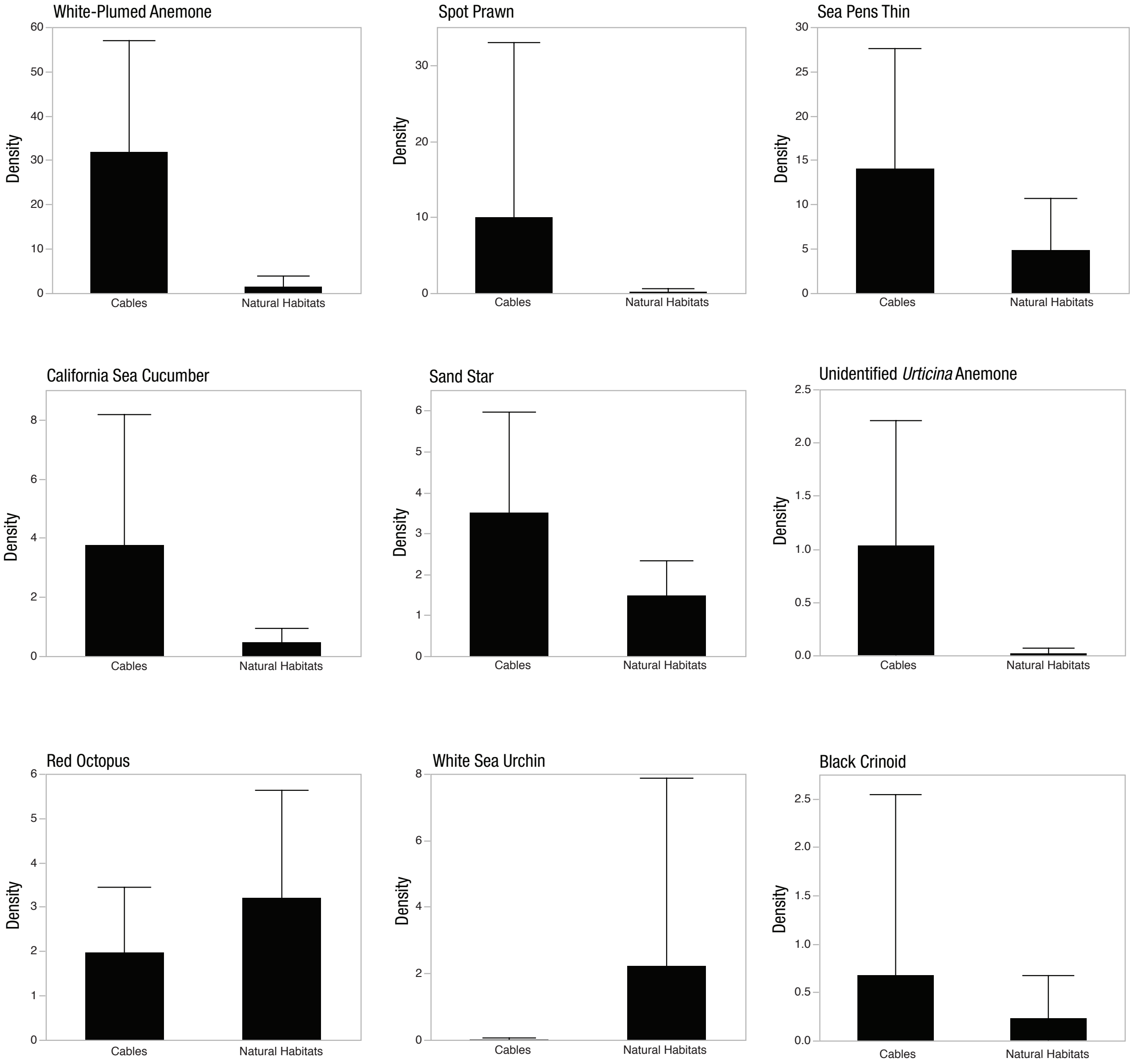


Table 3-1. Locations and lengths of transects made at energized and unenergized cables and natural habitat in 2012–2014. Transects are divided into depth categories and lengths are in meters. See Figures 3-3, 3-4, and 3-5 for locations.

2012 Cable		A		B		C		C[1]		Natural Habitat	
		Energized		Energized		Unenergized		Not Surveyed			
Transect Category	Depth Range (m)										
9	104–128		156				164			229	
10	112–144		97			181				206	
11	137–153		168		163	146				237	
12	146–154		170		182	183				188	
13	162–180		285			197				234	
14	175–192		240			267				195	
f	187–204									208	

2013 Cable		A		B		C		C[1]		Natural Habitat	
		Energized		Unenergized		Unenergized		Not Surveyed			
		West	East	West	East	West	East				
Transect Category	Depth Range (m)										
1	76–79		214		160					159	
2	80–81		179		238					167	
3	81–82		237		268					344	
4	82–84		208		186					180	
5	83–87		251		200					272	
6	86–87				135						
7	90–95										
8	94–107										
9	104–128	142	158		136	225	178			89	
10	112–144	69	163			104	99			185	
11	137–153	88	91			137	121			175	
12	146–154	169	182							202	
13	162–180										
14	175–192										
15	187–204		174		222					190	
16	192–203		105		162		82			177	
17	200–213						241				

Table 3-1. Continued. Locations and links of transects made at energized and unenergized cables and natural habitat in 2012–2014. Transects are divided into depth categories and lengths are in meters. See Figures 3-3, 3-4, and 3-5 for locations.

2014 Cable		A		B		C		C[1]		Natural Habitat	
		Energized		Energized		Unenergized		Unenergized			
		West	East	West	East	West	East				
Transect Category	Depth Range (m)										
7	90–95	143	100								
8	94–107	124	100							60	
9	104–128	59	61			93	90			110	
10	112–141	143	139			107	96			161	
11	137–153	98	112			137	122	122	129	133	

Table 3-2. Electromagnetic fields (EMFs) in microteslas (µT) measured at Cable A in 2012. Measurements were taken at three distances from the cable (0 m – on cable, 0.5 m, and 1 m) and at four locations along cable.

EMF (µT)				
Location	Bottom Depth (m)	Distance from Cable		
		0 m	0.5 m	1 m
1	108	67.6	22.6	3.2
2	112	107.7	26.5	20.1
3	135	91.1	39.8	4.1
4	158	106.0	31.3	2.7
Mean		93.1	30.1	7.5
SD		18.6	7.4	8.4

Table 3-3. Mean, minimum, and maximum electromagnetic fields (EMFs) in microteslas (μT) (with standard deviations) measured directly on cables A, B, C, and C1, and on the natural habitat during 2012, 2013, and 2014. N = the number of sites along a cable where EMF was measured during the surveys.

2012					
Site	N	Mean EMF	SD	Min.	Max.
A (energized)	6	101.2	19.2	67.6	120.7
B (energized)	3	110.1	10.3	101.5	121.5
C (unenergized)	4	1.2	0.3	0.9	1.5
C1 (unenergized)	1	1.2			
Natural Habitat	4	0.9	0.1	0.8	1
2013					
A (energized)	4	85.3	30.7	51	115
B (unenergized)	3	0.4	0.1	0.3	0.5
C (unenergized)	1	0.3			
C1 (unmeasured)					
Natural Habitat	1	0.3			
2014					
A (energized)	3	100.7	45.4	51	140
B (energized)	1	36.2			
C (unenergized)	5	0.0	0.0	0	0
C1 (energized)	2	178.0	38.2	151	205
Natural Habitat	1	0.3			

Table 3-4. Effects of cable state (energized, unenergized), side of cable surveyed (west, east) nested in cable state, stratum group (1–4), and year (2012–2014) on fish density tested using a generalized linear model (normal distribution, identity link), $p<0.05$. Densities were $\log(x+1)$ transformed. Cable State = energized or unenergized. Stratum groups are discussed under Results. * = statistically significant.

Taxon		Whole Model Difference	Cable State	Cable Side	Stratum Groups	Year
	DF	8	1	2	3	2
Halfbanded rockfish	X2	26.133	1.116	0.210	6.707	13.735
	p	0.0010*	0.2908	0.9003	0.0819	0.0010*
Stripetail rockfish	X2	54.474	3.344	0.549	51.093	9.687
	p	<.0001*	0.0674	0.7599	<.0001*	0.0079*
Unidentified poachers	X2	57.808	2.761	0.142	49.148	6.836
	p	<.0001*	0.0966	0.9314	<.0001*	0.0328
Shortspine combfish	X2	46.427	0.793	10.287	22.828	5.225
	p	<.0001*	0.3731	0.0058*	<.0001*	0.0733
Greenstriped rockfish	X2	36.740	3.583	1.320	18.111	5.222
	p	<.0001*	0.0584	0.5168	0.0004*	0.0735
Lingcod	X2	25.439	2.178	0.867	10.116	20.052
	p	0.0013*	0.1400	0.6484	0.0176*	<.0001*
Unidentified sanddabs	X2	12.909	0.331	0.993	7.405	4.965
	p	0.1150	0.5649	0.6088	0.0601	0.0835
Unidentified eelpouts	X2	51.044	0.103	0.191	45.158	2.645
	p	<.0001*	0.7484	0.9091	<.0001*	0.2665
Total fishes	X2	8.7853	2.1205	1.0314	1.4355	3.2553
	p	0.3607	0.1453	0.5971	0.6972	0.1964

Table 3-5. Comparisons of the mean sizes and size frequency distributions of fishes observed over energized and unenergized cables and natural habitats in southern California, 2012–2014. Mean sizes were compared with the Welch's Test and size frequency distributions using the Kolmogorov Smirnov Two-Sample Test.

Welch's Test		
Energized Cable v Unenergized Cable		
F Ratio	df	p
260.36	1	<.0001
Energized Cable v Natural Habitats		
F Ratio	df	p
18.37	1	<.0001
Unenergized Cable v Natural Habitats		
F Ratio	df	p
36.51	1	<.0001
Kolmogorov Smirnov Two-Sample Test		
Energized Cable v Unenergized Cable		
N	KS	p
8,146	0.142	<.0001
Energized Cable v Natural Habitats		
N	KS	p
5,984	0.060	<.0001
Unenergized Cable v Natural Habitats		
N	KS	p
5,220	0.067	<.0001

Table 3-6. Common and scientific names of fishes observed at bottom depths of 76–213 m over energized and unenergized cables and natural habitats in southern California, 2012–2014.

Bearded eelpout	*Lyconema barbatum*
Bigfin eelpout	*Lycodes cortezianus*
Blackbelly eelpout	*Lycodes pacificus*
Bluebarred prickleback	*Plectobranchus evides*
Bocaccio	*Sebastes paucispinis*
Bull sculpin	*Enophrys taurina*
Calico rockfish	*Sebastes dallii*
California lizardfish	*Synodus lucioceps*
California skate	*Raja inornatus*
California smoothtongue	*Leuroglossus stilbius*
Copper rockfish	*Sebastes caurinus*
Cowcod	*Sebastes levis*
Darkblotched rockfish	*Sebastes crameri*
Dover sole	*Microstomus pacificus*
English sole	*Parophrys vetulus*
Flag rockfish	*Sebastes rubrivinctus*
Greenblotched rockfish	*Sebastes rosenblatti*
Greenspotted rockfish	*Sebastes chlorostictus*
Greenstriped rockfish	*Sebastes elongatus*
Halfbanded rockfish	*Sebastes semicinctus*
Icelinus sculpins	*Icelinus spp.*
Lingcod	*Ophiodon elongatus*
Longspine combfish	*Zaniolepis latipinnis*
Pacific argentine	*Argentina sialis*
Pacific hake	*Merluccius productus*
Pacific sanddab	*Citharichthys pacificus*
Pink surfperch	*Zalembius rosaceus*
Pygmy rockfish	*Sebastes wilsoni*
Shortspine combfish	*Zaniolepis frenata*
Speckled sculpin	*Citharichthys stigmaeus*
Spotted ratfish	*Hydrolagus colliei*
Splitnose rockfish	*Sebastes diploproa*
Spotfin sculpin	*Icelinus tenuis*
Stripetail rockfish	*Sebastes saxicola*
Swordspine rockfish	*Sebastes ensifer*
Threadfin sculpin	*Icelinus filamentosus*
Treefish	*Sebastes serriceps*
Unidentified eelpout	*Zoarcidae*
Unidentified fishes	*Osteichthyes*
Unidentified flatfishes	*Pleuronectiformes*
Unidentified combfishes	*Zaniolepis spp.*
Unidentified cuskeel	*Ophidiidae*
Unidentified poachers	*Agonidae*
Unidentified rockfishes	*Sebastes spp.*
Unidentified pricklebacks	*Stichaeidae*
Unidentified sanddabs	*Citharichthys spp.*
Unidentified sculpins	*Cottidae*
Unidentified *Sebastomus*	*Sebastomus spp.*
Vermilion rockfish	*Sebastes miniatus*
Wolf-eel	*Anarrhichthys ocellatus*

Table 3-7. All fishes observed at bottom depths of 76–213 m near and over energized and unenergized cables and on natural habitats in southern California, 2012–2014. Density is in fish per 100 m^3. FO = frequency of occurrence (of 85 transects).

Common Name	Number	Density	Percent Abundance	FO
Halfbanded rockfish	4,154	9.1	42.9	59
Unidentified flatfishes	1,449	2.3	15.0	81
Stripetail rockfish	702	1.4	7.3	31
Unidentified poachers	596	1.2	6.2	75
Unidentified fishes	333	0.6	3.4	77
Shortspine combfish	312	0.6	3.2	61
Unidentified combfishes	284	0.6	2.9	71
Unidentified rockfishes	294	0.5	3.0	60
Greenstriped rockfish	208	0.4	2.1	53
Lingcod	182	0.4	1.9	59
Unidentified sanddabs	170	0.3	1.8	55
Unidentified eelpouts	183	0.3	1.9	34
Unidentified *Sebastomus* rockfishes	98	0.2	0.9	37
Longspine combfish	91	0.2	0.9	28
Greenspotted rockfish	61	0.1	0.6	21
Pacific argentine	53	0.1	0.5	19
Flag rockfish	38	0.1	0.4	17
Unidentified sculpins	61	0.1	0.6	21
California lizardfish	45	0.1	0.5	20
Pacific hake	53	0.1	0.5	7
Pink surfperch	45	0.1	0.5	21
Bigfin eelpout	39	0.1	0.4	18
Pygmy rockfish	26	0.1	0.3	2
Greenblotched rockfish	20	0.1	0.2	11
Bocaccio	27	<0.1	0.3	11
English sole	18	<0.1	0.2	14
Calico rockfish	19	<0.1	0.2	7
Cowcod	13	<0.1	0.1	11
Spotfin sculpin	11	<0.1	0.1	4
Vermilion rockfish	8	<0.1	<0.1	2
Copper rockfish	13	<0.1	0.1	3
Splitnose rockfish	10	<0.1	0.1	4
Unidentified pricklebacks	9	<0.1	<0.1	6
Swordspine rockfish	7	<0.1	<0.1	5
Blackbelly eelpout	8	<0.1	<0.1	3
Spotted ratfish	5	<0.1	<0.1	4
Wolf-eel	4	<0.1	<0.1	4
Pacific sanddab	4	<0.1	<0.1	3
Darkblotched rockfish	4	<0.1	<0.1	2
Bluebarred prickleback	3	<0.1	<0.1	2
Bearded eelpout	2	<0.1	<0.1	2
Treefish	2	<0.1	<0.1	2
Speckled sanddab	1	<0.1	<0.1	1
Bull sculpin	1	<0.1	<0.1	1
Threadfin sculpin	1	<0.1	<0.1	1
Icelinus sculpin	1	<0.1	<0.1	1
California smoothtongue	1	<0.1	<0.1	1
Unidentified cuskeel	1	<0.1	<0.1	1
California skate	1	<0.1	<0.1	1
Totals	**9,675**	**19.15**		**85**

Table 3-8. All fishes observed at bottom depths of 76–203 m over and near energized cables in southern California, 2012–2014. Density is in fish per 100 m^3. FO = frequency of occurrence (of 34 transects).

Common Name	Number	Density	Percent Abundance	FO
Halfbanded rockfish	2494	14.5	56.0	28
Unidentified flatfishes	430	1.8	9.7	30
Unidentified poachers	194	1.1	4.4	29
Stripetail rockfish	211	0.9	4.7	11
Shortspine combfish	147	0.7	3.3	28
Unidentified combfishes	136	0.7	3.1	30
Unidentified fishes	130	0.6	2.9	30
Unidentified rockfishes	118	0.5	2.6	25
Lingcod	96	0.5	2.2	30
Greenstriped rockfish	84	0.4	1.9	23
Unidentified sanddabs	74	0.3	1.7	19
Unidentified *Sebastomus* rockfishes	42	0.2	0.9	17
Longspine combfish	47	0.2	1.1	11
Flag rockfish	26	0.2	0.6	9
Pygmy rockfish	26	0.1	0.6	2
Pink seaperch	24	0.1	0.5	10
Greenspotted rockfish	19	0.1	0.4	8
Pacific argentine	15	0.1	0.3	7
Unidentified sculpins	25	0.1	0.6	9
Unidentified eelpouts	20	0.1	0.4	10
California lizardfish	16	0.1	0.4	6
Greenblotched rockfish	10	0.1	0.2	5
Spotfin sculpin	9	<0.1	0.2	3
Pacific hake	5	<0.1	0.1	2
Unidentified pricklebacks	7	<0.1	0.2	4
Cowcod	5	<0.1	0.1	5
Calico rockfish	7	<0.1	0.2	4
Swordspine rockfish	4	<0.1	0.1	3
English sole	5	<0.1	0.1	4
Bigfin eelpout	6	<0.1	0.1	3
Wolf-eel	3	<0.1	0.1	3
Spotted ratfish	3	<0.1	0.1	3
Bocaccio	3	<0.1	0.1	2
Bluebarred prickleback	3	<0.1	0.1	2
Dover sole	3	<0.1	0.1	2
Splitnose rockfish	2	<0.1	<0.1	2
Unidentified cuskeels	1	<0.1	<0.1	1
California smoothtongue	1	<0.1	<0.1	1
Icelinus sculpin	1	<0.1	<0.1	1
Treefish	1	<0.1	<0.1	1
Bull sculpin	1	<0.1	<0.1	1
Pacific sanddab	1	<0.1	<0.1	1
Totals	4,455	23.8	100.0	34

Table 3-9. All fishes observed at bottom depths of 104–213 m over and near unenergized cables in southern California, 2012–2014. Density is in fish per 100 m^3. FO = frequency of occurrence (of 29 transects).

Common Name	Number	Density	Percent Abundance	FO
Halfbanded rockfish	1,382	8.4	37.4	21
Stripetail rockfish	470	2.9	12.7	13
Unidentified flatfishes	459	2.2	12.4	29
Unidentified poachers	307	1.8	8.3	29
Unidentified rockfishes	149	0.9	4.0	22
Shortspine combfish	122	0.6	3.3	21
Unidentified fishes	110	0.6	3.0	27
Greenstriped rockfish	100	0.6	2.7	23
Unidentified combfishes	98	0.6	2.7	25
Lingcod	67	0.4	1.8	20
Unidentified sanddabs	49	0.3	1.3	19
Unidentified *Sebastomus* rockfishes	43	0.3	1.2	16
Greenspotted rockfish	37	0.2	1.0	10
Pacific hake	44	0.2	1.2	3
Pacific argentine	30	0.2	0.8	8
Longspine combfish	28	0.1	0.8	10
Bocaccio	22	0.1	0.6	8
Pink seaperch	17	0.1	0.5	8
Flag rockfish	11	0.1	0.3	7
Unidentified sculpins	20	0.1	0.5	6
Unidentified eelpouts	17	0.1	0.5	9
English sole	11	0.1	0.3	8
California lizardfish	11	0.1	0.3	7
Vermilion rockfish	8	0.1	0.2	2
Copper rockfish	13	0.1	0.4	3
Calico rockfish	12	0.1	0.3	3
Bigfin eelpout	9	<0.1	0.2	7
Cowcod	7	<0.1	0.2	5
Greenblotched rockfish	7	<0.1	0.2	4
Splitnose rockfish	8	<0.1	0.2	2
Blackbelly eelpout	5	<0.1	0.1	1
Spotted ratfish	2	<0.1	0.1	1
Swordspine rockfish	3	<0.1	0.1	2
Unidentified pricklebacks	2	<0.1	0.1	2
Darkblotched rockfish	3	<0.1	0.1	1
Dover sole	1	<0.1	<0.1	1
Threadfin sculpin	1	<0.1	<0.1	1
Treefish	1	<0.1	<0.1	1
Wolf-eel	1	<0.1	<0.1	1
Bearded eelpout	1	<0.1	<0.1	1
California skate	1	<0.1	<0.1	1
Pacific sanddab	1	<0.1	<0.1	1
Speckled sanddab	1	<0.1	<0.1	1
Totals	3,691	21.2	100.0%	29

Table 3-10. All fishes observed at bottom depths of 76–204 m over natural habitats in southern California, 2012–2014. Density is in fish per 100 m^3. FO = frequency of occurrence (of 22 transects).

Common Name	Number	Density	Percent Abundance	FO
Unidentified flatfishes	560	3.2	36.6	22
Halfbanded rockfish	278	1.7	18.2	10
Unidentified eelpouts	146	0.9	9.5	15
Unidentified poachers	95	0.7	6.2	17
Unidentified fishes	93	0.6	6.1	20
Unidentified combfishes	50	0.4	3.3	16
Unidentified sanddabs	47	0.3	3.1	17
Shortspine combfish	43	0.3	2.8	12
Unidentified rockfishes	27	0.2	1.8	13
Greenstriped rockfish	24	0.2	1.6	7
Bigfin eelpout	24	0.1	1.6	8
Stripetail rockfish	21	0.1	1.4	7
California lizardfish	18	0.1	1.2	7
Lingcod	19	0.1	1.2	9
Longspine combfish	16	0.1	1.0	7
Unidentified sculpins	16	0.1	1.0	6
Unidentified *Sebastomus* rockfishes	13	0.1	0.9	4
Pacific argentine	8	0.1	0.5	4
Greenspotted rockfish	5	<0.1	0.3	3
Pink seaperch	4	<0.1	0.3	3
Pacific hake	4	<0.1	0.3	2
Blackbelly eelpout	3	<0.1	0.2	2
Greenblotched rockfish	3	<0.1	0.2	2
English sole	2	<0.1	0.1	2
Bocaccio	2	<0.1	0.1	1
Pacific sanddab	2	<0.1	0.1	1
Spotfin sculpin	2	<0.1	0.1	1
Bearded eelpout	1	<0.1	0.1	1
Cowcod	1	<0.1	0.1	1
Darkblotched rockfish	1	<0.1	0.1	1
Flag rockfish	1	<0.1	0.1	1
Totals	1,529	9.4	100.0	22

Table 3-11. Effects of cable state (energized, unenergized), side of cable surveyed (W, E) nested in cable state, stratum group (1-4), and year (2012-2014) on invertebrate density tested using a generalized linear model (normal distribution, identity link), p<0.05. Densities were log(x+1) transformed. Cable State = energized or unenergized. Stratum groups are discussed under Results. * = statistically significant.

Taxon		Whole Model Difference	Cable State	Cable Side	Stratum Groups	Year
	DF	8	1	2	3	2
White-plumed anemone	X2	77.190	5.485	1.564	57.817	7.843
	p	<.0001*	0.019	0.458	<.0001*	0.020*
Spot prawn	X2	73.407	0.911	0.271	56.182	37.781
	p	<.0001*	0.340	0.873	<.0001*	<.0001*
Sea pen, thin	X2	93.957	0.009	66.213	46.116	9.299
	p	<.0001*	0.925	<.0001*	<.0001*	0.010*
California sea cucumber	X2	80.209	1.141	2.368	75.479	5.471
	p	<.0001*	0.285	0.306	<.0001*	0.065
Sand star	X2	45.971	12.983	0.960	4.591	24.452
	p	<.0001*	0.0003*	0.619	0.204	<.0001*
Red octopus	X2	27.199	0.019	14.847	10.446	0.003
	p	0.001*	0.889	0.001*	0.015*	0.999
Unidentified *Urticina* anemone	X2	75.522	5.480	1.954	58.734	4.900
		<.0001*	0.019	0.376	<.0001*	0.086
Black crinoid	X2	42.274	7.728	6.192	27.052	12.625
	p	<.0001*	0.005*	0.045	<.0001*	0.002*
White sea urchin	X2	11.896	1.430	7.024	2.203	3.951
	p	0.156	0.232	0.030*	0.531	0.139
Total invertebrates	X2	53.719	5.147	2.146	48.160	11.601
	p	<.0001*	0.023*	0.342	<.0001*	0.003*

Table 3-12. Common and scientific names of invertebrates observed at bottom depths of 76–213 m over energized and unenergized cables and natural habitats in southern California, 2012–2014.

Acanthogorgia gold corals	*Acanthogorgia spp.*
Basket star	*Gorgonocephalus eucnemis*
Bat star	*Asterina miniata*
Bat star/red sea star	*Asterina miniata/M. aequalis*
Brittle star	*Ophiopsila californica*
Brown box crab	*Lopholithodes foraminatus*
Buccinidae whelks	*Buccinidae*
California sea cucumber	*Apostichopus californicus*
Cancer crabs	*Cancer spp.*
Ceremaster cookie star	*Ceramaster spp.*
Christmas tree coral	*Antipathes dendrochristos*
Fish-eating anemone	*Urticina piscivora*
Fragile pink urchin	*Strongylocentrotus fragilis*
Henricia blood stars	*Henricia sp.*
King crab	*Paralithodes californiensis*
Leptasterias six-arm sea star	*Leptasterias spp.*
Linckia sea stars	*Linckia spp.*
Orthasterias rainbow stars	*Orthasterias spp.*
Painted urticina	*Urticina crassicornis*
Paragorgia sea fan (white with red polyps)	*Paragorgia spp.*
Parastichopus sea cucumbers	*Parastichopus spp.*
Psolus slipper sea cucumber	*Psolus spp.*
Ptilosarcus orange sea pens	*Ptilosarcus sp.*
Red gorgonian	*Leptogorgia chilensis*
Red octopus	*Octopus rubescens*
Red sea star	*Mediaster aequalis*
Sand Star	*Luidia spp.*
Sea pens thick	*Pennatulacea*
Sea pens thin	*Pennatulacea*
Sea slug	*Pleurobranchaea californica*
Serpula worms	*Serpula sp.*
Solaster sea stars	*Solaster sp.*
Spot prawn	*Pandalus platyceros*
Stylasterias fish-eating sea stars	*Stylasterias spp.*
Unidentified anemones	*Actinaria*
Unidentified brachiopods	*Brachiopoda*
Unidentified crabs	*Malacostraca*
Unidentified black crinoid	*Crinoidea*
Unidentified corals	*Hexacorallia/Octocorallia*
Unidentified gastropods	*Gastropoda*
Unidentified gorgonians	*Holaxonia*
Unidentified hydroids	*Hydrozoa*
Unidentified invertebrates	*Invertebrata*
Unidentified nudibranchs	*Opistobranchia*
Unidentified red sea fans	*Swiftia spp.*
Unidentified sea pen (thin)	*Pennatulacea*
Unidentified sea stars	*Asteroidea*
Unidentified sea urchins	*Echinoidea*
Unidentified sponges	*Porifera*
Unidentified tunicates	*Aplidium sp.*
Unidentified sunstars	*Pycnopodia/Rathbunaster*
Urticina anemones	*Urticina spp.*
Tube-dwelling anemones	*Cerianthidae*
White-plumed anemone	*Metridium farcimen*
White sea urchin	*Lytechinus pictus*

Table 3-13. All invertebrates observed at bottom depths of 76–213 m over or near energized and unenergized cables and natural habitats in southern California, 2012–2014. Density is in invertebrates per 100 m^3. FO = frequency of occurrence (of 85 transects).

Common Name	Number	Density	Percent Abundance	FO
White-plumed anemone	13,232	28.4	43.4	74
Spot prawn	4,407	9.8	14.4	21
Sea pen thin	5,582	9.4	18.3	82
California sea cucumber	1,610	3.1	5.3	73
Sand star	1,617	2.9	5.3	83
Red octopus	1,215	2.1	4.0	83
Unidentified *Urticina* anemone	388	0.8	1.3	50
Black crinoid	371	0.8	1.3	42
White sea urchin	451	0.6	1.5	11
Sea slug	243	0.5	0.8	69
Serpulid worms	173	0.4	0.6	23
Fragile pink urchin	176	0.4	0.6	11
Unidentified invertebrates	105	0.2	0.3	42
Tube dwelling anemones	128	0.2	0.3	36
Unidentified gorgonians	107	0.2	0.3	18
Fish-eating star	80	0.2	0.3	32
Cancer crab	80	0.1	0.3	37
Sea pen thick	77	0.1	0.3	21
Unidentified whelks	56	0.1	0.2	19
Unidentified sea stars	58	0.1	0.2	32
Bat star	65	0.1	0.2	19
Red sea fans	36	0.1	0.1	13
Painted *Urticina*	34	0.1	0.1	15
Unidentified corals	43	0.1	0.1	17
Fish-eating anemone	33	0.1	0.1	13
Brachiopoda	9	<0.1	<0.1	1
Unidentified anemones	19	<0.1	0.1	9
Sunstar	19	<0.1	0.1	13
Red sea star	18	<0.1	0.1	11
Slipper sea cucumber	8	<0.1	<0.1	4
Unidentified crabs	11	<0.1	<0.1	7
Basket star	9	<0.1	<0.1	5
Unidentified sea fans	6	<0.1	<0.1	2
Unidentified gastropods	10	<0.1	<0.1	2
Unidentified sponges	8	<0.1	<0.1	3
Unidentified hydroids	5	<0.1	<0.1	3
Blood star	4	<0.1	<0.1	4
Cookie star	2	<0.1	<0.1	2
King crab	3	<0.1	<0.1	3
Red gorgonians	3	<0.1	<0.1	3
Rainbow star	2	<0.1	<0.1	2
Brown box crab	2	<0.1	<0.1	1
Gold coral	1	<0.1	<0.1	1
Six-arm sea star	1	<0.1	<0.1	1
Christmas tree coral	2	<0.1	<0.1	2
Orange sea pen	2	<0.1	<0.1	2
Sea star	2	<0.1	<0.1	2
Unidentified sea urchins	2	<0.1	<0.1	1
Bat star/red sea star	2	<0.1	<0.1	2
Brittle star	1	<0.1	<0.1	1
Sun star	1	<0.1	<0.1	1
Unidentified nudibranch	1	<0.1	<0.1	1
Sea fan (white with red polyps)	1	<0.1	<0.1	1
Tunicate	1	<0.1	<0.1	1
Unidentified sea cucumber	1	<0.1	<0.1	1
Total Invertebrates	**30,523**	**61.0**	**100**	**85**

Table 3-14. All invertebrates observed at bottom depths of 76–203 m over or near energized cables in southern California, 2012–2014. Density is in invertebrates per 100 m^3. FO = frequency of occurrence (of 34 transects).

Common Name	Number	Density	Percent Abundance	FO
White-plumed anemone	5,347	29.8	39.9	34
Sea pen thin	3,311	13.5	24.7	31
Spot prawn	2,023	13.3	15.1	8
California sea cucumber	638	3.3	4.8	31
Sand star	569	2.7	4.3	33
Red octopus	379	1.7	2.8	33
Black crinoid	285	1.7	2.1	22
Unidentified *urticina* anemones	172	1.0	1.3	26
Sea slug	98	0.5	0.7	27
Serpulid worms	55	0.3	0.4	13
Unidentified invertebrates	47	0.3	0.4	16
Tube dwelling anemone	57	0.2	0.4	16
Unidentified gorgonians	51	0.2	0.4	9
Fish-eating star	38	0.2	0.3	18
Sea pen thick	41	0.2	0.3	11
Unidentified corals	29	0.2	0.2	10
Cancer crab	32	0.2	0.2	16
Red sea fan	20	0.2	0.1	6
Fragile pink urchin	20	0.1	0.1	3
Unidentified whelks	24	0.1	0.1	11
Painted *urticina*	18	0.1	0.1	7
Fish-eating anemone	18	0.1	0.1	5
Brachiopoda	9	0.1	0.1	1
Unidentified sea stars	17	0.1	0.1	13
Unidentified anemones	17	0.1	0.1	8
Bat star	12	0.1	0.1	9
Slipper sea cucumber	7	0.1	0.1	3
Unidentified crabs	7	<0.1	0.1	5
Unidentified gastropods	10	<0.1	0.1	2
Basket star	7	<0.1	0.1	4
Red sea star	7	<0.1	0.1	3
Unidentified sponges	6	<0.1	<0.1	1
Sunstar	4	<0.1	<0.1	4
White sea urchin	2	<0.1	<0.1	2
Brown box crab	2	<0.1	<0.1	1
Red gorgonian	2	<0.1	<0.1	2
King crab	1	<0.1	<0.1	1
Blood star	1	<0.1	<0.1	1
Sun star	1	<0.1	<0.1	1
Unidentified nudibranch	1	<0.1	<0.1	1
Paragorgia sea fan	1	<0.1	<0.1	1
Unidentified hydroid	1	<0.1	<0.1	1
Sea star	1	<0.1	<0.1	1
Totals	13,388	70.0	100	34

Table 3-15. All invertebrates observed at bottom depths of 104–213 m over or near unenergized cables in southern California, 2012–2014. Density is in invertebrates per 100 m^3. FO = frequency of occurrence (of 29 transects).

Common Name	Number	Density	Percent Abundance	FO
White-plumed anemone	7,671	47.3	52.5	29
Spot prawn	2,360	13.3	16.1	9
Sea pen thin	1,548	8.0	10.6	29
California sea cucumber	892	4.8	6.1	27
Sand star	790	4.1	5.4	29
Red octopus	339	1.8	2.3	28
Unidentified *urticina* anemones	213	1.4	1.5	21
Serpulid worms	115	0.8	0.7	8
Sea slug	97	0.6	0.7	26
Fragile pink urchin	83	0.5	0.6	5
Black crinoid	55	0.3	0.3	14
Unidentified gorgonians	56	0.3	0.3	9
Fish-eating star	42	0.2	0.3	14
Unidentified invertebrates	40	0.2	0.3	16
Cancer crab	40	0.2	0.3	17
Bat star	47	0.2	0.3	8
Unidentified sea stars	30	0.2	0.2	12
Tube dwelling anemone	34	0.1	0.2	10
Unidentified whelks	29	0.1	0.2	6
Painted *urticina*	15	0.1	0.1	7
Sea pen thick	14	0.1	0.1	6
Red sea fan	13	0.1	0.1	6
Sunstar	14	0.1	0.1	8
Fish-eating anemone	13	0.1	0.1	6
Unidentified corals	11	0.1	0.1	6
Unidentified sea fans	6	0.1	<0.1	2
Red sea star	9	0.1	0.1	6
White sea urchin	13	0.1	0.1	3
Unidentified hydroids	4	<0.1	<0.1	2
Unidentified crabs	4	<0.1	<0.1	2
Cookie star	2	<0.1	<0.1	2
Blood star	2	<0.1	<0.1	2
Unidentified anemones	2	<0.1	<0.1	1
Unidentified sponges	2	<0.1	<0.1	2
Rainbow star	2	<0.1	<0.1	2
Gold coral	1	<0.1	<0.1	1
Six-arm sea star	1	<0.1	<0.1	1
Unidentified sea urchins	2	<0.1	<0.1	1
Brittle star	1	<0.1	<0.1	1
Slipper sea cucumber	1	<0.1	<0.1	1
Red gorgonian	1	<0.1	<0.1	1
Tunicate	1	<0.1	<0.1	1
Christmas tree coral	1	<0.1	<0.1	1
Unidentified sea star	1	<0.1	<0.1	1
King crab	1	<0.1	<0.1	1
Bat star/red sea star	1	<0.1	<0.1	1
Totals	14,619	84.9	100	29

Table 3-16. All invertebrates observed at bottom depths of 76–204 m over natural habitats in southern California, 2012–2014. Density is in invertebrates per 100 m^3. FO = frequency of occurrence (of 22 transects).

Common Name	Number	Density	Percent Abundance	FO
Sea pen thin	723	4.9	28.7	22
Red octopus	497	3.2	19.6	22
White sea urchin	436	2.2	17.3	6
Sand star	258	1.5	10.3	21
White-plumed anemone	214	1.4	8.5	11
Fragile pink urchin	73	0.5	2.9	3
California sea cucumber	80	0.5	3.2	15
Sea slug	48	0.3	1.9	16
Black crinoid	31	0.2	1.2	6
Tube dwelling anemone	37	0.2	1.5	10
Spot prawn	24	0.2	0.9	4
Sea pen thick	22	0.1	0.9	4
Unidentified invertebrates	18	0.1	0.7	10
Unidentified sea stars	11	0.1	0.4	7
Cancer crab	8	0.1	0.3	4
Unidentified whelks	3	<0.1	0.1	2
Bat star	6	<0.1	0.2	2
Unidentified *urticina* anemone	3	<0.1	0.1	3
Serpulid worms	3	<0.1	0.1	2
Unidentified corals	3	<0.1	0.1	1
Red sea fan	3	<0.1	0.1	1
Basket star	2	<0.1	<0.1	1
Fish-eating anemone	2	<0.1	<0.1	2
Orange sea pen	2	<0.1	<0.1	2
Red sea star	2	<0.1	<0.1	2
Painted *urticina*	1	<0.1	<0.1	1
King crab	1	<0.1	<0.1	1
Blood star	1	<0.1	<0.1	1
Christmas tree coral	1	<0.1	<0.1	1
Sunstar	1	<0.1	<0.1	1
Sea cucumber	1	<0.1	<0.1	1
Bat star/red sea star	1	<0.1	<0.1	1
Totals	2,516	15.4	100	22

Table 3-17. Effect of cable side (energized and unenergized combined) on the densities of red octopus, thin sea pen, and white sea urchins. Depths distributions of strata groups are defined under Results in the text.

Red Octopus			
	Number	Mean Density	SD
Side			
West	21	0.95	0.62083
East	42	2.16	1.43992
Model	DF	X^2	p
Side Surveyed	1	14.460	0.0001
Sea Pen Thin			
	Number	Mean Density	SD
Side			
West	21	1.78	3.0911
East	42	15.56	13.5315
Model	DF	X^2	p
Side Surveyed	1	42.284	<.0001

The Department of the Interior

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

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The Bureau of Ocean Energy Management (BOEM) promotes energy independence, environmental protection, and economic development through responsible, science-based management of offshore conventional and renewable energy resources.

The BOEM Environmental Studies Program

The mission of the Environmental Studies Program (ESP) is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments.