

## ATOC/Pioneer Seamount cable after 8 years on the seafloor: Observations, environmental impact

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Received 14 April 2005; received in revised form 2 January 2006; accepted 25 January 2006

### Abstract

A study was conducted on the impacts of the presence of the Acoustic Thermometry of Ocean Climate (ATOC)/Pioneer Seamount cable on the benthos from nearshore waters adjacent to its origin at Pillar Point Air Force Station in Half Moon Bay, California to its terminus 95 km along its length on Pioneer Seamount. The coaxial Type SD cable was installed, unburied on the seafloor in 1995. Thirteen sites along the cable route were surveyed using the Monterey Bay Aquarium Research Institute (MBARI) ROVs *Ventana* and *Tiburón* equipped with cable-tracking tools. Quantitative comparisons of biological communities and seafloor features between cable and control sites were performed at nine stations. Forty-two hours of video footage and 138 push cores were collected over 15.1 km of seafloor. Approximately 12.1 km of the cable was observed (13% of the cable route).

This study documents the appearance and condition of the cable and the underlying seafloor, and the effects of the cable on biological communities along its route. Limited self-burial of the cable has occurred during the 8-year deployment, particularly over the continental shelf and upper slope. Cable strumming by nearshore wave action has incised rocky siltstone outcrops. Several observations of kinks and snags in the cable on the upper slope (~240 m depth) suggest contact with trawling gear.

Few changes in the abundance or distribution of benthic fauna were detectable from video observations (epifaunal) and sediment core samples (infauna). Of 17 megafaunal groups and 19 infaunal taxa, no tests evaluating the overall effect of the cable were statistically significant. While these results indicate that the biological impacts of the cable are minor at most, three megafaunal groups exhibited cable-related changes at one or more stations. Actinarians (sea anemones) colonized the cable when it was exposed on the seafloor, and were therefore generally more abundant on the cable than in surrounding, sediment-dominated seafloor habitats. Some fishes were also more abundant near the cable, apparently due to the higher habitat complexity provided by the cable. The study also documents general changes in the benthos across the Central California continental margin.

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**Keywords:** Submarine cables; Benthic biota; Environmental impact; ATOC; Continental margin; Sediments

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## 1. Introduction

Over the last century, millions of kilometers of seafloor submarine cables have been installed for telecommunications purposes. These cables are typically 2–8 cm in diameter and are able to transmit power and data over long distances. The telecommunications industry has built an extensive undersea network that interconnects the large urban centers of the world (Williams, 2000).

Interest in using subsea cables for scientific purposes is increasing. Scientists want to utilize the power and data transmission capability of underwater cables to develop seafloor observatories (Chave et al., 2004). A variety of coastal and marine scientific cabled observatories such as Leo-15 and H2O Hawaii have already been installed (e.g. Kasahara et al., 2000; Pettitt et al., 2002; Schofield et al., 2002) and others such as NEPTUNE (<http://www.neptune.washington.edu/>), VENUS (<http://www.venus.uvic.ca/>), and MARS (<http://www.mbari.org/mars/>) are in varying stages of development. Whereas the traditional mode of marine data collection consists of shipboard surveys, seafloor cables allow continuous data collection and transmission from instruments and experiments. High-frequency observations promise to improve our understanding of the ocean and could lead to major new discoveries regarding marine systems. Electric power supplied by cables also makes

new generations of seafloor instrument systems possible.

Submarine cable installation, maintenance, presence on the seabed, and removal affect the environment (Zajac, 1957; Horne, 2002). While burial assessment (BAS) and post-lay inspection and burial (PLIB) surveys are frequently conducted with the focus of documenting substrate type and cable burial, the information generated by these surveys is usually available only in obscure gray literature reports or in regulatory agency files. Few published studies exist on the interaction between cables and the marine environment (Andrulewicz et al., 2003; Heezen, 1957; Marra, 1989; Reiter and Deis, 2000; Sultzman et al., 2002).

Concern regarding impacts to the environment persist, thus there is a need to improve our understanding of the actual environmental impacts of submarine cables. This paper provides a case history of the effect of the coaxial Type SD Acoustic Thermometry of Ocean Climate (ATOC)/Pioneer Seamount cable on the benthic environment.

## 2. ATOC/Pioneer Seamount cable history

The ATOC/Pioneer Seamount submarine cable extends approximately 95 km between Pioneer Seamount and the Pillar Point Air Force Station in Half Moon Bay, California (Howe, 1996; Mercer, 1999; Fig. 1). The cable was installed for scientific

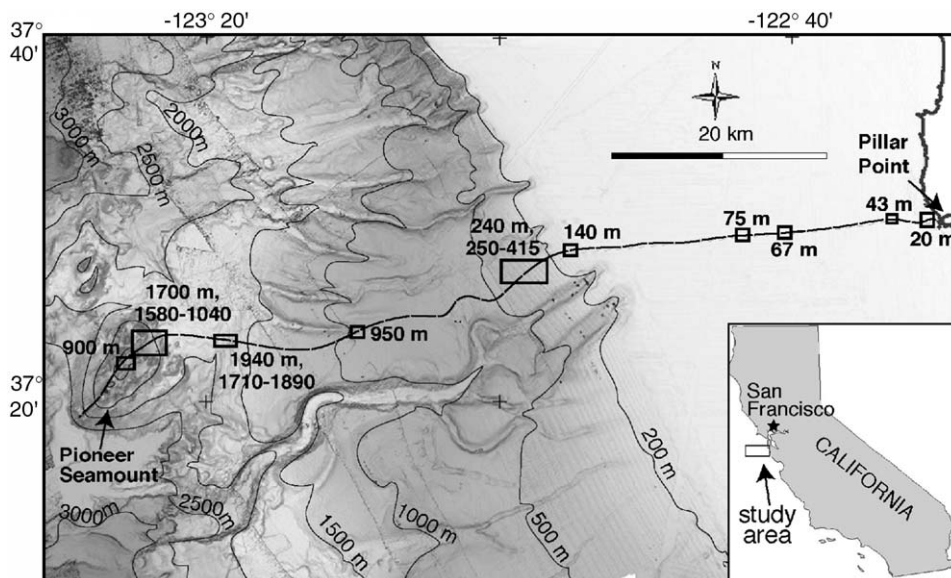


Fig. 1. Shaded relief map showing the location of the ATOC/Pioneer Seamount cable (dashed line) and the 13 survey locations (boxes). Basemap is courtesy of David Caress (MBARI).

research purposes in October 1995 as part of the ATOC project. Initially, the cable was connected to an acoustic projector and hydrophone on Pioneer Seamount for performing acoustic tomography in the North Pacific. In 2001, the National Oceanic and Atmospheric Administration division of Oceanographic and Atmospheric Research (NOAA-OAR) began using the cable for passive monitoring of ocean sound.

The cable (Fig. 2) consists of coaxial Type SD pieces spliced together from three previously used military cables (Howe, 1996). The 5.6 km section of cable extending from shore to 46 m water depth is double armored (6.6 cm outer diameter). The armor is tapered over a 15 m interval and the cable is unarmored (outside diameter of 3.2 cm) from the 46 m isobath to its termination on Pioneer Seamount (Mercer, 1999; Howe, 1996).

The shore terminus is in a maintenance building on a bluff within the Pillar Point Air Force Station. The cable extends from the maintenance shed along a conduit parallel to a drainage ditch terminating at the beach. The cable was buried 0.6 m below the beach during installation and was not buried from this location out to its termination on Pioneer Seamount. More modern cable installation practices involve cable burial on the shelf and upper slope. The cable path extends from shore across the 35 km broad continental shelf, descends the continental slope to a maximum depth of approximately 2000 m, and climbs back upslope to near the crest of Pioneer Seamount and onto where a NOAA hydrophone array is located at 998 m (Fig. 1).

The cable is currently damaged and has not been transmitting data from the seamount since September 25, 2002. This is the second failure in the cable's history. Based on calculations from time delay reflectometer (TDR) data, the damaged section is at

a location in 300–500 m water depth approximately 50 km along the cable from its shore termination (Mercer and Gullings, 2002, personal communication). The first failure and repair occurred in 1997 in 881 m water depth (Humphrey, 2003, personal communication).

### 3. Methods

#### 3.1. Side-scan sonar survey

Side-scan sonar data were collected from the MBARI R/V *Zephyr* on October 22–24, 2002 along the continental shelf portion of the cable route. Differential GPS navigated data were collected using a 100 kHz, single-frequency side-scan sonar imaging system (Klein<sup>®</sup> System 595). Two–four swaths covered a corridor around the cable's path that was 400–800 m wide. Five focused surveys ranging in width from 500 to 1.5 km wide and 1–2.5 km long were performed perpendicular to the cable path in areas of interest based on shipboard images of the along-cable surveys. The data were processed using Triton-Elics International Isis software and mosaiced to produce a backscatter image of the seafloor at a pixel resolution of 0.2 m.

#### 3.2. ROV surveys

Thirteen sites along the cable route were surveyed using ROVs during research cruises on February 10–14, 2003 and July 28–August 1, 2003. ROV locations were determined relative to the support ship using ultra-short baseline tracking systems, which measure range and bearing from the ship to the ROV. Quantitative comparison between cable and control sites was performed at nine stations. The remaining four sites were used for qualitative



Fig. 2. Photograph of a piece of cable similar to the ATOC/Pioneer Seamount cable. The 3.2 cm wide, coaxial Type SD cable has been cut open to expose interior sections. The cable has a copper inner conductor that contains steel wires, a white polyethylene insulating material, an outer copper sheath, and a black, high-density polyethylene jacket. Cable specification information from University of Washington (1995). Sample courtesy of UCSD-SIO.

information and are termed ‘video-only transects’. All stations were named by water depth. Four stations (43, 67, 70, 240 m) and one video-only transect (20 m) were studied on the February 2003 cruise from the MBARI R/V *Point Lobos* using the ROV *Ventana*. Six additional stations (140, 240, 950, 1800, 1930, seamount 900 m) and three video-only transects (250–415, 1040–1580, 1710–1890 m) were studied in July 2003 from the MBARI R/V *Western Flyer* using the ROV *Tiburón*. Survey locations were chosen to target representative substrate and habitat types (e.g. nearshore rock outcrops, continental shelf silt belt, sandy sediments), features of interest (e.g. location of cable fault, location of linear feature seen on side-scan sonar mosaic), and logistical reasons (e.g. avoiding crab pots, shipping lanes, hydrophone array on Seamount). ROV obstacle avoidance scanning sonar provided additional information on substrate variability.

Two different cable-tracking systems were utilized during these surveys to locate the cable and measure burial depth: an Innovatum Ultra 44 was installed on the ROV *Ventana* during the February 2003 survey and a TSS 350 was installed on the ROV *Tiburón* during the July 2003 cruise. Tone generators were connected to the shore end of the cable during each cruise and used to send a 25 Hz signal along the cable that was detectable by the cable-tracking apparatus installed on the ROVs. Cable burial depth measurement was recorded using both tools; however, the Innovatum tool provided consistent, reasonable readings whereas the TSS tool provided widely variable data with unreasonable values (e.g. 90 and 180 cm burial depth readings at one location while sitting on the seafloor in an area where the cable was exposed). Mechanical problems with the energy converter powering the Innovatum Ultra 44 cable tracker tool prevented collection of burial depth information at the 240 m station. Thus, length of buried cable was determined for all stations but average burial depth was determined only for the 43, 67, and 75 m stations.

To compare the impact of the cable on epifaunal and infaunal organisms, video, digital still images and shallow sediment cores were collected along transects near (<1 m) and distant (~100 m) from the cable. Transect lengths at sites where cable and control data were collected ranged from 30 to 870 m with most transects 200–500 m long. Video-only transects ranged from 1321 to 3547 m. A cable tracker was used to locate and follow the cable

where the cable was buried. The ROV landed on the seafloor to measure the depth of cable burial at haphazardly selected locations along the cable route at each station. If the substrate was soft sediment, push cores up to 20 cm long were collected at most ROV landing locations.

Forty-two hours of video footage were analyzed post-cruise to assess potential effects of the cable on the seafloor and seafloor biological community. The abundance and location (i.e. latitude, longitude) of all epifaunal animals large enough to be seen in video images were noted. Taxonomic identification was performed to the lowest practical taxonomic level. For each station, the cable and control video transects were subdivided into 30 m<sup>2</sup> bins to describe organism variability within each transect and analyze the distribution of animals. Organisms were grouped into the following taxa: Porifera, Cnidaria (Actiniaria, Cerianthidae, Alcyonacea, Gorgonacea, Pennatulacea), Mollusca (Gastropoda, Bivalvia), Arthropoda (Decapoda, Isopoda, Maxillopoda), Ectoprocta, Echinodermata (Asterozoa, Ophiurozoa, Asterozoa, Gorgonocephalidae, Crinozoa, Echinozoa, Holothurozoa), and Chordata (Vertebrata). Drift kelp was also counted along each video transect. Mean abundances of each group were determined for each transect.

Comparisons of the abundance of each faunal group between cable and non-cable areas were performed using nested analysis of variance, *t*-tests (paired or unpaired), or a non-parametric *t*-test alternative (Kruskal–Wallace). Selection of the appropriate test was determined by the compliance of data distributions of each group to the assumptions of parametric statistics. Heteroscedasticity was assessed using *F*-tests between groups. Data transformations [ $\log(X)$  square root ( $X$ ), or square root (square root ( $X$ ))] were applied to reduce heteroscedasticity. If *F*-tests remained significant, non-parametric alternatives were used to compare cable and control sites. Normality of data groups was assessed using quantile tests, which frequently indicated significant departures from normality (Lilliefors test; Systat 11), owing to the large number of zero abundance observations for cores or transect sections. Because non-normality is less problematic for parametric statistics than heteroscedasticity (Zar, 1984), data groups with non-normal distributions were analyzed using parametric tests, unless other criteria excluded those tests. Analyses for each faunal group included only

stations (but not replicates) where faunal abundance was non-zero. Nested ANOVA was used for faunal groups where the variance in abundance was similar among stations. Paired *t*-tests of means within stations were used to compare groups with highly heterogeneous variances among stations, but similar variances between control and cable treatments. Non-parametric *t*-tests were used for groups with highly heterogeneous variances using any data transformation. Comparisons of the abundance of epifaunal between-cable and control treatments at individual stations were performed using paired *t*-tests or non-parametric alternatives, depending on data distributions as above. Bonferroni adjustments of significance levels were applied due to the high number (81) of tests performed.

Analysis of percentage cover of fauna was used to detect differences in biotic and physical features near and distant from the cable. A mean percentage cover of all faunal categories was determined from 20 randomly chosen still video images at each station, except the 1930 m station. Due to the short transect lengths at the 1930 m station, four still frames were analyzed from the cable transect and 16 from the control. A  $48 \times 66 \text{ cm}^2$  region of interest (ROI) was determined for each still frame using the

ROV lasers as a scale for distance. The random point contact method was used for data analysis (Coyer et al., 1999; Foster et al., 1991).

To evaluate the impact of the cable on infaunal organisms, the abundances of all identifiable infaunal organisms were determined from a total of 138 push cores collected at all stations. The top 5 cm from each 7 cm diameter core was gently washed through a 0.3 mm mesh sieve using cold seawater. Organisms were preserved in a 4% formaldehyde (10% formalin) solution for several days and then stored in 70% ethanol. Organisms were sorted to the lowest practical taxonomic category. The number of taxa was estimated based on obvious morphological characteristics. Comparisons of both the number of taxa or number of individuals of each taxon per core were made using the statistical approach described above for epifaunal organisms.

## 4. Results

### 4.1. Side-scan sonar data

One hundred and fifty kilometers of side-scan imagery was collected from 14 to 120 m water depths. Image quality was good from water depths

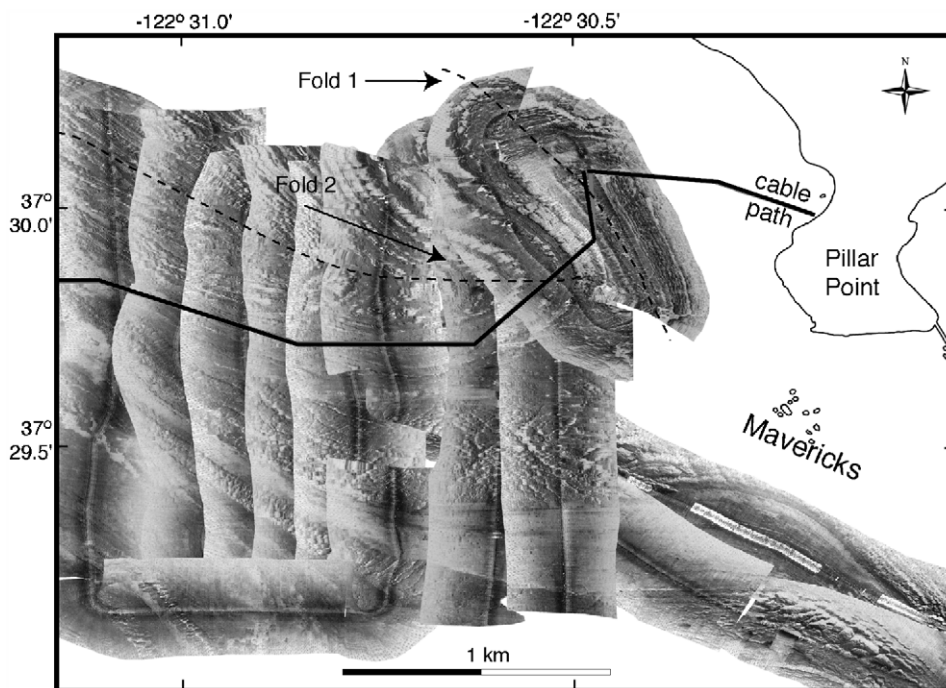


Fig. 3. Side-scan sonar mosaic of the seafloor west of pillar Point showing curving backscatter patterns interpreted as three plunging folds in strata. Dashed lines trace fold axes. Locations of the cable path (solid line) and Maverick's surfing site are indicated. Angularity of cable path is an artifact of connecting waypoints.

less than 80 m and deteriorated with increasing depth. No entanglements with the cable large enough to be resolved by side-scan sonar imagery were seen. The majority of the survey area extending from 37 to 120 m water depth west of  $122^{\circ}32'00''$  was typified by bland sonargrams. In contrast, nearshore side-scan imagery within  $\sim 6$  km of shore along the cable path west of Pillar Point, where rock outcrops occur, show distinct reflection patterns of broadly undulating substrate (Fig. 3). The 1169 m section of cable surveyed at the 20 m station was within this rocky nearshore zone.

#### 4.2. Physical observations

##### 4.2.1. Cable location

The cable was located and tracked visually and with cable-tracking tools. The cable was found 15–975 m away from its reported position during these ROV surveys (Howe, 1996). A 330 m long, linear backscatter feature (Fig. 4) was imaged in 43 m water depth parallel to and 20–40 m south of the cable's reported position. This feature is located seaward of the undulating seafloor patterns described above, and is probably associated with the ATOC/Pioneer Seamount cable. Cable tracker data from the 43 m station confirms that the cable is located in the same area. The linear feature is not an imaging artifact of the data since it was imaged on two different swaths collected from two different directions. ROV video observations show that at least a portion of the cable's steel armor has unraveled in this location.

##### 4.2.2. Condition of cable

Damage to the cable and kelp snagged on the cable were observed at the 20 and 43 m stations.

Evidence of damage at the 20 m station includes parting of the steel cable armor and fraying or unraveling of underlying polypropylene layers (Figs. 5A and B). Kelp debris was frequently intertwined with frayed cable at both stations. Only one instance of kelp on the seafloor was annotated in the 43 m station control transect.

Twelve distinct kinks (Fig. 6B) and 14 lower angle bends were seen in a white cable at the 240 m station. Two of the kinks were tight ( $\sim 90^{\circ}$ ) and were located approximately 350 m apart. The apices of these kinks were exposed and slightly suspended, whereas the apices of the low-angle bends were frequently buried.

##### 4.2.3. Burial data

Although the cable was not buried during installation, substantial sections of the cable have undergone self-burial (Table 1; Figs. 6A and 7B). The percentage of the cable burial was high ( $91 \pm 16\%$  (mean  $\pm 1\sigma$ ;  $n = 3$ )) at sediment-dominated stations on the continental shelf ( $< 120$  m water depth). Mean burial depth was  $11 \pm 7$  cm ( $n = 30$ ) and ranged from 0 cm (exposed on the seafloor) to 27 cm. The 43 m station was characterized by sand waves, with the cable exposed in troughs and buried under the crests. The cable was buried entirely beneath rippled, unconsolidated substrates at the 67 and 75 m stations (Fig. 5E). Percentage burial at stations between 140 and 950 m depth ranged from 37% to 83% (mean =  $61 \pm 19\%$  ( $n = 4$ )). The cable was exposed in local bathymetric depressions and over rock slabs. The cable was wholly exposed west of the 950 m station and over rocky substrata at both the 20 m station and on Pioneer Seamount (Figs. 5A–D, 6D–F).

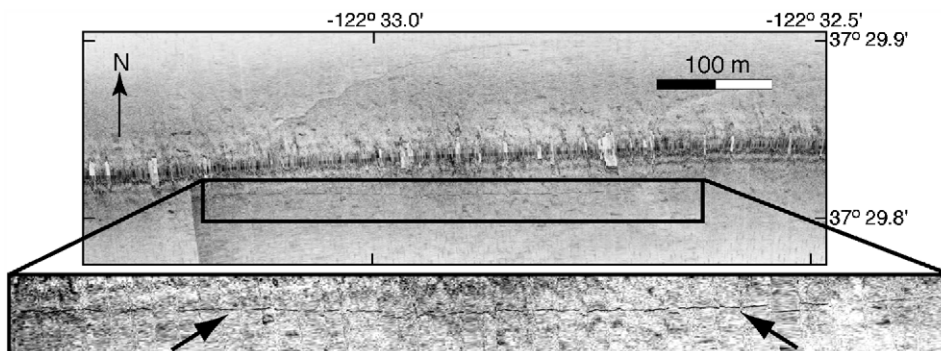


Fig. 4. Side-scan sonar image showing a linear backscatter feature that is likely associated with the ATOC/Pioneer Seamount cable. Linear feature is magnified in inset box. Arrows point to the linear backscatter feature.

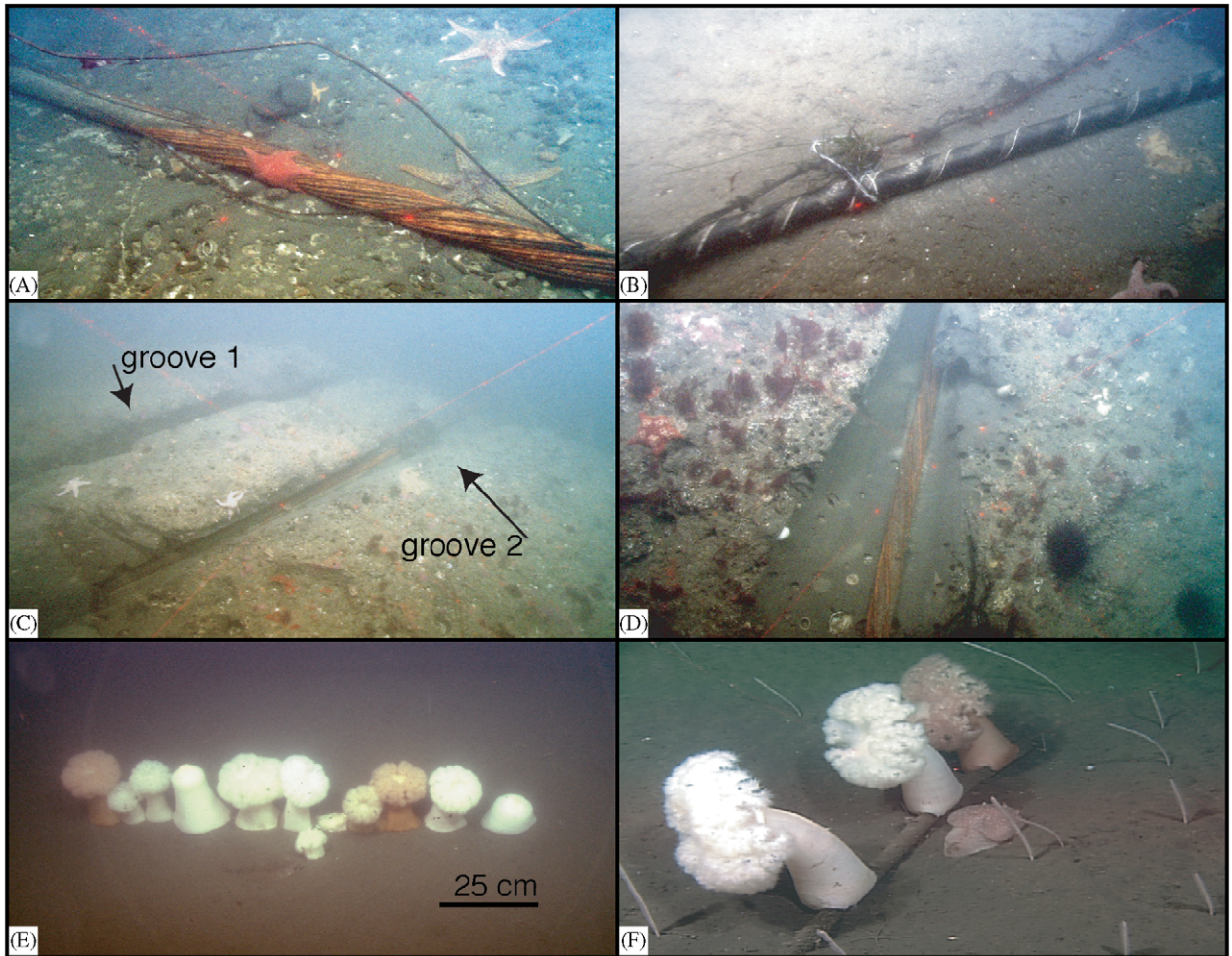


Fig. 5. Video images of the ATOC/Pioneer Seamount cable at selected sites on the continental shelf are shown. Red dots and/or lines are laser beams. The cable is double-armored (6.6 cm wide) in images (A)–(D) at the 20 m station and is unarmored (3.2 cm wide) in images (E) (75 m station) and (F) (140 m station). Substrate in images (A)–(D) is siltstone (likely Purisima Formation) and is unconsolidated sandy silt in images (E) and (F). (A) Photograph showing loose steel that has separated from the cable's armor in 14 m of water. (B) Photograph showing unraveling polypropylene cable material. The outer steel armor appears missing at this site in 15 m water depth. (C) Photograph showing two parallel grooves in the rock with the cable lying in groove 2 in 10 m water depth. (D) Photograph showing a cone-shaped groove apparently generated by cable strumming in 10 m of water. The incision is approximately 40 cm wide at the bottom of this image. (E) Photograph showing a line of *Metridium farcimen* colonizing the cable in 72 m of water. A cable-tracking device verified the cable's position. (F) Photograph showing three *M. farcimen* positioned directly on the cable in 134 m of water. The abundant, thin, white organisms are seapens (*Halipteris* sp.).

#### 4.2.4. Effects on substrate

At shallow water depths where wave action likely shifted the cable, several features were indicative of its interaction with the seafloor environment. The cable was incised into rock outcrops in 12 locations at the 20 m station. Incisions varied in depth from surficial scrapes to vertical grooves (Figs. 5B–D). Groove width ranged from 6.6 cm (diameter of double-armored cable) to 45 cm wide. At all other depths, there was little evidence of effects of the cable on the seafloor, regardless of cable exposure.

One exception to this pattern was our observation of a subtle, 13 cm wide, surficial furrow within a patch of sediment near the crest of Pioneer Seamount (924 m depth).

#### 4.2.5. Cable suspensions

The cable was suspended off the seafloor in both rock and unconsolidated sediment substrates. The most notable suspensions were in rocky areas with irregular bathymetry. Suspensions up to 40 m long and greater than 1 m high were observed in the

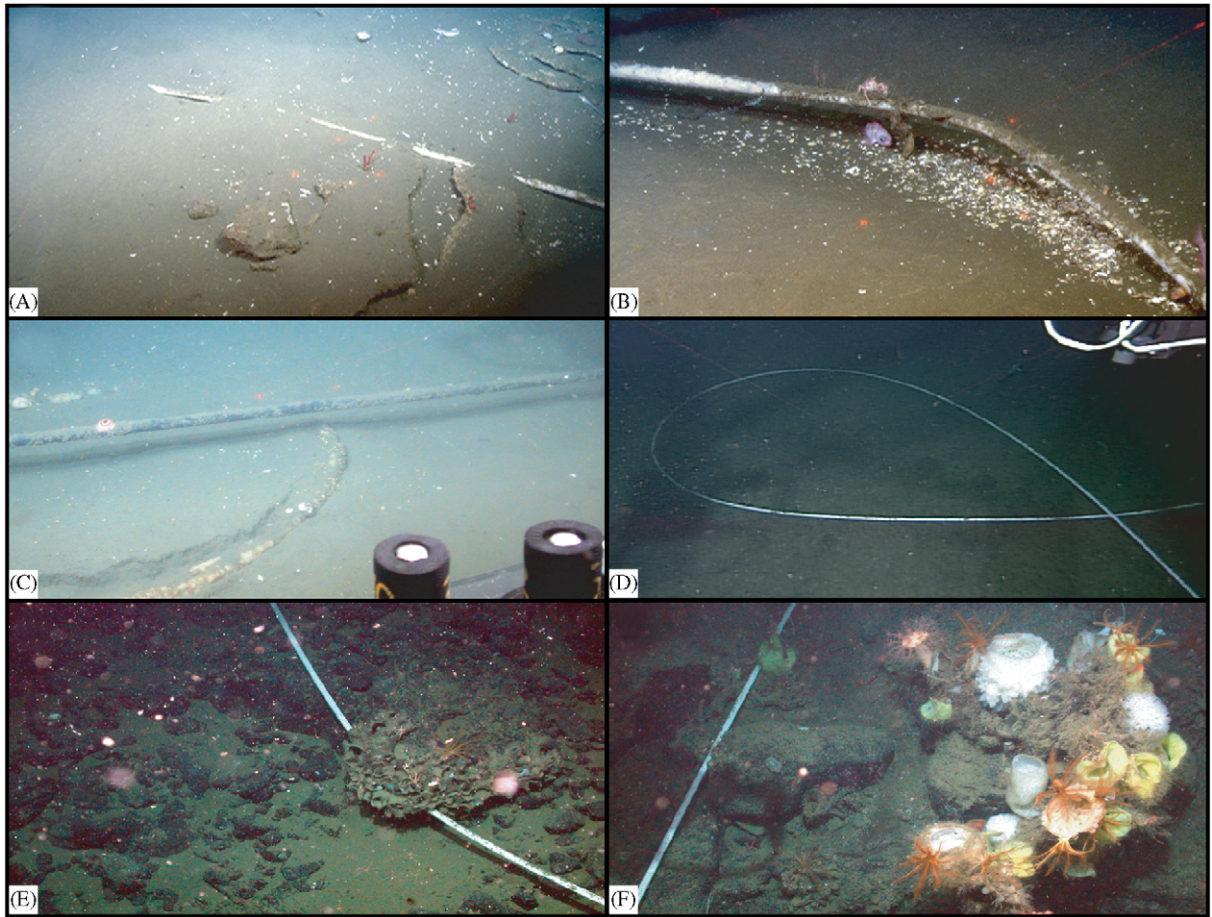


Fig. 6. Video images are shown of the ATOC/Pioneer Seamount cable at selected sites from the continental slope, deep sea, and Pioneer Seamount. Unconsolidated sediment is intermittently present in image (A) and is the substrate in images (B)–(D). Rocks sampled from Pioneer Seamount (images (E) and (F)) consisted of vesicular basalt, volcanic sandstone, and volcanoclastic breccia with Mn crusts. Red dots and/or lines are laser beams. The cable is 3.2 cm wide. (A) Photograph showing the cable intermittently buried in fine-grained sediments among flat-lying rock slabs in 237 m of water. Four  $\delta^{13}\text{C}$  measurements were made on the rock slabs yielding values ranging between  $-18.37$  and  $-22.31$   $\delta^{13}\text{C}$  (PDB) indicating that the slabs are cemented with methane-derived carbonates. (B) Photograph showing a sharp kink in a short cable suspension in 220 m of water. Shell hash is concentrated in proximity to the cable and a *Sebastes* sp. (rockfish) is seen underneath the cable. (C) Photograph showing the ATOC/Pioneer Seamount cable crossing over a second cable that may be the 1903 San Francisco–Hawaii Telegraph cable. Location of crossing occurs in 344 m water depth. The identity of the black cable as the ATOC/Pioneer Seamount cable was verified using the cable-tracking apparatus. (D) Photograph showing a flat-lying loop in the cable in a trough between outcrops on the side of Pioneer Seamount in 1328 m of water. (E) Photograph showing the cable bent under a porifera (sponge) attached to a rock in 1485 m water depth. Note shadow below the cable indicating a suspension. (F) Photograph showing the cable adjacent to a cluster of porifera, *Florometra serratissima* (crinoids), and *Anthomastus ritteri* (mushroom coral) in 1160 m water depth on Pioneer Seamount.

nearshore rocky area at the 20 m station and up to 25 m long and 2 m high on Pioneer Seamount. Short ( $\sim 10$  cm) suspensions bridged low spots associated with irregular topography in sediment substrate areas and were particularly common at the 240, 250–415, and 950 m stations (Figs. 6B and C). The cable conformed to the bathymetry where slack cable was present.

#### 4.2.6. Cable loops

The cable path was generally sinuous; however, the cable crossed itself at the 950 and 1580–1040 m stations. Five nearly flat-lying loops were observed at the 950 m station and one flat-lying loop was observed at the 1580–1040 m transect (Fig. 6D). No entanglements of any objects with the cable loops were seen.

Table 1  
Data collected from survey stations along the ATOC/Pioneer Seamount cable route

Station	Water depth range (m)	Mean burial depth (cm)	Transect length (m)		# of video bins		# of push cores	
			Cable	Control	Cable	Control	Cable	Control
20	10–20	n/a	1170	0	39	0	0	0
43	42–44	12 ± 8	360	210	12	7	9	10
67	66–68	9 ± 6	360	210	12	7	10	10
75	73–75	13 ± 6	240	390	8	13	9	11
140	134–145	n/a	690	660	23	22	10	10
240	229–246	n/a	330	600	11	20	5	5
250–415	250–415	n/a	3547	0	118	0	0	0
950	947–960	n/a	420	510	14	7	10	10
1710–1890	1710–1890	n/a	1321	0	44	0	0	0
1940	1930–1958	n/a	30	90	1	3	5	5
1700	1610–1811	n/a	870	180	29	6	5	5
1040–1580	1040–1580	n/a	2296	0	77	0	0	0
900	900–930	n/a	180	210	5	7	5	5

#, number; n/a, data not available.

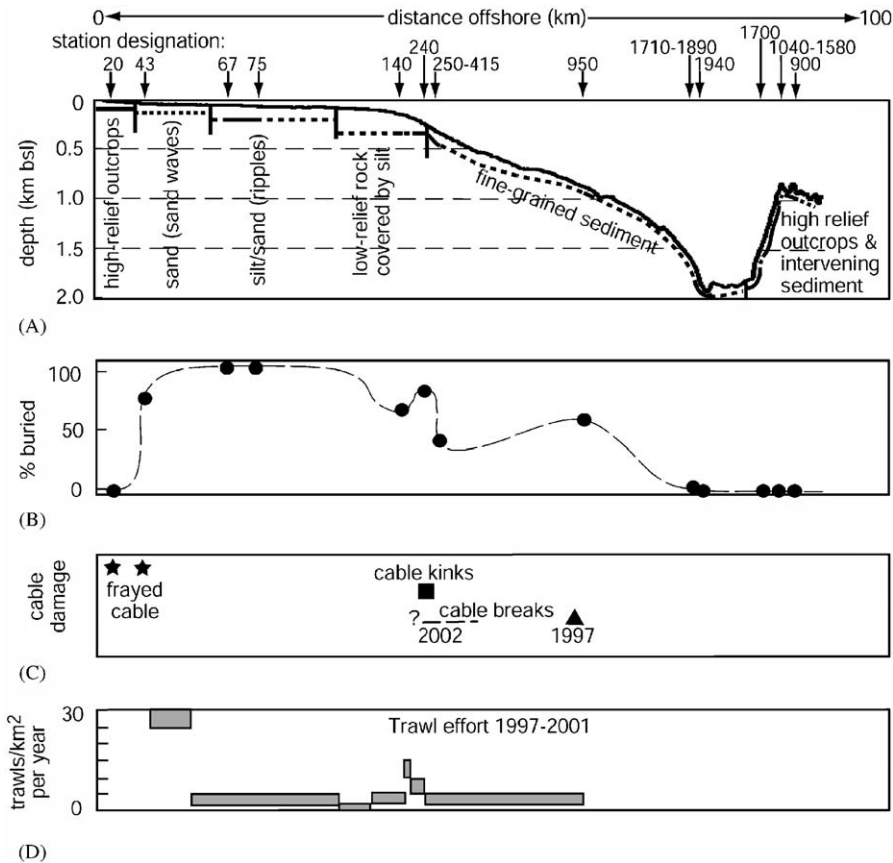


Fig. 7. Plots showing the depth profile and substrate description (A), percent cable burial (B), cable damage locations (C), and trawl effort (D) with distance offshore. Arrows indicate station locations and plot in the center of each station. (A) Depth profile along the cable path from shore to its termination on Pioneer Seamount is shown. Map view of the cable path is seen in Fig. 1. Substrate information is schematic and photographs of selected sites are shown in Figs. 5 and 6. Dashed lines are drawn where seafloor type is inferred. (B) Graph of buried cable length versus distance offshore is shown. Data points are plotted in the center of each transect. (C) Locations of areas where cable damage was observed are indicated. The exact location of the 2002 cable break is unknown. (D) Mean trawl effort along the cable path is indicated. Eastern limit of trawling in this area is the California state water boundary (3 nautical miles from shore). Approximate western limit of trawling is 1000m water depth. Data provided by Janet Mason, 2004, personal communication.

#### 4.2.7. Cable crossings

The ATOC/Pioneer Seamount cable crossed above other seafloor cables at two locations during the ROV survey. Cable crossings were seen in 13 m water depth at 37°29'50"N, 122°33'04"W and in 344 m water depth at 37°29'54"N, 122°30'30"W (Fig. 6C). Although the identities of the other cables were not confirmed, the 1903 San Francisco–Honolulu Telegraph (SFHT) cable is known to be located near the ATOC/Pioneer cable in ~344 m depth. While the reported location of the SFHT cable is 1 km south of the observed crossing (Wilson, 2002, personal communication), it is potentially the SFHT cable considering the imprecise navigation available during its installation in the early 1900s.

#### 4.2.8. ROV scanning sonar

The cable was generally not detectable using the forward-looking ROV-mounted scanning sonar. However, several long linear shadows generally oriented perpendicular to the cable path were imaged at the 950 m station, a location proximal to the 1997 cable break. These features were believed to result from subtle seafloor scours approximately 1–2 m wide. Such features are commonly attributed to 'otter boards' of seafloor trawling gear.

### 4.3. Effects of ATOC cable on seafloor biota

#### 4.3.1. Epifauna

Epifaunal assemblages were generally similar between cable and nearby control areas. Brittle stars (Ophiuroidea), anemones (Actiniaria), sea pens (Pennatulacea), *Anthomastus ritteri* and gorgonians (Alcyonaria), and sponges (Porifera) were the most abundant epifaunal groups, accounting for 84.2% of total epifaunal abundance (Fig. 8). Epifaunal abundances varied considerably among sites, especially on the continental shelf, where faunal abundances ranged from a mean of 1 organism per 30 m<sup>2</sup> bin at the 43 m station to 726 organisms per 30 m<sup>2</sup> bin at the 67 m station. Brittle stars were the most abundant continental shelf taxon. The seapen *Halipteris californica* dominated the shelf/slope break region (140 m station) and urchins *Allocentrotus fragilis* dominated the 240 m station. Deeper sites (250–415, 950, 1710–1890, and 1940 m) were characterized by large numbers of Actiniaria. The major taxa on Pioneer Seamount were Actiniaria, *A. ritteri* (mushroom coral),

gorgonians, the crinoid *Florometra serratissima*, and large sponges.

Although the effects of the cable over the entire length were non-significant ( $p > 0.05$  for cable effect tests over the entire length) for all major epifaunal taxa (Table 2), the abundance of a few taxa differed among cable and control areas at some stations. Only six of 81 comparisons of the abundances of major epifaunal taxa at individual stations indicated significant differences between cable and control treatments (Fig. 8). Notably, Actiniaria were commonly more abundant ( $p < 0.05$ ) where the cable was exposed on the seafloor at sediment-dominated stations (paired *t*-test for sediment-only stations:  $t = 3.8$ ,  $p < 0.001$ ) than at adjacent control areas. Actiniaria were significantly ( $p < 0.05$ ) greater in abundance near the cable at four stations (75, 140, 240, 950 m), accounting for most of the cable-related effects on the epifaunal assemblage. At such stations, anemones, which live almost exclusively on hard surfaces, colonized the cable itself, but were usually absent from the surrounding sediment or nearby sediment-dominated control areas. Although this was the most striking association of epifaunal taxa with the cable, Actiniarians did not differ among control and cable transects at five other stations, indicating that the effects of the cable are restricted among stations. Fishes, especially flatfishes (Pleuronectiformes), were significantly more abundant near the cable at two shallow stations (43, 75 m) where they appeared to prefer the structurally more heterogeneous habitat near the cable than the smooth bottom at the control area for each of these stations. Fishes were present at seven additional stations, but their abundance at these stations did not differ between cable and control transects. The abundance of sea cucumbers (Holothuroidea), a minor element of the seafloor fauna, was lower near the cable than along the control transect at the 1700 m station, but did not differ among treatments at five other stations inhabited by holothurians. No other significant variation in epifaunal (or drift kelp) abundance was detected between cable and control transects.

#### 4.3.2. Percent cover analysis

Few differences were detected between cable and control sites in the percent cover analysis. The mean cover of shell hash was greater ( $p < 0.05$ ) along the cable than the adjacent control area at the 43 m station, perhaps related to the hydrodynamic effects of the cable. The percentage cover of sediment in the

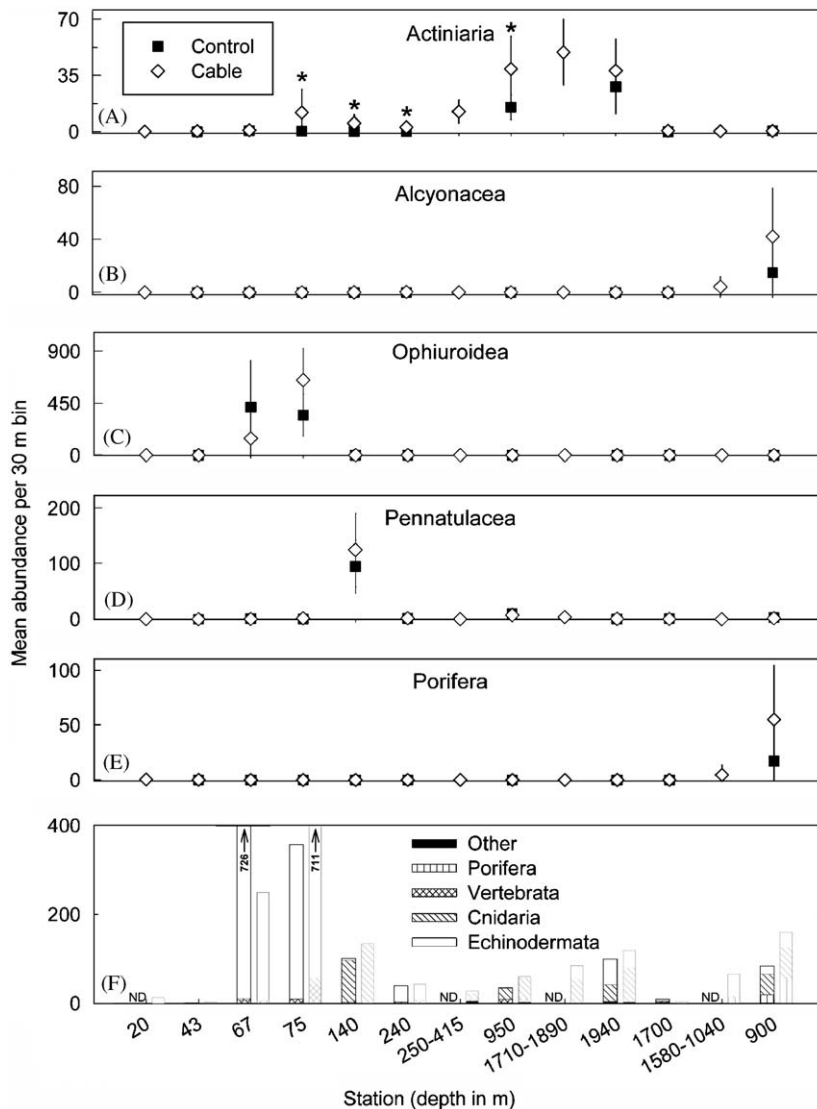


Fig. 8. Epifaunal video transect data as a mean/30m bin for each station. (A) The abundance of Actiniarians (anemones), was significantly (\*) higher on the cable transects at 75, 140, 240 and 950 m when compared to the control transects. (B) Alcyonacea (*A. ritteri* and gorgonians) were abundant on the seamount at 900 m. (C) Ophiuroidea were abundant on the continental shelf (67, 75 m). (D) Dense fields of Pennatulacea (sea pens) were seen at 140 m. (E) Porifera (sponges) were highly abundant on the seamount at 900 m. (F) Echinoderms were the most abundant organisms along the route, followed by Cnidrians (anemones and sea pens). Control transect data are shown on the left, cable transect data on the right. Error bars = St dev., ND = no data available.

240, 950, 1940, 1700, 900 m stations was lower in cable transects, due only to the cable occupying space on the seafloor. Although there was a statistically lower percentage cover of ripple marks along the cable at both the 67 and 75 m stations, this result appears to be an artifact related to greater ROV height above the seafloor and greater turbidity during the cable transects, rather than any affect of the cable on ripple formation.

#### 4.3.3. Infaunal organisms

Polychaete worms, nematodes, and amphipod crustaceans accounted for the majority of infaunal abundance along the ATOC/Pioneer Seamount cable route (Table 3; Fig. 9A). Polychaetes, with up to 33 taxa per station, were by far the most diverse group infaunal taxon (Fig. 9B).

Although infaunal groups were abundant at all sediment-dominated sites, their abundance and

Table 2

Comparison of epifaunal cumulative mean abundance between cable and control data over all the sites indicates no significant differences ( $p > 0.05$ )

Taxon	Cable		Control		<i>F</i> (treatment)	<i>p</i> -value	<i>n</i>
	Mean #/m <sup>2</sup>	SD	Mean #/m <sup>2</sup>	SD			
Actiniaria	11.26	18.01	3.56	8.36	1.73	0.21	9
Alcyonaria	1.48	7.41	0.94	5.15	0.08	0.8	2
Asteroidea	2.98	4.34	2.19	2.52	0.09	0.77	9
Bivalvia <sup>a</sup>	0.02	0.26	0.01	0.10			1
Cerianthidae	0.01	0.09	0.05	0.21	1.6	0.28	3
Crinoidea <sup>b</sup>	0.78	2.34	0.33	1.76		0.87	4
Decapoda	1.00	6.05	0.47	0.81	0.26	0.61	9
Echinoidea	1.44	7.26	5.76	14.97	0	0.96	2
Ectoprocta <sup>a</sup>	0.02	0.19	0.00	0.00			1
Gastropoda	0.14	0.46	0.08	0.43	0.89	0.38	4
Holothuroidea	3.41	11.02	2.31	8.79	0.09	0.77	6
Isopoda <sup>a</sup>	0.00	0.05	0.01	0.10			1
Ophiuroidea <sup>b</sup>	19.88	106.05	87.19	214.76		0.98	4
Pennatulacea	7.81	32.52	21.26	42.74	0.33	0.57	8
Porifera <sup>b</sup>	1.82	9.59	1.11	7.84		0.28	3
Vertebrata	3.81	8.10	3.65	4.44	0.19	0.67	9
Kelp	0.11	0.39	0.06	0.28	0.12	0.74	7

*n* = number of stations in which the taxon group was present.

<sup>a</sup>Insufficient data for *t*-test.

<sup>b</sup>Paired *t*-test.

diversity varied little among control and cable samples throughout the cable route (Tables 3 and 4). No significant differences were detected for overall comparisons of cable effects for 24 infaunal groups. Nor did comparisons of the abundance of infaunal organisms at each station detect effects of the cable on faunal abundance or diversity. Of 101 *t*-tests, comparisons of the abundance and diversity of 24 infaunal groups at individual stations, none were statistically significant, indicating that the effects of the cable on infaunal biotic assemblages are undetectable or negligible.

## 5. Discussion

### 5.1. Causes of cable damage and substrate alteration

Damage to the cable and abrasion of rock outcrops by cable strumming occurred at nearshore stations (Figs. 5A–D). The shore crossing of the ATOC/Pioneer Seamount cable is located less than 1 km from ‘Mavericks’, a world-class surfing location off Pillar Point, where breaking waves greater than 10 m occur (Fig. 3). The observed rock incisions indicate that the cable has strummed. Additionally, multiple grooves in a single location

indicate that the cable shifted position with time. The rock outcrops are likely of the Purisima Formation, a poorly consolidated marine siltstone of Pliocene age. Apparently, the high wave energy in this area has caused the cable to strum and resulted in abrasion to both rock and cable.

In the nearshore rocky region, incisions into rock substrate and damage to the cable’s exterior were only observed over topographic highs and in areas of cable suspensions. The undulating backscatter pattern imaged in the side-scan sonar data is interpreted as folded beds within the strata (Fig. 3). Suspensions occur between exposed rock ledges. Side-scan sonar data indicated that the relief of the ledges diminishes seaward until outcrops become sediment covered 2.5 km west of Pillar Point. Thus, nearshore suspensions become less frequent and smaller to the west, and the resulting rock incisions also diminish to the west.

Frayed material observed on the cable at the 43 m station, as seen at the 20 m station, reflects damage to the cable’s armor that probably resulted from seafloor abrasion during high-energy events. However, unlike the nearshore rocky area, the 43 m station is characterized by sediment-dominated substrate (Fig. 7A). The presence of sand waves

Table 3

Comparison of cumulative infaunal mean density between cable and control data over all the sites indicates no significant differences ( $p > 0.05$ )

Taxon	Density per core				<i>F</i> (treatment)	<i>p</i> -value	<i>n</i>
	Cable		Control				
	Mean #/core	SD	Mean #/core	SD			
Amphipod <sup>a</sup>	5.51	10.07	5.62	10.75		1.00	9
Anemone <sup>a</sup>	0.61	1.26	0.89	2.42		0.51	5
Aplacophoran	0.38	1.05	0.80	0.45	0.49	0.50	6
Bivalve <sup>a</sup>	2.15	2.48	2.06	2.09		0.92	9
Brachyura	0.18	0.39	0.13	0.34	0.36	0.58	3
Chiton <sup>b</sup>	0.17	0.41	0.20	0.45		0.90	1
Cumacean	0.60	1.07	0.49	0.77	0.05	0.83	9
Echiuran <sup>c</sup>	0.00	0.00	0.20	0.45			1
Gastropod <sup>a</sup>	1.03	1.23	0.73	1.00		0.27	9
Harpacticoid <sup>a</sup>	0.60	1.14	0.85	2.27		0.50	6
Hermit <sup>b</sup>	0.44	1.33	0.07	0.26		0.49	2
Holothurian	0.06	0.24	0.08	0.27	0.19	0.67	6
Hydroid	0.05	0.23	0.05	0.22	0	1.00	2
Isopod	0.38	0.60	0.63	1.15	0.35	0.57	7
Nematode <sup>a</sup>	10.54	21.26	14.58	30.15		0.66	9
Nemertea	1.06	1.41	1.07	1.19	0.26	0.62	9
Oligochaete	0.12	0.33	0.47	1.30	1.51	0.27	4
Ophuroid	0.78	1.17	0.76	1.04	0.13	0.73	9
Ostracod	0.53	0.73	0.55	0.83	0.03	0.87	9
Pennatulacea	0.20	0.45	0.20	0.45	0	1.00	4
Phoronid	0.84	1.81	0.78	1.01	0	0.97	5
Polychaeta <sup>a</sup>	17.38	11.31	16.65	11.01		0.92	9
Pycnogonid <sup>c</sup>	0.00	0.00	0.09	0.30			1
Scaphopod	0.48	0.70	0.51	0.99	0	0.95	7
Sipunculid	0.50	0.53	0.00	0.00	1.59	0.30	2
Tanaid	0.48	0.78	0.98	1.66	0.48	0.50	6

<sup>a</sup>Paired *t*-test.

<sup>b</sup>*t*-test.

<sup>c</sup>Insufficient data for *t*-test.

indicates that this location also experiences high wave energy. The 43 m station also coincides with the transition from double-armored to unarmored cable, which is an inherent zone of weakness in the cable. Intense trawling activity has occurred in close proximity to this location and is another possible cause of damage to the cable (Figs. 7C and D).

Even though Pioneer Seamount stations were characterized by irregular, rocky topography with cable suspensions up to 2 m off the bottom, there was no noticeable evidence of damage to the cable or to the rocks (Figs. 6E and F). The cable is unarmored on Pioneer Seamount and the volcanogenic rocks found there are harder and more competent than the nearshore Purisima Formation. We infer that the currents on Pioneer Seamount (>800 m) are inadequate to generate substantial cable strumming or movement. Additionally,

trawling activities, the main cause of submarine cable faults worldwide (Featherstone et al., 2001), were not recorded on Pioneer Seamount between 1997 and 2003 (Fig. 7D) (Mason, personal communication). Strong currents and anthropogenic activities known to damage cables are absent on Pioneer Seamount and coincide with a region where no evidence of cable damage was observed.

Kinks in the cable at the 240 m station indicate that the cable was snagged (Fig. 6B), presumably by bottom trawling activities (Fig. 7D). Snagging during trawling can result in bending and abrasion of the cable, as well as displacement from its deployed location. High levels of trawling in this region from 1994 to 2001 (Mason, 2004, personal communication; National Research Council, 2002) indicate that trawling gear could have snagged the ATOC/Pioneer cable.

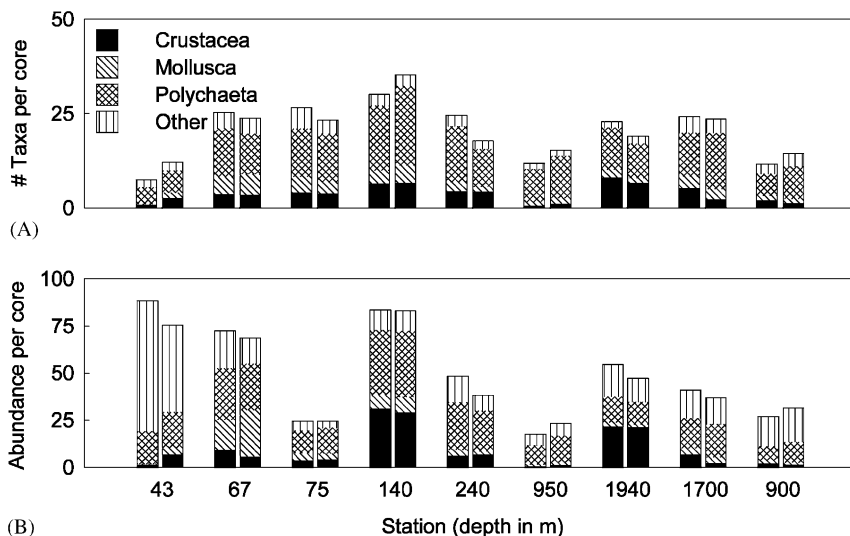


Fig. 9. Plots showing the average number of infaunal taxa (A) and average abundance of infauna, (B) per sample at each station. Samples consist of organisms from the upper 5 cm of sediments collected from 7 cm diameter push cores. Control data are represented by bars on the left and cable data by bars on the right. 'Other' category includes Cnidaria, Echinodermata, Echiuran, Nematoda, Nemertea, Phoronida, Pycnogonida, and Sipunculid.

The cable's position at the 250–415 m station is 975 m north of its reported position. This apparent offset may simply be the result of an incorrect waypoint reported post-installation (Howe, 1996). However, it is also possible that the cable was snagged and dragged from its original position.

Linear shadows seen on ROV sonar at the 950 m station that run perpendicular to the cable path and preferentially along the contours are likely relic trawl or other fishing marks. The cable splice seen at the 950 m station is probably a result of the 1997 repair. The location of the former break coincides with relict trawl marks suggesting that bottom gear may have caught and damaged the cable.

### 5.2. Relationship between cable exposure and damage

After 8 years, the ATOC/Pioneer Seamount cable has become largely buried in sediments on the continental shelf, partly buried on the continental slope, and remains exposed in the deep sea and in areas of rocky terrain (Figs. 7A and B). The continental shelf is known to contain a wedge of modern sediments (Edwards, 2002; Ettoreim et al., 2002). The mean depth of burial (~10 cm) is too deep to have resulted primarily from regional sediment deposition (Lewis et al., 2002). Intermittent burial and episodic exposure is likely due to

storms and shifting substrate. The cable was only buried intermittently in stations from 140 to 950 m water depth (Figs. 5F and 6A) and was exposed further seaward indicating lower sediment mobility in these offshore and deeper regions. Additionally, if the identity of the exposed cable crossing underneath the ATOC/Pioneer Seamount cable at 344 m water depth is the 1903 Hawaii–San Francisco Telegraph cable, it suggests that appreciable burial has not occurred in 100 years (Fig. 6C).

Observed areas of cable exposure and damage are coincident on the continental shelf and slope (Figs. 7A–C). Nearshore, sections of the cable were exposed and damage is clearly associated with high wave energy. The continental slope, where partial burial occurs, is the other area with cable damage and contains the present cable fault. However, damage on the slope is coincident with the distribution of trawling activity and is likely a result of bottom fishing. We note that cable damage is harder to determine where the cable is buried. However, cable faults have not occurred in those regions regardless of fishing effort (Fig. 7D).

### 5.3. Biological effects of the ATOC Pioneer Seamount cable

One study objective was to determine the effect, if any, of a subsea cable on benthic biological

Table 4

Comparison of cumulative infaunal mean number of taxa per core between cable and control transects over all the sites indicates no overall significant differences ( $p > 0.05$ )

Taxon	Number of taxa per core				<i>F</i> (treatment)	<i>p</i> -value	<i>n</i>
	Cable		Control				
	Mean #/core	SD	Mean #/core	SD			
Amphipod	1.45	1.48	1.59	1.66	0.13	0.73	9
Anemone	0.45	0.55	0.48	0.66	0.01	0.91	5
Aplacophoran	0.24	0.53	0.18	0.39	0.11	0.75	6
Bivalve	1.48	1.27	1.52	1.34	0	0.99	9
Brachyura	0.19	0.40	0.13	0.34	0.44	0.54	3
Chiton <sup>a</sup>	0.20	0.45	0.20	0.45		1	1
Cumacean	0.50	0.69	0.44	0.65	0.1	0.76	9
Echiuran <sup>b</sup>	0.00	0.00	0.20	0.45			1
Gastropod	0.92	1.10	0.75	1.00	0.05	0.83	9
Harpacticoid	0.37	0.53	0.47	0.50	0.44	0.52	6
Hermit	0.08	0.28	0.07	0.26	0.1	0.78	2
Holothurian	0.07	0.25	0.08	0.27	0.28	0.61	6
Hydroid	0.06	0.24	0.05	0.22	0	1	2
Isopod	0.33	0.52	0.45	0.71	0.4	0.54	7
Nematode	0.88	0.37	0.87	0.38	0.13	0.72	9
Nemertea	0.64	0.62	0.82	0.76	0.55	0.47	9
Oligochaete	0.13	0.34	0.22	0.42	1.07	0.34	4
Ophuroid	0.55	0.69	0.58	0.61	0.12	0.73	9
Ostracod	0.50	0.65	0.47	0.59	0.05	0.83	9
Pennatulacea	0.20	0.45	0.20	0.45	0	1	4
Phoronid	0.41	0.50	0.59	0.50	0.41	0.54	5
Polychaeta	12.02	5.82	11.04	5.94	0.33	0.58	9
Pycnogonid <sup>b</sup>	0.00	0.00	0.09	0.30			1
Scaphopod	0.43	0.50	0.31	0.47	0.16	0.7	7
Sipunculid	0.50	0.53	0.00	0.00	0.35	0.66	2
Tanaid	0.46	0.72	0.78	1.21	0.53	0.48	6

<sup>a</sup>*t*-test.

<sup>b</sup>Insufficient data for *t*-test.

communities. The results indicate that there are very few effects of the ATOC Pioneer Seamount Cable on epifaunal or infaunal organisms from the continental shelf to the deep-sea, and including sediment-dominated and rocky sites. Actinarians, such as the anemones *M. farcimen* and *Stomphia* spp., were significantly more abundant in sediment-dominated areas where the cable was exposed on the seafloor. Where the cable was buried, the presence of linear rows of anemones proved to be a reliable indicator of the cable's position. This effect, observed at four of nine stations surveyed, was the only taxon of either epifauna or infauna that was frequently more (or less) abundant near the cable (Figs. 5E and F). *M. farcimen* is known to recruit to hard substrata on the continental shelf (Fautin and Hand, 2000; Fautin et al., 1989) and the cable functions as a colonization surface similar to outcrops and isolated rocks. The effect of the cable

on Actinarian density is greatest on the continental shelf and upper slope especially where naturally occurring, exposed hard substrate is rare.

While the increase in Actinarian densities appears to be related directly to increased availability of suitable colonization surfaces (i.e. hard substrata), minor enhancement of fishes at two stations (43, 75 m) appears to result from the increased heterogeneity caused by the cable at these stations. Because increased habitat complexity will provide suitable microenvironments for more species than a uniform habitat (Barry and Dayton, 1991), it is not surprising that the abundance and diversity of some animals is elevated near the cable.

#### 5.4. Hydrodynamic effects

Accumulations of shell hash near the cable are possibly due to subtle hydrodynamic effects of the

cable on the local environment (Fig. 6B). The majority of shell hash was observed in topographic lows. Shell-producing molluscs were not seen in large numbers nor were they encountered in cores in great enough numbers to produce the shell hash in situ. Thus, hydrodynamic forces that transport and concentrate shell material near the cable may be related to the cable's presence on the seabed. Additionally, subtle hydrodynamic effects associated with a cable's presence on the seabed may also indirectly contribute to increased epifaunal abundance by further increasing the heterogeneity and complexity of the local habitat.

## 6. Summary

Observations were made regarding the condition of the ATOC cable and its influence on the seafloor environment. Even though the cable was installed directly on the seafloor, extrapolation of data from spot surveys indicates that, after 8 years, shallow burial has occurred over ~50% of the route. On the continental shelf and slope, the areas of cable exposure and damage were coincident. No entanglements with fishing gear or marine mammals were observed. The cable and rock outcrops were damaged by high-energy wave conditions in the nearshore area whereas cable damage on the continental slope was likely caused by anthropogenic activities. Additionally, there was no evidence of damage to either the cable or the rocks on Pioneer Seamount.

Few effects on the epifaunal and infaunal biological communities inhabiting rocky and sediment-dominated habitats along the cable route were detected. Overall effects of the cable were non-significant over the entire cable route for all 13 epifaunal and 19 infaunal groups. Analyses of individual stations indicated that the abundance of three epifaunal groups differed between cable and control treatments for at least one station, while no infaunal taxa differed at those sites.

The only obvious biological effect of the ATOC/Pioneer Seamount subsea cable was a modest enhancement of epifaunal biota in sediment-dominated areas by the increased availability of suitable settlement surfaces (i.e. the cable) for sessile invertebrates such as Actiniaria (anemones). A small increase in habitat heterogeneity at some stations may affect the distribution of epifauna, with cascading, but presently undetectable, impacts on the structure and function of local epifaunal and

infaunal assemblages. The cable may also subtly affect local hydrodynamic conditions that concentrated shell hash. The presence of the cable on the seafloor has had no detectable effect on infaunal abundance. Overall, the biological impacts of the presence of this submarine cable are minor, particularly in the context of other anthropogenic impacts in this region.

## Acknowledgments

The David and Lucile Packard Foundation, NOAA-Oceanic and Atmospheric Research, NOAA-National Marine Sanctuary Program, and the Monterey Bay National Marine Sanctuary provided support. We very much appreciate the assistance and generosity of Innovatum, Inc. and TSS Ltd. with the use of their cable-tracking equipment.

## Disclaimer

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