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Diablo Canyon Power Plant

Surfgrass (*Phyllospadix*) in the Vicinity of the Diablo Canyon Power Plant Discharge

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Prepared for:
Pacific Gas and Electric Company
77 Beale Street
San Francisco, CA 94105

TENERA Environmental Services
One Market, Spear Tower, Suite 1850, San Francisco, CA 94105
(415) 536-4744, FAX (415) 536-4714
P.O. Box 400, Avila Beach, California 93424
(805) 595-2407, FAX: (805) 595-2106.

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PREFACE

This report analyzes and presents results of scientific studies carried out by Tenera, Inc. for Pacific Gas and Electric Company. The following staff members contributed to the field data collection and report preparation:

Report preparation:	Mr. Scott Kimura, Lead Scientist Mr. John Steinbeck, Data Manager
Field data collection:	Mr. Mike Behrens Mr. David Innis Mr. Scott Kimura Mr. John Steinbeck Mr. Jim Strampe Mr. Jeff Tupen

SUMMARY

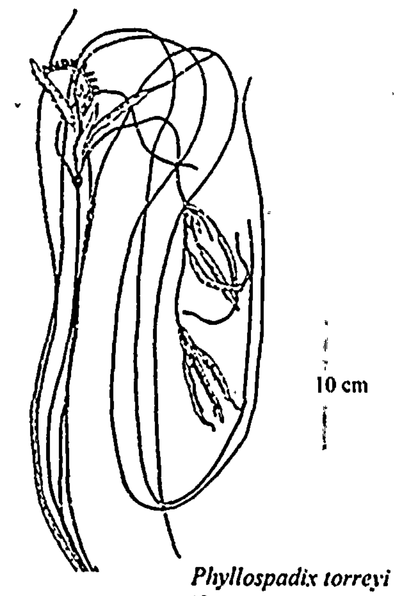
Surfgrass (*Phyllospadix* spp.) is often the predominant plant growing along the open coast between about the zero MLLW tide level and -3 m (-10 ft), providing important habitat for invertebrates and fishes. Results presented in the Thermal Effects Monitoring Program (TEMP) Analysis Report (Tenera, Inc., 1997) submitted to the Regional Water Quality Control Board (Board) showed that the Diablo Canyon Power Plant thermal discharge caused surfgrass to become less abundant at its upper and lower elevational fringes of distribution. However, data were not available on changes in surfgrass abundance in the low intertidal/shallow subtidal surf zone where it is more abundant. Surveys were not conducted in this zone on a regular basis due to difficulties in sampling effectively and consistently. In response to a request from Board staff and their independent consultant, dive surveys were completed in summer/fall 1997 to describe the spatial extent of surfgrass in the surf zone within Diablo Cove and neighboring areas. Summaries of past studies are presented to describe historical changes in surfgrass.

Based on earlier surveys, surfgrass once formed a nearly continuous band around the shoreline of Diablo Cove, covering an estimated area of about 2 hectares (5 acres) between the low intertidal and shallow subtidal (0 MLLW to -2 m MLLW). Severe storm waves in winter 1982/83 before power plant start-up reduced surfgrass cover in Diablo Cove to about 0.4 hectare (1 acre). Surveys in summer/fall 1997 showed that surfgrass cover in Diablo Cove was about 0.1 hectare (0.25 acre). Based on these qualitative estimates, the discharge reduced the cover of surfgrass in Diablo Cove by about 0.3 hectare (0.75 acre). Lack of recovery to pre-storm abundances represents a potential loss of approximately 1.9 hectares (4.75 acres) of surfgrass in Diablo Cove. The specific causes for the declines in Diablo Cove during power plant operation, and reasons for the lack of recovery are unexplained, but are likely related to factors associated with the discharge.

North of Diablo Cove, intertidal surfgrass increased in Field's Cove after the 1982/83 storms and during power plant operation, but the increase was not as large as at control stations. Statistical analysis detected the change as a significant decline in intertidal surfgrass abundance in Field's Cove, relative to control populations. There is no baseline information for determining discharge effects to subtidal surfgrass in this region. Surfgrass occurs to depths of -3 m (-10 feet) in Field's Cove. Although the potential exists for effects on subtidal surfgrass in Field's Cove, the summer/fall 1997 surveys noted subtidal surfgrass in Field's Cove appeared similar in abundance to the other areas that were examined north and south of Diablo Cove. No effects on subtidal surfgrass were observed in areas south of Diablo Cove.

INTRODUCTION

Surfgrass is a perennial, marine flowering plant (seagrass) that reproduces from seeds, unlike algae (seaweeds and kelps) that reproduce from spores. Two species of surfgrass (*Phyllospadix scouleri* Hook and *P. torreyi* S. Watson) occur along the coast, growing mainly on rock platforms and boulder fields in the zone between about the zero MLLW tide level and -3 m (-10 ft). The two species are similar in appearance, and are distinguished by blade and flower characteristics (Hickman, 1993). The most apparent difference is *P. scouleri* has slightly wider blades (1-4 mm) than *P. torreyi* (0.5-1.0 mm). Both species range from Alaska to Baja California. Due to their southern ranges, both are considered warm water tolerant species (Abbott and North, 1971). Eelgrass (*Zostera marina*) is another type of seagrass that occurs mainly in protected bays and estuaries, and is uncommon along the coast.



Phyllospadix torreyi
(from Dawson 1966)

During low tide surfgrass often appears as an emerald green belt fringing the shoreline. Surfgrass is characteristically the predominant plant in this low intertidal/shallow subtidal zone, providing important refuge and nursery habitat for invertebrates and fishes (Stewart et al., 1978, Stewart and Myers, 1980). The width of the surfgrass zone and patch sizes of surfgrass are largely dependent on the slope of the shoreline, topographical relief, and substratum availability. In addition to growing on rocks, both species of *Phyllospadix* grow in sandy areas, attached to rocks buried beneath the sand, and the rhizomes and dense blades, in turn, stabilize the sand. *Smithora naiadum*, a red blade alga, *Melobesia mediocris*, an encrusting red alga, and *Notoacmaea palacea*, a limpet, are obligate species on surfgrass.

PG&E submitted a report (TEMP Analysis Report; Tenera, Inc., 1997) that included surfgrass in descriptions of impacts from the Diablo Canyon Power Plant (DCPP) discharge. This report presents additional information on surfgrass. The TEMP Analysis Report showed statistically significant declines in surfgrass cover, relative to controls, at intertidal and subtidal stations in Diablo Cove. However, the analysis was limited to sampling results from discrete stations located at the upper and lower margins of the surfgrass zone. As a result, Board staff and their independent consultant requested PG&E to conduct reconnaissance surveys to collect data on the current status of surfgrass abundance and distribution in areas where it is more abundant (deeper than the intertidal stations and shallower than the subtidal stations). These surveys were completed in summer/fall 1997. The review of surfgrass in this report includes data from the reconnaissance surveys, descriptions not previously reported on cove-wide changes in the spatial extent of surfgrass cover in Diablo Cove, including descriptive accounts from previous studies.

METHODS

1997 Dive Surveys

As its name implies, surfgrass in central California occurs mainly in the surf zone. This zone is difficult to sample. Access must coincide with low tide during calm seas, and under those

conditions only the upper portion of habitat occupied by surfgrass becomes exposed for a couple of hours. Surfgrass is best observed by diving, but subtidal sampling is also difficult due to high surge, waves, and generally poor visibility.

In this study, qualitative diving surveys were done as the best approach to map surfgrass. Surveys were completed over several consecutive days in August and October 1997, and extended from North Control to South Control, a swimming distance of about 8 kilometers (5 miles) following the shoreline (Figure 1). In addition to mapping, notes were taken on the general condition of surfgrass (blade condition, amount of epiphytes, presence/ absence of flower structures), as well as substratum characteristics along segments of the coast. Offshore islands (e.g., Diablo Rock and Lion Rock) were not surveyed, as they have a narrow intertidal/shallow subtidal zone due to steep vertical relief, and because previous observations before and during power plant operation found that surfgrass was absent in those areas. The main zone of surfgrass along the shore was surveyed during relatively calm seas when the tide was about +0.9 m (+3 ft) MLLW. However, the lower intertidal zone could not be easily surveyed, due to surf conditions and poor visibility.

Previous Studies at DCPP

Some of the previous studies at DCPP that sampled surfgrass began before the TEMP in 1976 and were largely confined to Diablo Cove. The reports provide background on historical conditions of surfgrass within the cove. The findings are summarized in the results section of this report.

RESULTS

1997 Dive Surveys

Results from the 1997 summer/fall mapping surveys are summarized in Table 1. A map showing the distribution of surfgrass from North Control to South Control compiled from the surveys is shown in Figure 2.

Distribution

Surfgrass occurred mostly on top of scattered boulder and rock outcroppings from North Control to South Control (Figure 2). The main

Table 1. Summary of observations on surfgrass made during the 1997 summer/fall dive surveys.

Area	Relative Abundance	Blade Length	Condition/Epiphytes
North Control	Abundant and commonly growing on rock outcroppings and boulders	Normal	Relatively clean and normal appearing
Lion Rock (inshore)	Abundant and commonly growing on rock outcroppings and boulders	Normal	Relatively clean and normal appearing
Field's Cove	Abundant and erect canopy formation at head of cove	Normal	Relatively clean and normal appearing
North Diablo Point	Abundant inside a small headland indentation	Normal	Relatively clean and normal appearing
North Diablo Cove	Sparse, confined to a small pocket near the cliff-base stairway	Normal but reduced in length after a storm event	Covered with dense *Ulva/Enteromorpha* and diatoms before a storm event, relatively clean after, but blades reduced in length by about half (0.5 m) from storms. Blades outside Diablo Cove were about twice as long.
South Diablo Cove	Sparse, several small patches	Normal but reduced in length after a storm event	Covered with dense *Ulva/Enteromorpha* and diatoms before a storm event, relatively clean after, but blades reduced in length by about half (0.5 m) from storms. Blades outside of Diablo Cove were about twice as long.
South Diablo Point	Absent	-	-
Breakwaters	Absent	-	-
Seal Haulout	Absent along steep walls	-	-
South Control	Abundant, dense stands, erect canopy formation at head of Patton Cove	Normal	Relatively clean and normal appearing

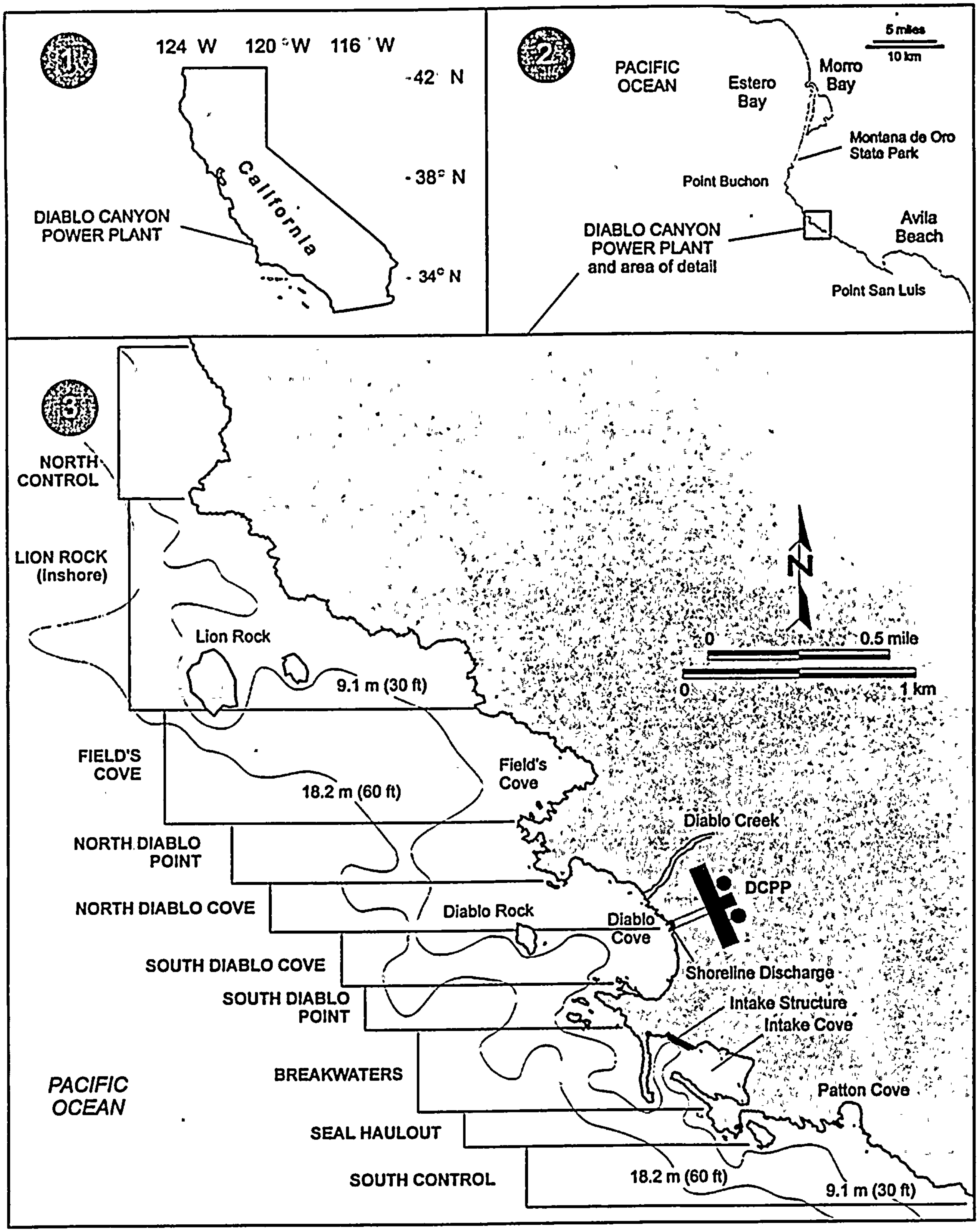


Figure 1. Location of the Diablo Canyon Power Plant (DCPP) and coastline segments surveyed for surfgrass.

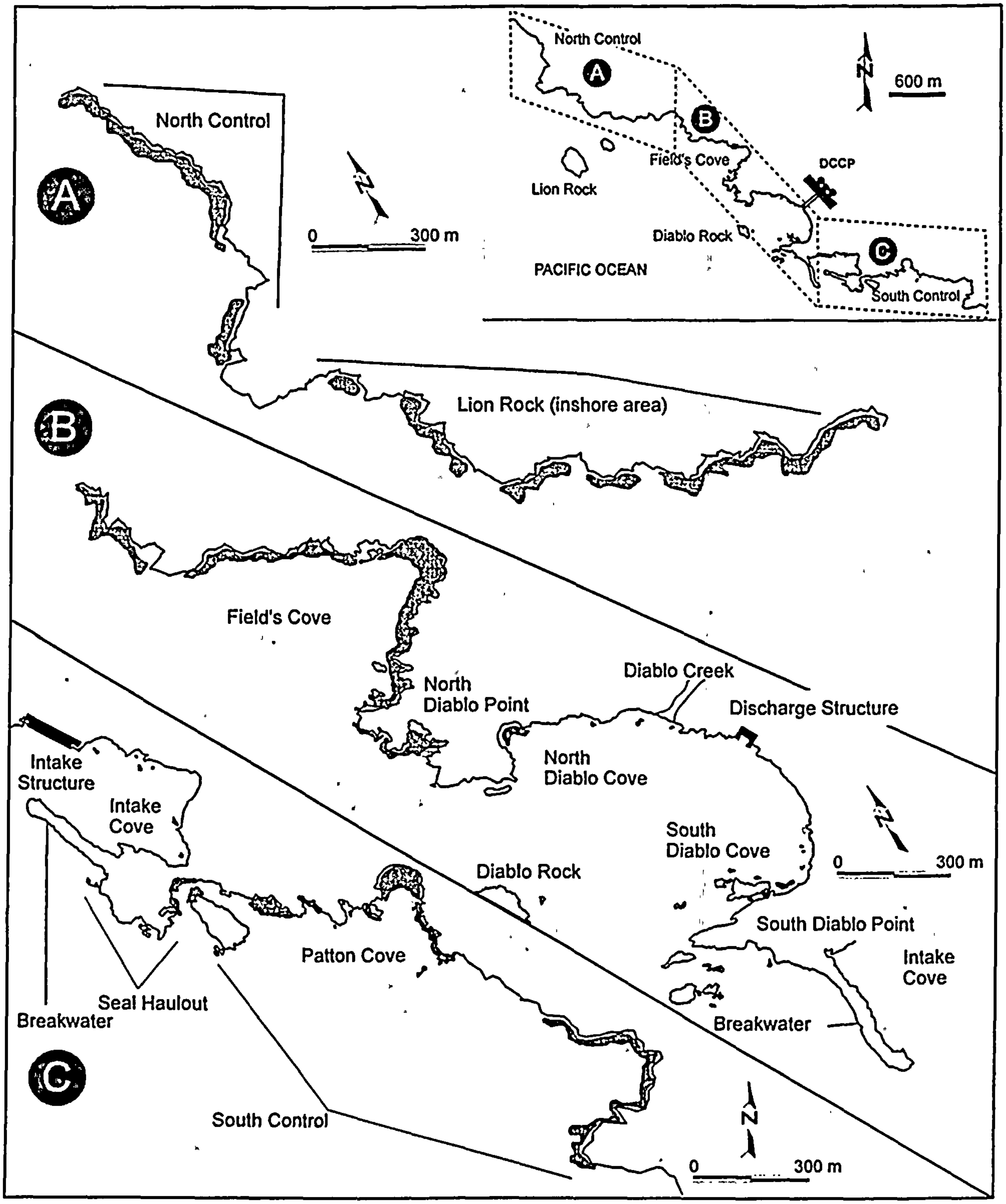


Figure 2. Map of the Diablo Canyon coastline and distribution of surfgrass from North Control to South Control from the 1997 summer/fall surveys. Areas that included surfgrass shown in dark shading. Areas outside Diablo Cove that lacked surfgrass were generally steep. Areas in Diablo Cove that lacked surfgrass were generally suitable for surfgrass in terms of substratum compostion and depth, but the areas were covered with algae.

zone of surfgrass was between approximately the zero MLLW tide level and -3 m (-10 ft) contours. The longest break in the shoreline distribution of surfgrass was within Diablo Cove.

Abundance

Phyllospadix scouleri was the predominant species, but several small patches of *P. torreyi* were present in the intertidal zone in Patton Cove located in the South Control area. Surfgrass was not present where steep vertical relief resulted in a narrow intertidal/shallow subtidal zone. Overall, surfgrass was least abundant in Diablo Cove. Patches of plants were present in both north and south Diablo Cove. Based on Geographic Information System (GIS) analysis, the coverage of surfgrass in Diablo Cove was about 0.1 hectare (0.25 acre). Surfgrass was more extensive outside Diablo Cove. Areas where surfgrass was sparse or absent, foliose red algae (primarily *Gigartina*, *Prionitis*, *Cryptopleura*, and articulated corallines) formed the predominant cover over the bottom. In Diablo Cove, the branched red alga *Gastroclonium subarticulatum* covered large areas in the surfgrass zone.

Condition

Surveys in Diablo Cove were conducted in August and again in October following a storm. Before the storm, surfgrass in Diablo Cove was covered with more epiphytes (mostly the foliose green algae *Ulva/Enteromorpha* spp.) than plants in Field's Cove and Patton Cove. The epiphytes were growing from near the distal ends of the surfgrass blades. In addition, the tips of nearly all surfgrass blades in Diablo Cove were generally more tattered than plants found outside the cove. Epiphytes typically grow on weakened host tissues, and therefore plants inside the cove appeared to be less healthy than plants outside the cove. After the storm, the blades of surfgrass in Diablo Cove had become noticeably shorter in length (change from about 1.0 m to about 0.5 m long), due to breakage at weakened tissue points. Although shorter, the remaining blade tissues were normal in color, had fewer epiphytes, and appeared relatively healthy. No change in the condition of surfgrass was observed outside Diablo Cove between surveys conducted before and after the storms. Blades were about one meter and greater in length. The lack of blade shortening from the storms was likely related to the plant tissues not being weakened by epiphytes. *Melobesia mediocris*, *Smithora naiadum*, and *Notoacmaea palacea* were not abundant on surfgrass blades in any area surveyed before or after the storms. No flower structures were observed during the surveys.

Previous Studies at DCPP

A number of previous studies at DCPP included recording the presence/absence or cover of surfgrass. Surfgrass thermal tolerance experiments were also completed at the PG&E on-site biological laboratory. The studies and findings are summarized in Table 2 and below.

North (1969) - Qualitative Subtidal Observations: The first biological dive surveys of Diablo Cove were done in 1966 and 1967 by North (1969). The qualitative study developed the cove's first species list and mapped the general distribution of the most conspicuous plant species in the cove. Subtidal surfgrass was noted as a principal plant species observed near the discharge in south Diablo Cove. No surveys were done outside Diablo Cove.

North et al. (1989) - Intertidal Vertical Band Transect Sampling: Sampling was conducted at four intertidal permanent locations from 1976 to 1987 (Figure 3). At each location a transect tape (about 50 meters long) was stretched from near the cliff base down to the water line (MLLW), running through permanent anchors. Sequentially placed 1m^2 quadrats were sampled along the tape. Sampling consisted of visual estimates of plant cover (including surfgrass) found in each quadrat.

North et al. (1989) recognized *Phyllospadix scouleri*, versus *P. torreyi*, as the more abundant of the two species. Data for surfgrass are shown in Figures 4 and 5. Surfgrass was absent at the Lion Rock (LCIX) transect, and therefore no

Table 2. Summary of surfgrass field and laboratory investigations at DCPP.

Investigating Organization or Author(s)	Report or Study Title	Duration	Zone Studied	Study Description	Findings
North (1969)	An Evaluation of the Marine Flora and Fauna in the Vicinty of Diablo Cove, California	1966-67	Subtidal	Qualitative surveys in Diablo Cove No surveys outside Diablo Cove	Surfgrass most abundant in south Diablo Cove in regions between about MLLW and -3 m (-10 ft)
North et al. (1989)	Wheeler J. North Ecological Studies at Diablo Canyon Power Plant	1976-87	Intertidal	Quantitative sampling at permanent vertical band transects in Diablo Cove No control population sampled	Large declines in surfgrass before power plant start-up due to 1982/83 storms and El Niño Additional declines in Diablo Cove late in the study, but no control for comparing changes to natural variation
Gotshall et al. (1984, 1986)	1984: A Quantitative Ecological Study of Selected Nearshore Marine Plants and Animals at the Diablo Canyon Power Plant Site 1986: Pre-Operational Basesine Studies of Selected Nearshore Biota at the Diablo Canyon Power Plant Site	1974-82	Intertidal	Fish and Game Studies: Quantitative random sampling within specific areas in Diablo Cove and at North Control	Increase in surfgrass abundance at all locations studied Study ended before the 1982/83 storms and El Niño
PG&E (1982)	Compendium of Thermal Effects Laboratory Studies	1979 and 1982	Lab	Thermal tolerance studies in 1979; reporting in 1982	Surfgrass tolerant to 24°C (75°F) for nine days and to 34°C (93°F) for three hours without deleterious effects
PG&E/Tenera (ongoing)	Thermal Effects Monitoring Program (TEMP) / Receiving Water Monitoring Program (RWMP)	1976 (ongoing)	Intertidal	Sampling at horizontal band transects	Declines in surfgrass in Diablo Cove after power plant start-up Surfgrass increased or remained unchanged outside Diablo Cove
			Intertidal	Sampling at vertical band transects in Diablo Cove for plant taxa beginning in 1979 Sampling at vertical band transects in Field's Cove for plant taxa beginning in 1985	Diablo Cove: declines in surfgrass after power plant start-up Field's Cove: surfgrass unchanged during power plant operation, but no pre-operation database for comparison
			Intertidal and Subtidal	Qualitative surveys and ancillary observations in Diablo Cove; none outside Diablo Cove	Surfgrass present as a nearly continous band around the shoreline of Diablo Cove, from about MLLW to -2 m (-6 ft) with some patches at -3 m (-10 ft) Large declines in 1982/83 from storm effects
			Subtidal	Sampling at benthic stations	Declines in surfgrass beginning in 1982/83 from storm effects and continued through power plant operation
Tenera, Inc. 1997	Changes in the Marine Environment Resulting from the Diablo Canyon Power Plant Discharge	Analysis of TEMP studies completed from 1976 to 1995	Intertidal	Analysis of TEMP horizontal band transect data	Statistically significant declines, relative to controls, at the upper zone of surfgrass in Diablo Cove, Field's Cove, and South Diablo Point
	Changes in the Marine Environment Resulting from the Diablo Canyon Power Plant Discharge	Analysis of TEMP studies completed from 1976 to 1995	Subtidal	Analysis of TEMP benthic station data	Statistically significant declines, relative to controls, at the lower zone of surfgrass in Diablo Cove

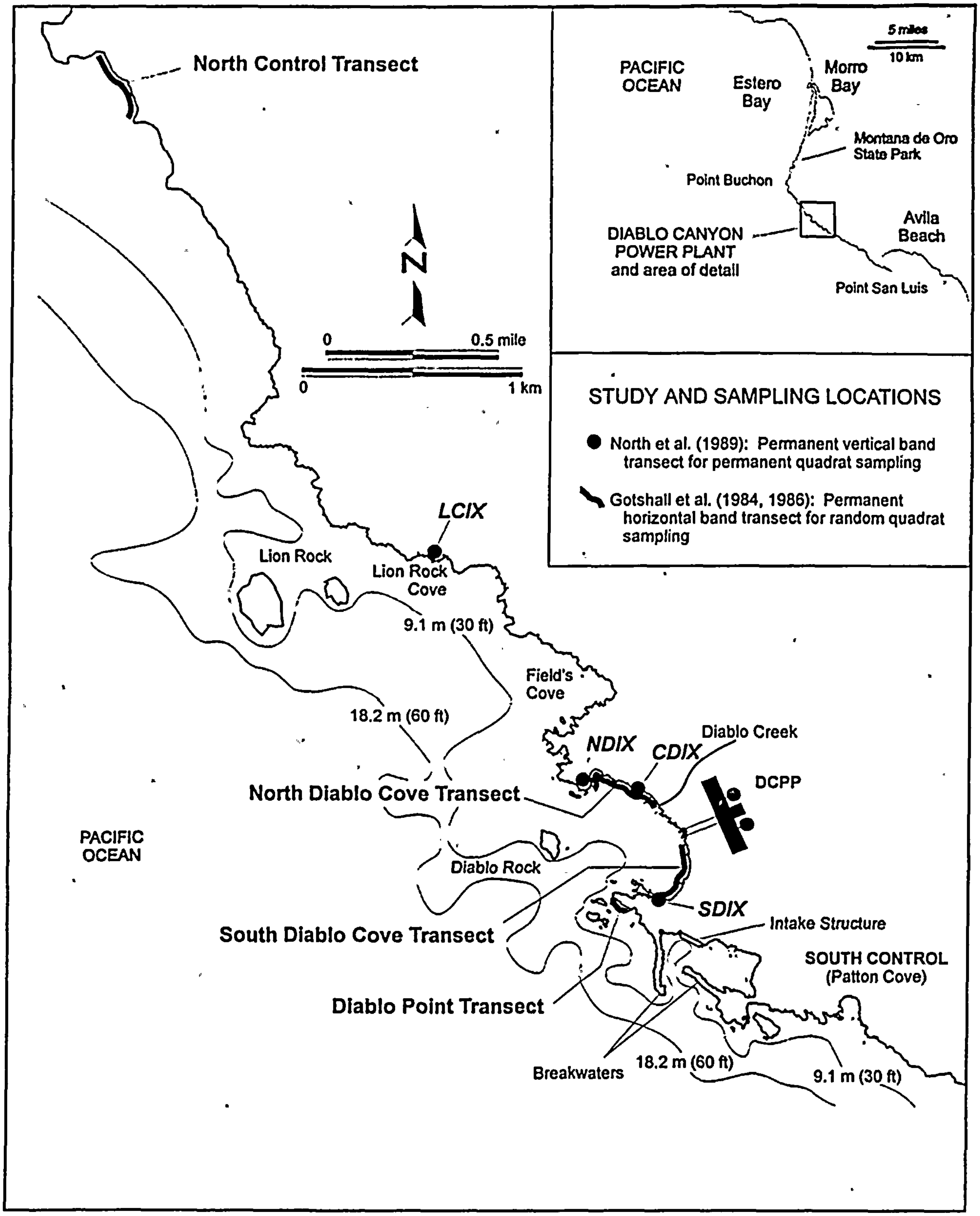


Figure 3. Locations of intertidal vertical band transects sampled by North et al. (1989) and transects of random quadrats sampled by Gotshall et al. (1984, 1986).

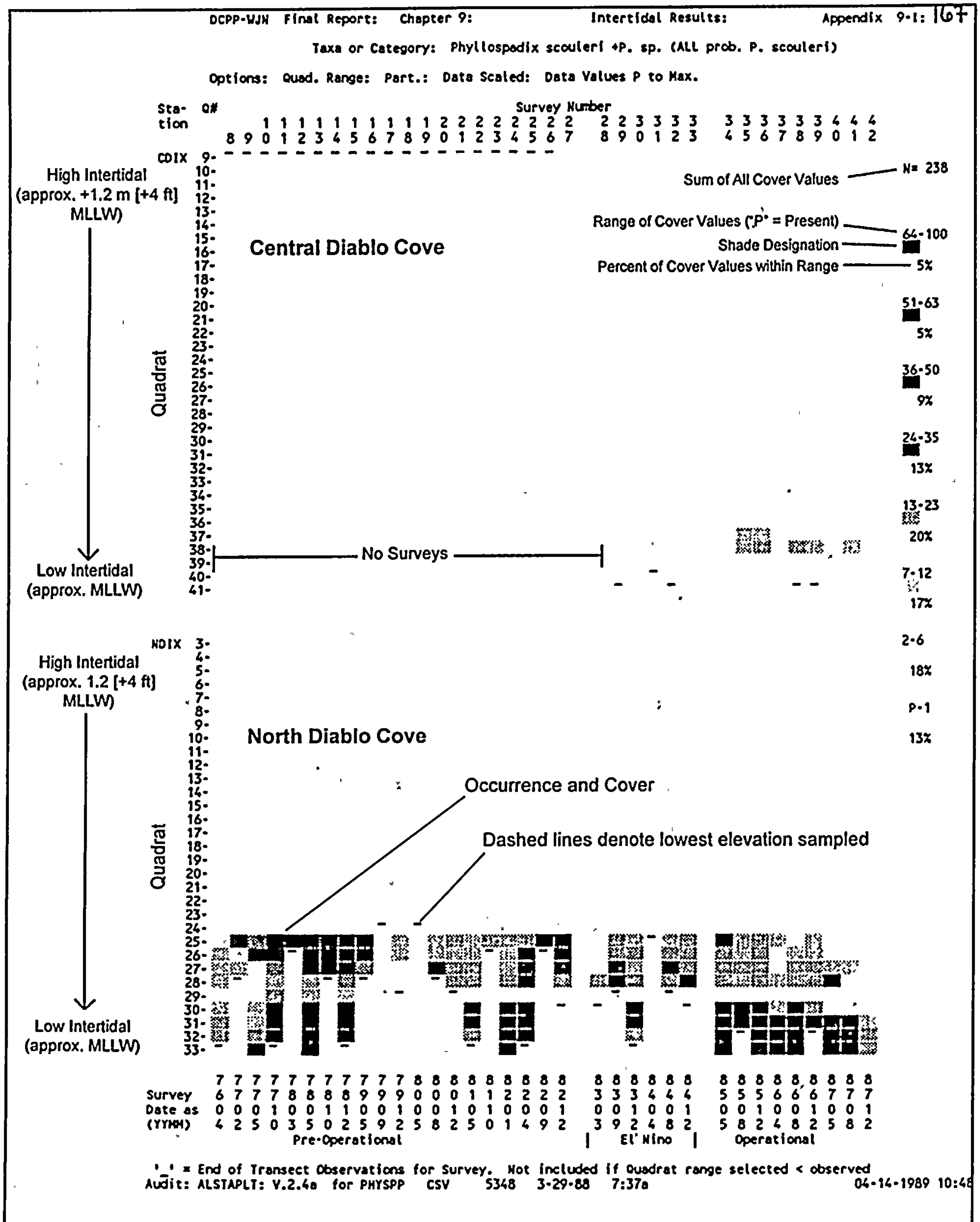


Figure 4. Graph from North et al. (1989) on changes in the occurrence and cover of surfgrass (*Phyllospadix*) at intertidal vertical transect stations CDIX (central Diablo Cove) and NDIX (north Diablo Cove). The darker the box shading the greater the observed cover. See Figure 4 for station locations.

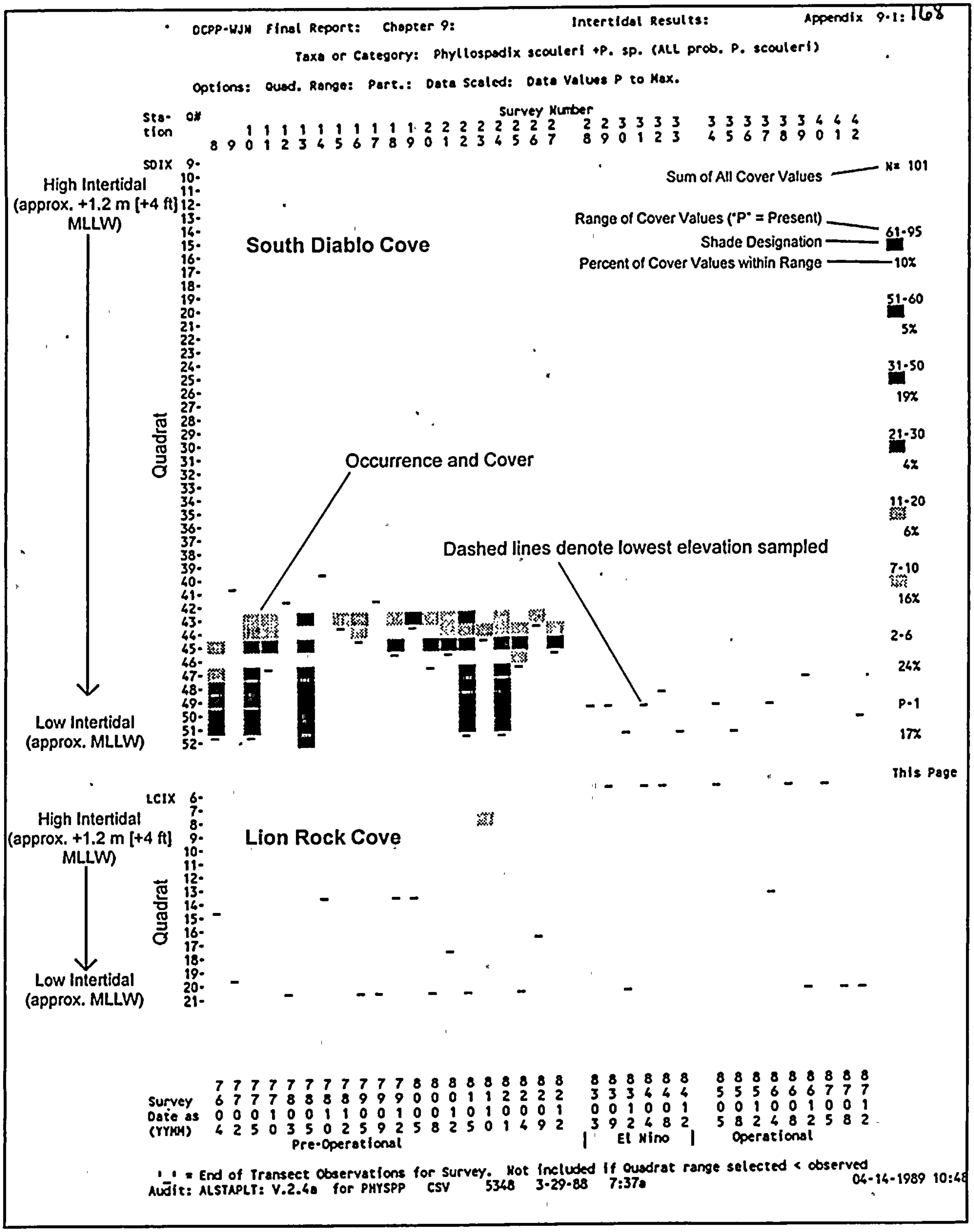


Figure 5. Graph from North et al. (1989) on changes in the occurrence and cover of surfgrass (*Phyllospadix*) at intertidal vertical transect stations SDIX (south Diablo Cove) and LCIX (Lion Rock Cove). The darker the box shading the greater the observed cover. See Figure 4 for station locations.

control population was sampled in this study. North et al. (1989) attributed a reduced abundance of surfgrass in Diablo Cove during power plant operation to reductions that occurred during the 1982/83 storms and El Niño.

Gotshall et al. (1984, 1986) - Intertidal Random Quadrat Sampling: Surfgrass was monitored as part of the California Department of Fish and Game intertidal study at DCPP. Surfgrass was absent at the South Diablo Point sampling area shown in Figure 3. The two species of surfgrass were not differentiated during sampling. In each area, the coverage of surfgrass was visually estimated in up to 40-0.25 m^2 quadrats randomly placed along transects near the zero MLLW tide level. The study began in 1974 and ended in 1982 just before power plant start-up and the 1982/83 El Niño and storms. During the study, surfgrass remained relatively abundant in each study area and generally increased in all areas from 1980 through 1982 (Figure 6). Surfgrass in the subtidal was not monitored by Gotshall et al. (1984, 1986).

Tenera, Inc. (1997) - TEMP Analysis Report, Intertidal Studies, Horizontal Band Transect Sampling: The primary intertidal results from 1976 to 1995 presented in Tenera, Inc. (1997) were based on the horizontal band transect study. In this study plant coverage was visually estimated for each taxa encountered in 10 fixed $1m^2$ quadrats positioned along permanent transect lines oriented parallel-to-shore. The transects were located at the +0.3 m (+1 ft) and +0.9 m (+3 ft) MLLW tide level in Diablo Cove and neighboring areas (Figure 7). Generally, a station consisted of both an upper and lower elevation transect. Surfgrass was present in some quadrats, although most quadrats were above the upper zone of surfgrass. *P. scouleri* was the more abundant of the two species.

Power plant effects on surfgrass were analyzed using data from the horizontal band transect study. Changes in surfgrass cover at all of the TEMP stations are shown in Figure 8. Only a subset of stations in Diablo Cove, Field's Cove, and South Diablo Point were suitable for statistical analysis (those with the greatest number of sampling completions over time and least physically damaged by the 1982/83 winter storms and 1983 El Niño). Analysis methods and station selection rationale were presented in the TEMP Analysis Report (Tenera, Inc., 1997).

Data for surfgrass in the horizontal band transect study did not meet the assumptions for analysis of variance, and were analyzed using the Fisher's exact test. The Fisher's exact test showed statistically significant declines in surfgrass cover ($p<0.1$), relative to controls for the station transects in Diablo Cove. The greatest declines occurred in north Diablo Cove, beginning in 1987 (Figure 8). In south Diablo Cove, surfgrass declined to near-absence before power plant start-up as a result of the 1982/83 storms and El Niño. The analysis also detected a significant decrease relative to the controls in Field's Cove and South Diablo Point. Surfgrass increased in abundance at the Field's Cove transect, but the increase was not as large as increases at the control transects, resulting in the significant difference. The South Diablo Point transects were not in a suitable area for surfgrass, as surfgrass remained absent at those transects both before and during power plant operation. The analysis detected the lack of change as a significant decrease relative to controls.

Tenera, Inc. (1997) - TEMP Analysis Report, Subtidal Studies, Benthic Station Sampling: In the TEMP subtidal study, the percentage cover of surfgrass was recorded at permanent benthic stations, $28m^2$ in area (Figure 9). The shallowest stations at -3 m (-10 ft) were at the lower depth limit of surfgrass. Percentage cover measurements were obtained using a random point contact sampling method. Two-hundred random points per station were sampled for the presence or absence of plants.

Surfgrass was present at only a few of the stations sampled, and declined in cover at those stations prior to power plant start-up during the 1982/83 winter storms and El Niño (Figure 10). Data from this study were statistically analyzed for power plant effects. The data were tested using a before-after/control-impact analysis of variance model (BACI analysis). The analysis showed statistically significant declines ($p<0.1$)

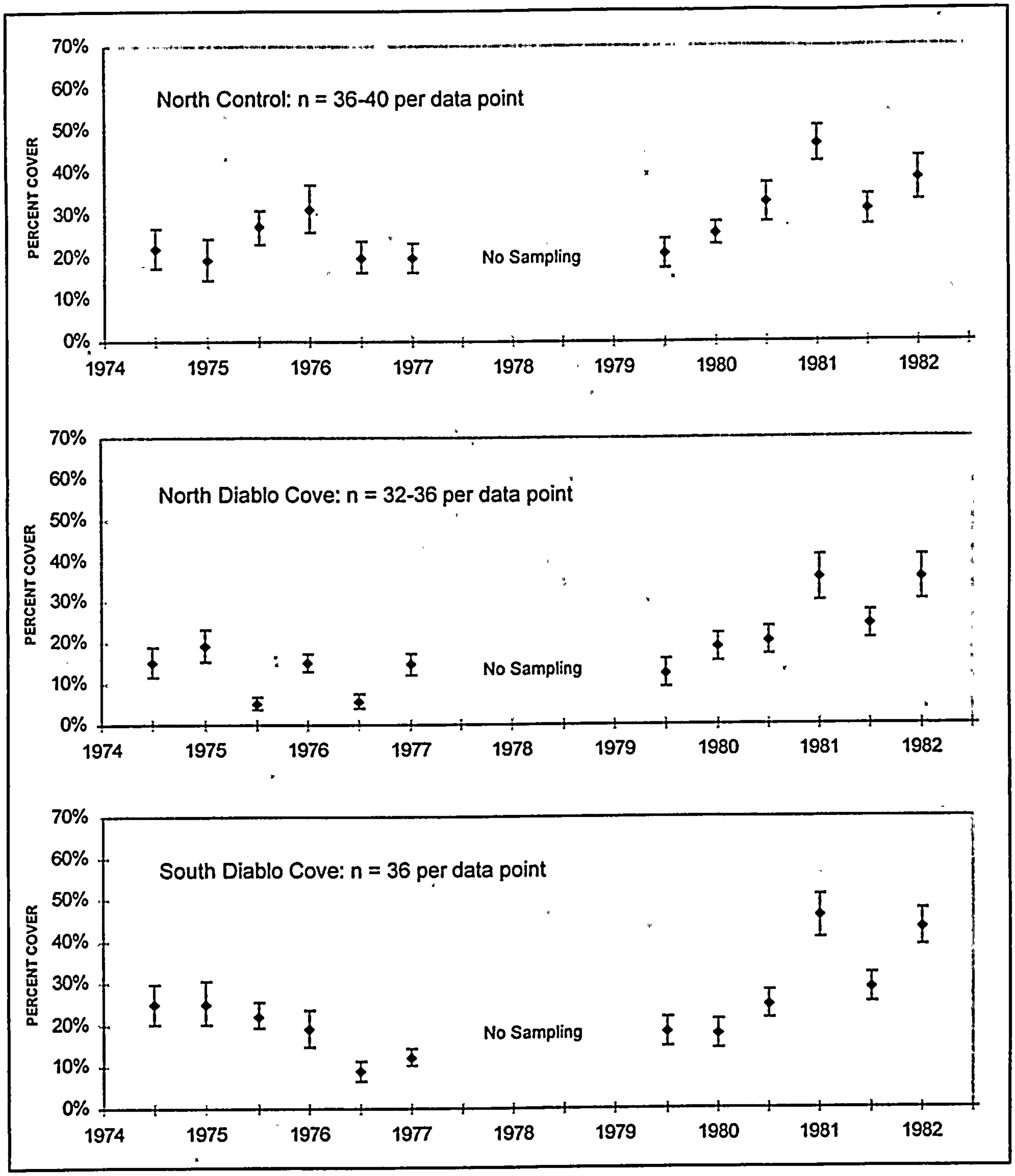


Figure 6. Changes in surfgrass cover from random 0.25m² quadrat sampling at the MLLW tide elevation. Vertical bars are +/- one standard error. Data compiled from Gotshall et al. (1984, 1986). See Figure 3 for sampling areas.

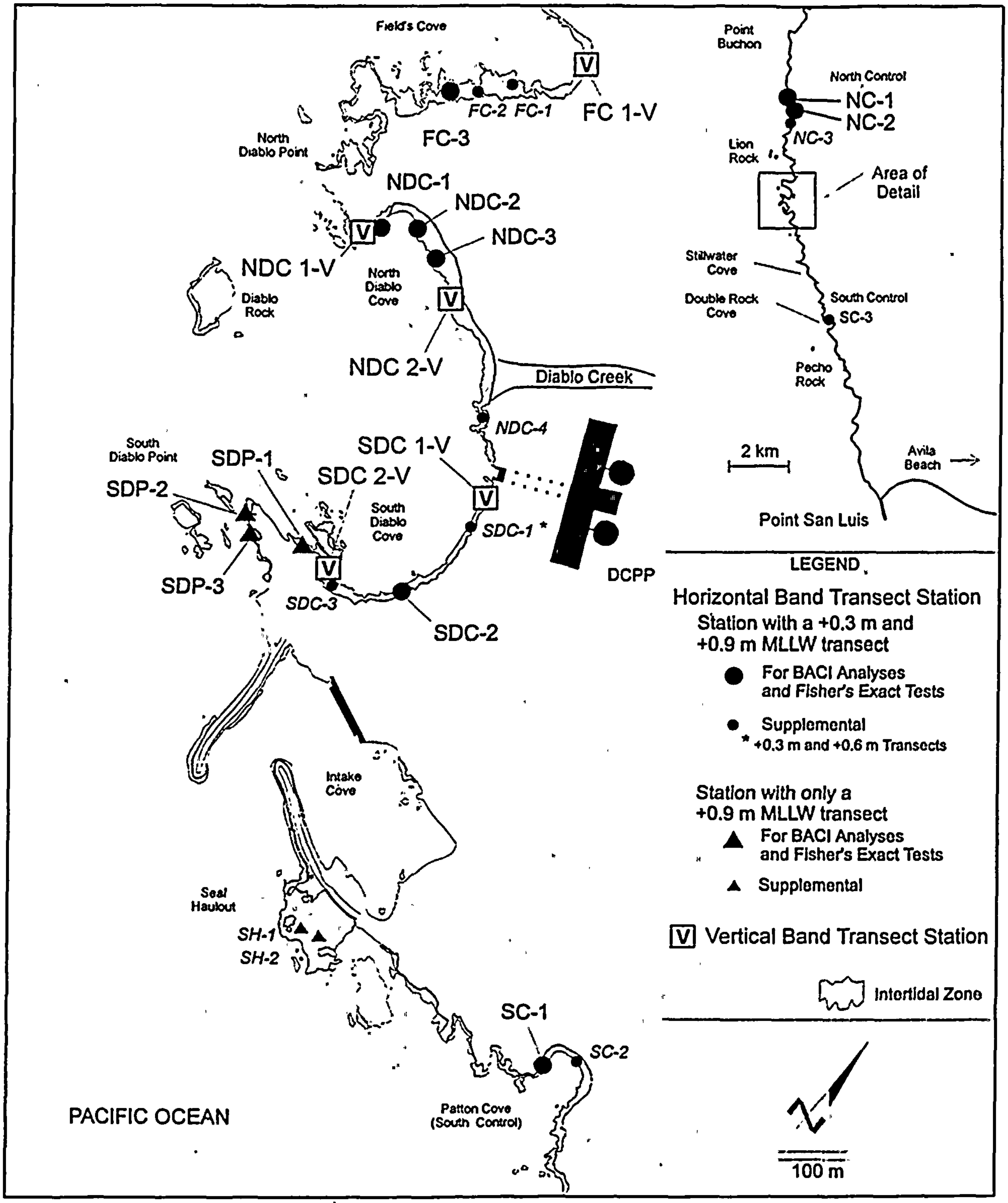


Figure 7. Locations of TEMP intertidal horizontal and vertical band transect stations.

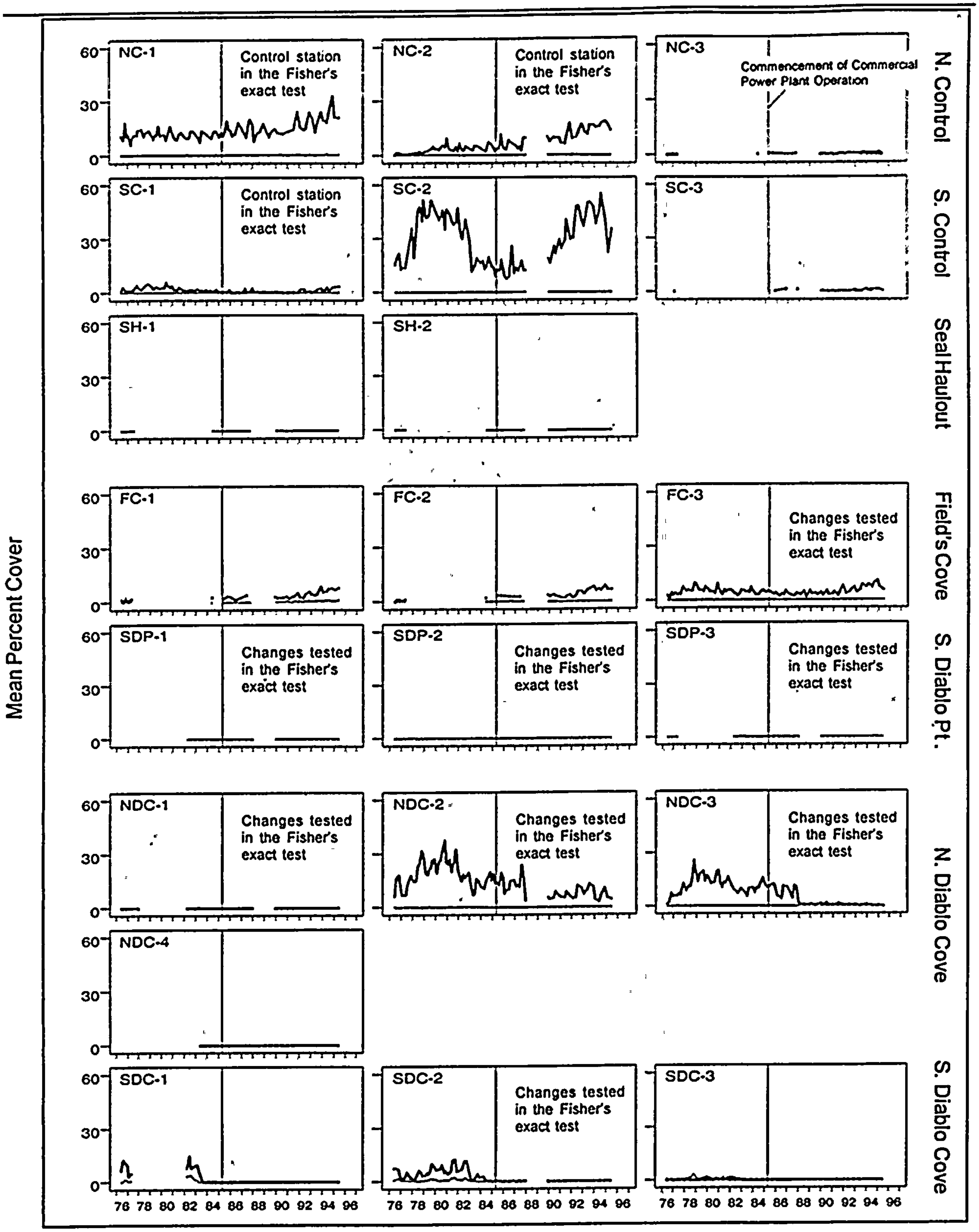


Figure 8. *Phyllospadix* spp.: changes in cover at the TEMP intertidal horizontal band transects. Wide and thin lines represent +0.3 m and +0.9 m MLLW transect data, respectively. See Figure 7 for transect locations. Note that before power plant start-up, *Phyllospadix* declined in abundance by about half in north Diablo Cove and to absence in south Diablo Cove from the 1982/83 storms and El Nino. Changes in Field's Cove were more similar to controls than to changes in Diablo Cove. *Phyllospadix* was generally always absent at all +0.9 m transects, including South Diablo Point. Graph from PG&E (1997).

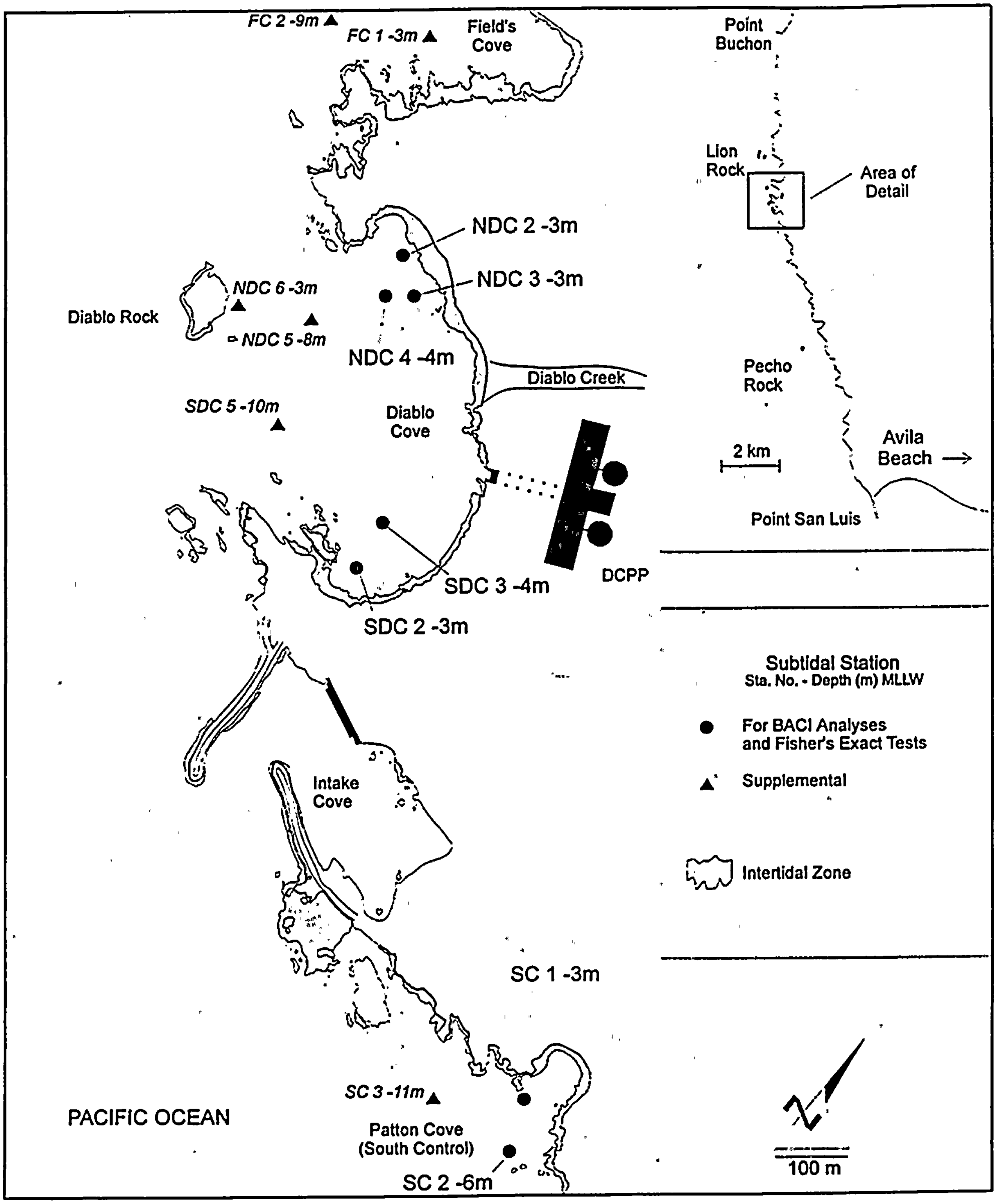


Figure 9. Locations of TEMP subtidal benthic stations.

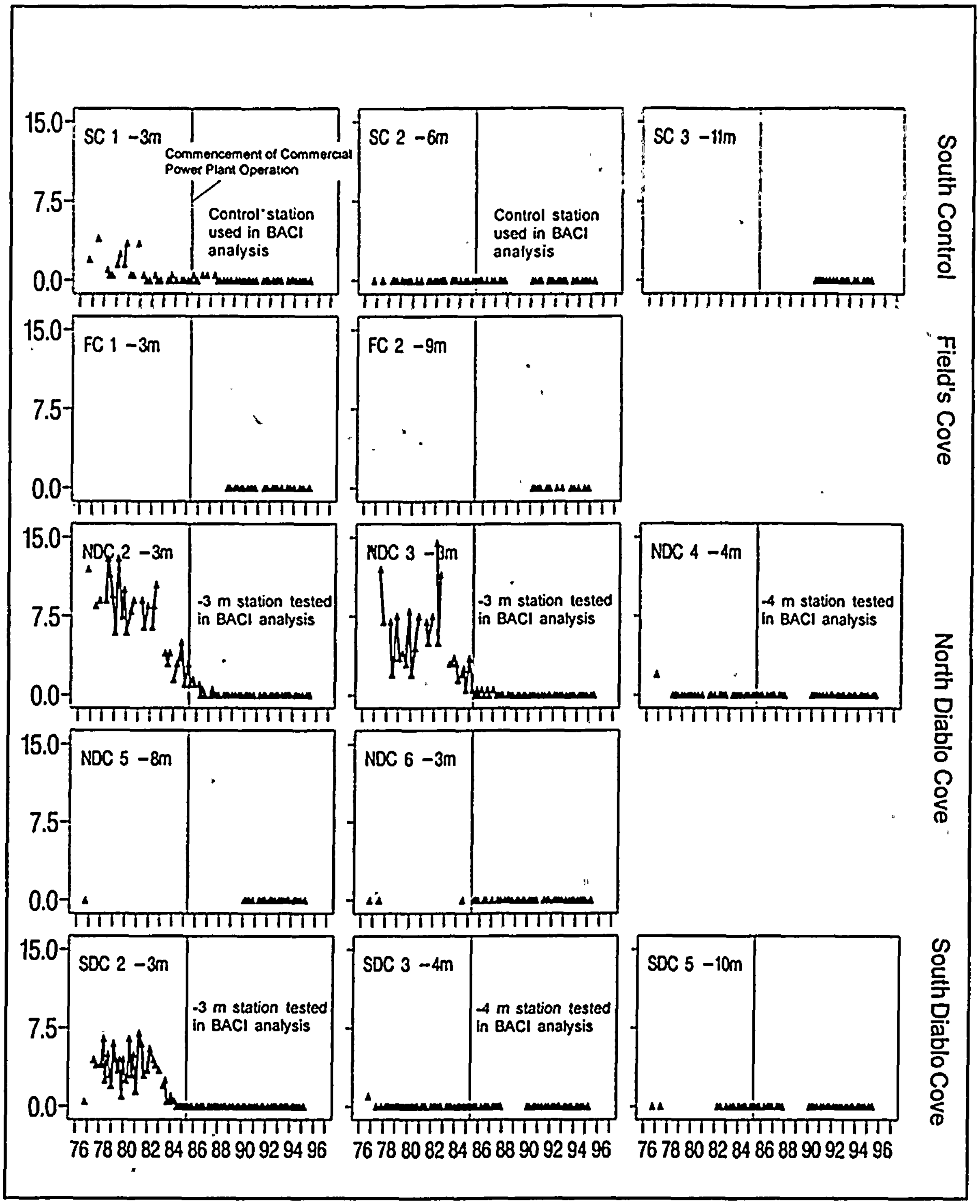


Figure 10. *Phyllospadix* spp.: changes in cover at the TEMP subtidal benthic stations. See Figure 9 for station locations. Changes in the control population were similar to changes at the Diablo Cove stations tested in the BACI analysis. Note that before power plant start-up, *Phyllospadix* declined in abundance from the 1982/83 storms and El Nino to about half the amount of previous abundances in north Diablo Cove and to absence in south Diablo Cove. *Phyllospadix* was generally always absent at the -4 m Diablo Cove stations tested in the BACI analysis. Graph from PG&E (1997).

at Diablo Cove -3 m (-10 ft) depth stations, relative to the control population, which also declined. Because the declines were largest at the Diablo Cove stations, the analysis interpreted the change as a significant relative decrease. In contrast, the analysis detected a significant increase for the -4 m (-15 ft) depth stations in Diablo Cove relative to the control. This was the result of surfgrass not occurring at the Diablo Cove -4 m (-15 ft) depth stations, and being compared to a declining control population (Figure 10) in the BACI analysis. (i.e., An unchanged surfgrass population in Diablo Cove was compared to a declining control population, resulting in a relative increase detected in the BACI analysis.)

TEMP - Intertidal Vertical Band Transect Sampling: In the vertical band transect study, the presence of plant species was recorded for 9-12 permanent $1m^2$ quadrats sampled along permanent transects oriented perpendicular-to-shore. The transects ran from about the +1.2 m (+4 ft) MLLW tide level to MLLW. Three parallel transects (separated by several meters) were positioned at each station. Four stations were located in Diablo Cove and one station was in Field's Cove (Figure 7). Results from this study for plant taxa were not reported in the TEMP Analysis Report (Tenera, Inc., 1997), since the data could not be analyzed statistically. The only station outside Diablo Cove was located in Field's Cove, and plant taxa were not sampled there before power plant start-up. It was also found that the mean water temperature in Field's Cove was increased by about 1°C (2°F) above ambient conditions during power plant operation (Tenera, Inc., 1997). Therefore, there were no data from a control population sampled before and after power plant start-up for this study.

The data for the vertical band transects are included in the present report, because the study sampled lower intertidal elevations occupied by surfgrass (i.e., elevations below those sampled by the TEMP horizontal band transects). However, changes at the vertical band transect stations (Figure 11) were similar to those observed at the horizontal band transect stations (Figure 8) for the same areas sampled by the two studies. Although there are no pre-operation data for the Field's Cove station, surfgrass remained relatively unchanged in occurrence at the Field's Cove station during power plant operation. However, it declined in occurrence between the high and low intertidal zones at north Diablo Cove stations. Surfgrass declined in occurrence before power plant start-up at south Diablo Cove stations. These results are also similar to those of North et al. (1989) (Figures 4 and 5).

TEMP Qualitative Observations: Thousands of hours were spent completing the various field tasks of the TEMP. Reproductive surfgrass and germinating seedlings were only occasionally seen during these efforts before and after power plant start-up.

TEMP divers conducted a qualitative surfgrass survey in 1976-77, noting the distribution and abundance of surfgrass in Diablo Cove (J. Blecha, pers. comm.). Surfgrass was found forming a nearly a continuous band around the shoreline of Diablo Cove and was the predominant plant in the zone between about MLLW and -2 m (-6 ft) with plants occasionally at -3 m (-10 ft). However, surfgrass was absent or sparse in the region of Diablo Creek. Based on a GIS analysis of maps redrawn by Blecha (pers. comm.), the coverage of surfgrass in Diablo Cove in 1976-77 was approximately 2 hectares (5 acres). No areas outside Diablo Cove were surveyed in the 1976-77 surveys.

Substantial reductions in the abundance of surfgrass occurred over large areas in Diablo Cove, particularly in south Diablo Cove, during the 1982/83 winter storms and El Niño. The transport of large quantities of sand from the subtidal onto the intertidal in south Diablo Cove and the erosion of cliff sediments backing the south Diablo Cove intertidal zone scoured the surfgrass zone in nearly all of south Diablo Cove. Other portions of the surfgrass zone in south Diablo Cove became buried under rock fragments from a collapsed cliff. As a consequence, surfgrass throughout nearly all areas of south Diablo Cove declined in abundance. Impacts from the storms were evident at south Diablo Cove stations (Figures 9,

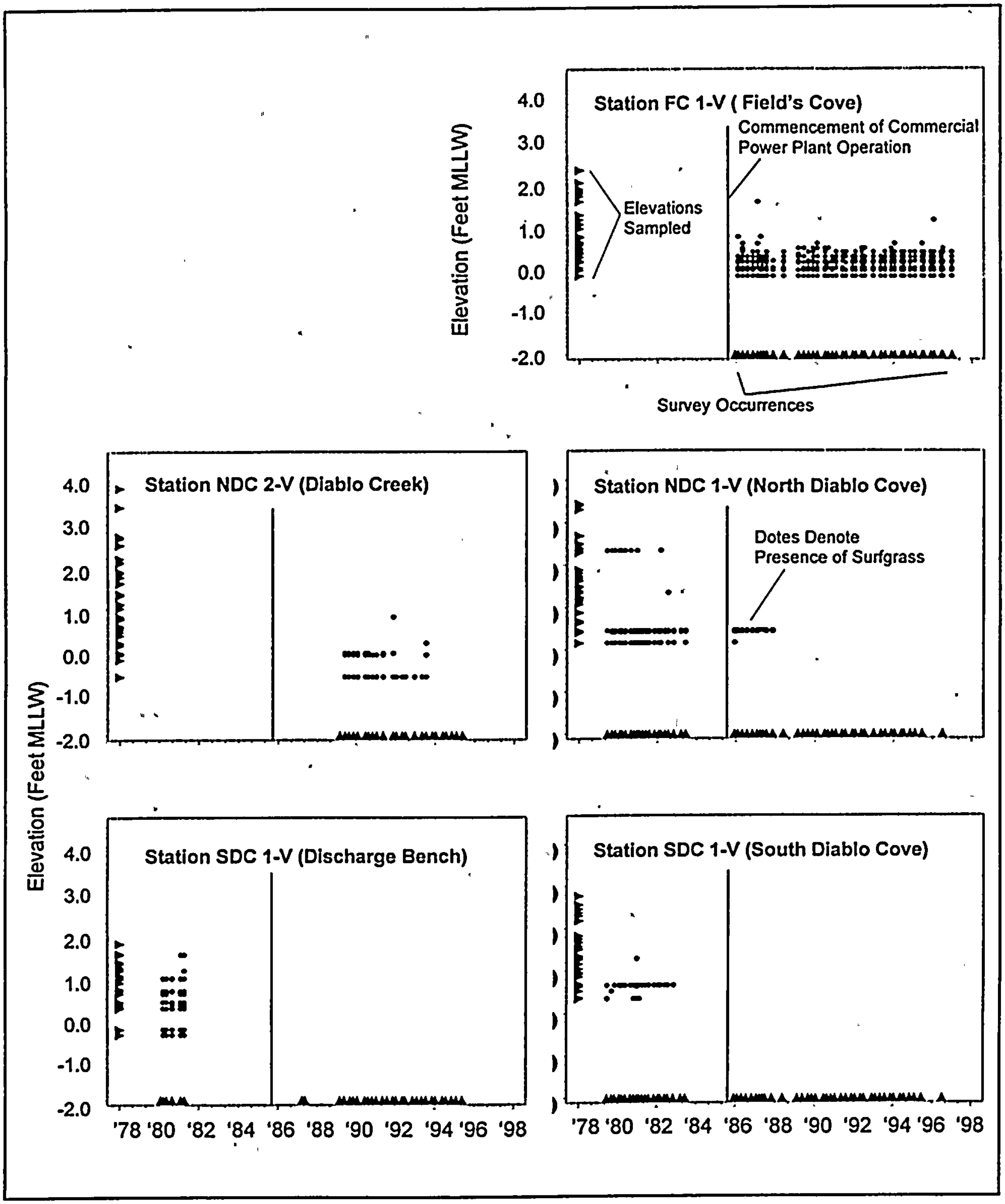


Figure 11. Changes in the vertidal distribution of surfgrass at the TEMP vertical band transect stations. Dots denote presence of surfgrass. Carrots along vertical axes represent elevations sampled. Carrots along horizontal axes denote survey occurrences. See Figure 7 for station locations. Years are positioned at January of each year.

10, 11). No observations were made outside the sampling stations to quantify storm impacts in other areas beyond Diablo Cove. In general, effects from the storms and El Niño were greatest in south Diablo Cove where surfgrass abundance was reduced to near-absence, while surfgrass in north Diablo Cove declined to about half from former levels of abundance.

PG&E (1982) - Thermal Effects Laboratory Studies: PG&E conducted a series of thermal tolerance studies on selected organisms. Surfgrass (*P. scouleri*) that was exposed to 75°F (24°C) for nine days did not exhibit any deleterious responses (tissue bleaching). Also, because a temperature controller malfunctioned during the experiment, the plants were exposed to 93°F (34°C) for three hours and were not adversely affected.

DISCUSSION

Results from surveys conducted during summer/fall 1997 show low surfgrass abundance in Diablo Cove compared to historical abundances and abundances in areas outside the cove (Figure 2). Changes in the amounts of surfgrass can be approximated from earlier TEMP qualitative descriptions, results from Gotshall et al. (1984, 1986), the summer/fall 1997 qualitative surveys, and statistical analysis results in the TEMP Analysis Report (Tenera, Inc., 1997).

Results from the TEMP qualitative surfgrass survey done during 1976-77 showed that surfgrass was abundant in Diablo Cove (estimated at 2 hectares; 5 acres). It occurred in various size patches around the perimeter of the cove but was largely absent in the region of Diablo Creek. Based on Gotshall et al. (1984, 1986) and other ancillary observations, surfgrass remained relatively constant at this level of abundance and may have increased through 1982, after which severe winter storms caused substantial reductions throughout the cove.

Using the results from the TEMP intertidal transect and subtidal benthic station studies, it is estimated that the storms removed about half of the surfgrass population in north Diablo Cove, and nearly the entire surfgrass population in south Diablo Cove. Thus, prior to power plant start-up, about 0.4 hectare (1 acre) of surfgrass was present in Diablo Cove, mostly in north Diablo Cove. Patches of surfgrass totaling about 0.1 hectare (0.25 acre) were observed in Diablo Cove during the 1997 summer/fall surveys, representing a loss of about 0.3 hectares (0.75 acres) of surfgrass in Diablo Cove during power plant operation. Lack of recovery to pre-storm abundances represents a potential loss of approximately 1.9 hectares (4.75 acres) of surfgrass in Diablo Cove.

Statistical analyses detected a significant decrease in surfgrass north and south of Diablo Cove for the high intertidal transect in Field's Cove and for transects analyzed for South Diablo Point. However, surfgrass was never abundant in these areas. The significant decline, relative to the control, occurred from the continued absence or near-absence of popula-tions in the high intertidal in Field's Cove and South Diablo Point being compared to increases in the control population (Figure 8).

Surfgrass in Field's Cove was common in the low intertidal and increased during power plant operation. However, the increase was not as large as increases observed at low intertidal control transects (Figure 8). Statistical analysis of the data detected the change as a significant decline in Field's Cove, relative to controls. Using the distance measurements of the TEMP Analysis Report, the spatial extent of documented effects should include partial reductions in surfgrass abundance in the low intertidal along 1.5 kilometers (0.9 miles) of shoreline, north from Diablo Cove and extending along the southern portion of Field's Cove.

No historical data was available to determine changes in subtidal surfgrass in Field's Cove, which occurs to depths of about -3 m (-10 ft). Increased water temperatures of about 1°C (1.8°F) above ambient have been recorded at -3 m in Field's Cove (Tenera, Inc., 1997). Therefore, there is the potential for effects on subtidal surfgrass in this region. However, the summer/fall 1997 dive surveys noted subtidal surfgrass in Field's Cove appeared similar in

abundance to other areas examined outside of Diablo Cove.

Although there has been a large decline in surfgrass mainly in Diablo Cove and mostly from the storms, it appears that the discharge caused further reductions in surfgrass in north and south Diablo Cove and may have directly or indirectly inhibited recovery. Statistically significant declines, relative to controls, were detected in intertidal surfgrass in Diablo Cove (Tenera, Inc., 1997). However, it is difficult to conclude from statistical analysis whether the declines in subtidal surfgrass in Diablo Cove after power plant start-up were the result of the discharge or continued effects from the 1982/83 storms (Figure 10). However, the 1997 summer/fall mapping surveys indicated the discharge has probably had some effect on subtidal surfgrass. Plants in Diablo Cove appeared more stressed than plants outside the cove, based on condition factors of shorter blade lengths and more epiphytes.

The mechanisms causing the decline in surfgrass in Diablo Cove during power plant operation are unknown. Currently, no conclusive evidence exists for effects on surfgrass from increased water temperature. Surfgrass is considered a warm water tolerant genus (Abbott and North, 1971), and laboratory experiments found that surfgrass can tolerate relatively high temperature exposures for short durations (PG&E, 1982). The temperature regimes used in the laboratory experiments rarely occur in Diablo Cove, except perhaps in a small area immediately in front of the discharge structure (Tenera Inc, 1997). Although surfgrass may be able to withstand these temperatures for short durations, nothing is known about the temperature tolerance of surfgrass when temperatures become only moderately warmed for longer periods. Both species of surfgrass occur in southern California where water temperatures are warmer than along the Diablo Canyon coast, but surfgrass in the vicinity of DCPP may be adapted to lower temperature regimes and unable to adjust to the new temperature regimes encountered in Diablo Cove.

The decline in surfgrass in Diablo Cove may have been the result of *Phyllospadix scouleri* and *P. torreyi* having different temperature tolerance thresholds, although both species have been categorized as warm water tolerant species (Abbott and North, 1971). Both can co-occur in mixed stands. They were not distinguished from one another in the quantitative studies, and therefore the two species cannot be analyzed separately for changes.

The decline in surfgrass abundance in Diablo Cove was probably not related to increased grazing. An increase in *Notoacmaea palacea*, a limpet grazer specific to surfgrass, was not observed in the TEMP study or during the 1997 summer/fall surveys. Development of sea urchin barrens (areas devoid of non-calcareous plants) in the intertidal and shallow subtidal in north Diablo Cove during the early 1990's occurred in areas previously covered with surfgrass (Tenera, Inc., 1997), but surfgrass had declined in those areas before the urchins became abundant (Figures 8 and 10). However, grazing from other limpet species and urchins that increased in abundance in Diablo Cove (Tenera, Inc., 1997) may have a role in hindering surfgrass recovery.

Flowering plants and germinating seedlings were rarely observed over the course of the TEMP studies. This suggests that the surfgrass population in Diablo Cove and neighboring areas is composed mainly of long-lived plants, which rely on vegetative growth of rhizomes and blades to replace old tissues as they degenerate and to expand in cover. Based on this theory, the potential for recovery may be low when disturbances remove plants and seed production and dispersal are affected in a negative manner.

Recovery in surfgrass has not occurred in areas of Diablo Cove where it was once abundant. In many of these areas, the branched red alga *Gastroclonium subarticulatum* has recruited and become the predominant plant. The inhibition of surfgrass recovery by algae is consistent with Turner (1985a,b), who found surfgrass slow to recover (over three years to recover) after algae became established. However, recovery potential is also related to

algae which function as "anchoring" structures for surfgrass seeds (Dawson, 1966). Nonetheless, surfgrass seeds were rarely observed in the study.

CONCLUSIONS

The scarcity of historical information, quantitative data, and descriptions of surfgrass in control areas make any assessment of changes in surfgrass from the power plant difficult. All of the available information obtained on surfgrass from the various studies at DCPP were integrated to create a reasonable scenario of changes. The TEMP qualitative surveys in 1976-77 and subsequent ancillary observations provided the only information for describing the aerial extent of surfgrass before power plant start-up, in which about 2 hectares (5 acres) of surfgrass was estimated to have been present in Diablo Cove. The 1982/83 storms and El Niño reduced the abundance to about 0.4 hectare (1 acre). The amount observed in 1997 was about 0.1 hectare (0.25 acre), representing a loss of about 0.3 hectares (0.75 acres) during power plant operation. Why surfgrass has not recovered from the storms, as observed outside Diablo Cove, is unexplained. The discharge may affect surfgrass by slowing vegetative growth, as well as hindering recruitment.

Although most effects to surfgrass were confined to Diablo Cove, the spatial description of documented effects includes partial reductions in surfgrass abundance in the low intertidal along 1.5 kilometers (0.9 miles) of shoreline, from Diablo Cove and extending along the southern portion of Field's Cove, considering shoreline indentations. No historical data were available to determine changes in subtidal surfgrass in this region, but the potential exists for effects on surfgrass to depths of -3 meters (-10 feet) in Field's Cove. No effects on surfgrass were observed in other areas examined outside of Diablo Cove.

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LETTER DATED 3/10/99 (DCL-99-517)
FROM DAVID OATLEY, PG&E
TO ROGER W. BRIGGS, RWQCB

Pacific Gas and
Electric Company

David H. Oatley
Vice President–Diablo Canyon
Operations and Plant Manager

Diablo Canyon Power Plant
P.O. Box 56
Avila Beach, CA 93424

805 545 6000

March 10, 1999

PG&E Letter DCL-99-517

Mr. Roger Briggs, Executive Officer
Central Coast Regional Water Quality Control Board
81 Higuera Street, Suite 200
San Luis Obispo, CA 93401-3147

Attn: Michael Thomas

Re: PG&E Diablo Canyon Submittal -

<u>Surfgrass (*Phyllospadix*) in the Vicinity
of Diablo Canyon Power Plant Discharge</u>

Dear Mr. Briggs:

This report was prepared to supplement the horizontal band transect (HBT) monitoring of surfgrass reported in the TEMP Analysis Report (PG&E 1997). This monitoring was performed based on the recommendation of the Regional Board's independent consultants (letters to CCRWQCB dated December 9,1996, February 12,1997). The purpose of the report is to provide qualitative information on surfgrass, particularly relative to its spatial distribution.

A draft of this report was distributed to the Thermal Effects Technical Workgroup in December 1997. This final report incorporates the comments received from the Regional Board's consultants. Results of this report were considered in the proposed redesign of the Receiving Water Monitoring Program submitted to the Regional Board on January 8, 1999 (PG&E Letter DCL-99-503).

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to ensure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, I certify that the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Sincerely,

David H. Oatley

99517/hxb/kmo

cc:	Pat Eckhardt	PG&E, 77 Beale
	Jeff Gardner	PG&E, DCPP
	Cal Gillies	PG&E, DCPP
	Anne Jackson	PG&E, 77 Beale
	Kathleen Jones	PG&E, 77 Beale
	Deborah Johnston	CDF&G
	Dave Mayer	TENERA
	John Steinbeck	TENERA - DCPP
	Michael Thomas	CCRWQCB
	ACTS/Env: Central Files	DCPP 104/5/2A
	RMS	DCPP

DCL-99-513

Diablo Canyon Power Plant

Surfgrass (*Phyllospadix*) in the Vicinity of the Diablo Canyon Power Plant Discharge

December 1998

Prepared for:
Pacific Gas and Electric Company
77 Beale Street
San Francisco, CA 94105

TENERA Environmental Services
One Market, Spear Tower, Suite 1850, San Francisco, CA 94105
(415) 536-4744, FAX (415) 536-4714
P.O. Box 400, Avila Beach, California 93424
(805) 595-2407, FAX: (805) 595-2106.

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PREFACE

This report analyzes and presents results of scientific studies carried out by Tenera, Inc. for Pacific Gas and Electric Company. The following staff members contributed to the field data collection and report preparation:

Report preparation: Mr. Scott Kimura, Lead Scientist
Mr. John Steinbeck, Data Manager

Field data collection: Mr. Mike Behrens
Mr. David Innis
Mr. Scott Kimura
Mr. John Steinbeck
Mr. Jim Strampe
Mr. Jeff Tupen

SUMMARY

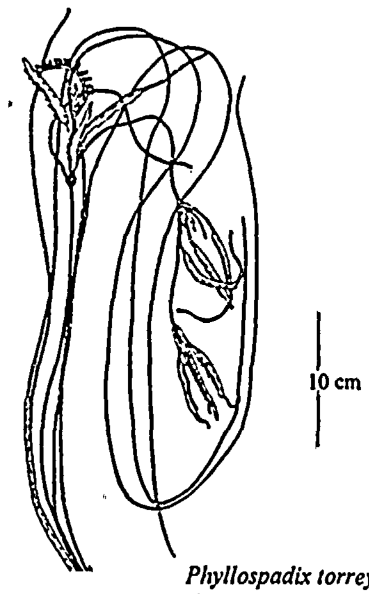
Surfgrass (*Phyllospadix* spp.) is often the predominant plant growing along the open coast between about the zero MLLW tide level and -3 m (-10 ft), providing important habitat for invertebrates and fishes. Results presented in the Thermal Effects Monitoring Program (TEMP) Analysis Report (Tenera, Inc., 1997) submitted to the Regional Water Quality Control Board (Board) showed that the Diablo Canyon Power Plant thermal discharge caused surfgrass to become less abundant at its upper and lower elevational fringes of distribution. However, data were not available on changes in surfgrass abundance in the low intertidal/shallow subtidal surf zone where it is more abundant. Surveys were not conducted in this zone on a regular basis due to difficulties in sampling effectively and consistently. In response to a request from Board staff and their independent consultant, dive surveys were completed in summer/fall 1997 to describe the spatial extent of surfgrass in the surf zone within Diablo Cove and neighboring areas. Summaries of past studies are presented to describe historical changes in surfgrass.

Based on earlier surveys, surfgrass once formed a nearly continuous band around the shoreline of Diablo Cove, covering an estimated area of about 2 hectares (5 acres) between the low intertidal and shallow subtidal (0 MLLW to -2 m MLLW). Severe storm waves in winter 1982/83 before power plant start-up reduced surfgrass cover in Diablo Cove to about 0.4 hectare (1 acre). Surveys in summer/fall 1997 showed that surfgrass cover in Diablo Cove was about 0.1 hectare (0.25 acre). Based on these qualitative estimates, the discharge reduced the cover of surfgrass in Diablo Cove by about 0.3 hectare (0.75 acre). Lack of recovery to pre-storm abundances represents a potential loss of approximately 1.9 hectares (4.75 acres) of surfgrass in Diablo Cove. The specific causes for the declines in Diablo Cove during power plant operation, and reasons for the lack of recovery are unexplained, but are likely related to factors associated with the discharge.

North of Diablo Cove, intertidal surfgrass increased in Field's Cove after the 1982/83 storms and during power plant operation, but the increase was not as large as at control stations. Statistical analysis detected the change as a significant decline in intertidal surfgrass abundance in Field's Cove, relative to control populations. There is no baseline information for determining discharge effects to subtidal surfgrass in this region. Surfgrass occurs to depths of -3 m (-10 feet) in Field's Cove. Although the potential exists for effects on subtidal surfgrass in Field's Cove, the summer/fall 1997 surveys noted subtidal surfgrass in Field's Cove appeared similar in abundance to the other areas that were examined north and south of Diablo Cove. No effects on subtidal surfgrass were observed in areas south of Diablo Cove.

INTRODUCTION

Surfgrass is a perennial, marine flowering plant (seagrass) that reproduces from seeds, unlike algae (seaweeds and kelps) that reproduce from spores. Two species of surfgrass (*Phyllospadix scouleri* Hook and *P. torreyi* S. Watson) occur along the coast, growing mainly on rock platforms and boulder fields in the zone between about the zero MLLW tide level and -3 m (-10 ft). The two species are similar in appearance, and are distinguished by blade and flower characteristics (Hickman, 1993). The most apparent difference is *P. scouleri* has slightly wider blades (1-4 mm) than *P. torreyi* (0.5-1.0 mm). Both species range from Alaska to Baja California. Due to their southern ranges, both are considered warm water tolerant species (Abbott and North, 1971). Eelgrass (*Zostera marina*) is another type of seagrass that occurs mainly in protected bays and estuaries, and is uncommon along the coast.



Phyllospadix torreyi
(from Dawson 1966)

During low tide surfgrass often appears as an emerald green belt fringing the shoreline. Surfgrass is characteristically the predominant plant in this low intertidal/shallow subtidal zone, providing important refuge and nursery habitat for invertebrates and fishes (Stewart et al., 1978, Stewart and Myers, 1980). The width of the surfgrass zone and patch sizes of surfgrass are largely dependent on the slope of the shoreline, topographical relief, and substratum availability. In addition to growing on rocks, both species of *Phyllospadix* grow in sandy areas, attached to rocks buried beneath the sand, and the rhizomes and dense blades, in turn, stabilize the sand. *Smithora naiadum*, a red blade alga, *Melobesia mediocris*, an encrusting red alga, and *Notoacmaea palacea*, a limpet, are obligate species on surfgrass.

PG&E submitted a report (TEMP Analysis Report; Tenera, Inc., 1997) that included surfgrass in descriptions of impacts from the Diablo Canyon Power Plant (DCPP) discharge. This report presents additional information on surfgrass. The TEMP Analysis Report showed statistically significant declines in surfgrass cover, relative to controls, at intertidal and subtidal stations in Diablo Cove. However, the analysis was limited to sampling results from discrete stations located at the upper and lower margins of the surfgrass zone. As a result, Board staff and their independent consultant requested PG&E to conduct reconnaissance surveys to collect data on the current status of surfgrass abundance and distribution in areas where it is more abundant (deeper than the intertidal stations and shallower than the subtidal stations). These surveys were completed in summer/fall 1997. The review of surfgrass in this report includes data from the reconnaissance surveys, descriptions not previously reported on cove-wide changes in the spatial extent of surfgrass cover in Diablo Cove, including descriptive accounts from previous studies.

METHODS

1997 Dive Surveys

As its name implies, surfgrass in central California occurs mainly in the surf zone. This zone is difficult to sample. Access must coincide with low tide during calm seas, and under those

conditions only the upper portion of habitat occupied by surfgrass becomes exposed for a couple of hours. Surfgrass is best observed by diving, but subtidal sampling is also difficult due to high surge, waves, and generally poor visibility.

In this study, qualitative diving surveys were done as the best approach to map surfgrass. Surveys were completed over several consecutive days in August and October 1997, and extended from North Control to South Control, a swimming distance of about 8 kilometers (5 miles) following the shoreline (Figure 1). In addition to mapping, notes were taken on the general condition of surfgrass (blade condition, amount of epiphytes, presence/absence of flower structures), as well as substratum characteristics along segments of the coast. Offshore islands (e.g., Diablo Rock and Lion Rock) were not surveyed, as they have a narrow intertidal/shallow subtidal zone due to steep vertical relief, and because previous observations before and during power plant operation found that surfgrass was absent in those areas. The main zone of surfgrass along the shore was surveyed during relatively calm seas when the tide was about +0.9 m (+3 ft) MLLW. However, the lower intertidal zone could not be easily surveyed, due to surf conditions and poor visibility.

Previous Studies at DCPP

Some of the previous studies at DCPP that sampled surfgrass began before the TEMP in 1976 and were largely confined to Diablo Cove. The reports provide background on historical conditions of surfgrass within the cove. The findings are summarized in the results section of this report.

RESULTS

1997 Dive Surveys

Results from the 1997 summer/fall mapping surveys are summarized in Table 1. A map showing the distribution of surfgrass from North Control to South Control compiled from the surveys is shown in Figure 2.

Distribution

Surfgrass occurred mostly on top of scattered boulder and rock outcroppings from North Control to South Control (Figure 2). The main

Table 1. Summary of observations on surfgrass made during the 1997 summer/fall dive surveys.

Area	Relative Abundance	Blade Length	Condition/Epiphytes
North Control	Abundant and commonly growing on rock outcroppings and boulders	Normal	Relatively clean and normal appearing
Lion Rock (inshore)	Abundant and commonly growing on rock outcroppings and boulders	Normal	Relatively clean and normal appearing
Field's Cove	Abundant and erect canopy formation at head of cove	Normal	Relatively clean and normal appearing
North Diablo Point	Abundant inside a small headland indentation	Normal	Relatively clean and normal appearing
North Diablo Cove	Sparse, confined to a small pocket near the cliff-base stairway	Normal but reduced in length after a storm event	Covered with dense *Ulva/Enteromorpha* and diatoms before a storm event, relatively clean after, but blades reduced in length by about half (0.5 m) from storms. Blades outside Diablo Cove were about twice as long.
South Diablo Cove	Sparse, several small patches	Normal but reduced in length after a storm event	Covered with dense *Ulva/Enteromorpha* and diatoms before a storm event, relatively clean after, but blades reduced in length by about half (0.5 m) from storms. Blades outside of Diablo Cove were about twice as long.
South Diablo Point	Absent	-	-
Breakwaters	Absent	-	-
Seal Haulout	Absent along steep walls	-	-
South Control	Abundant, dense stands, erect canopy formation at head of Patton Cove	Normal	Relatively clean and normal appearing

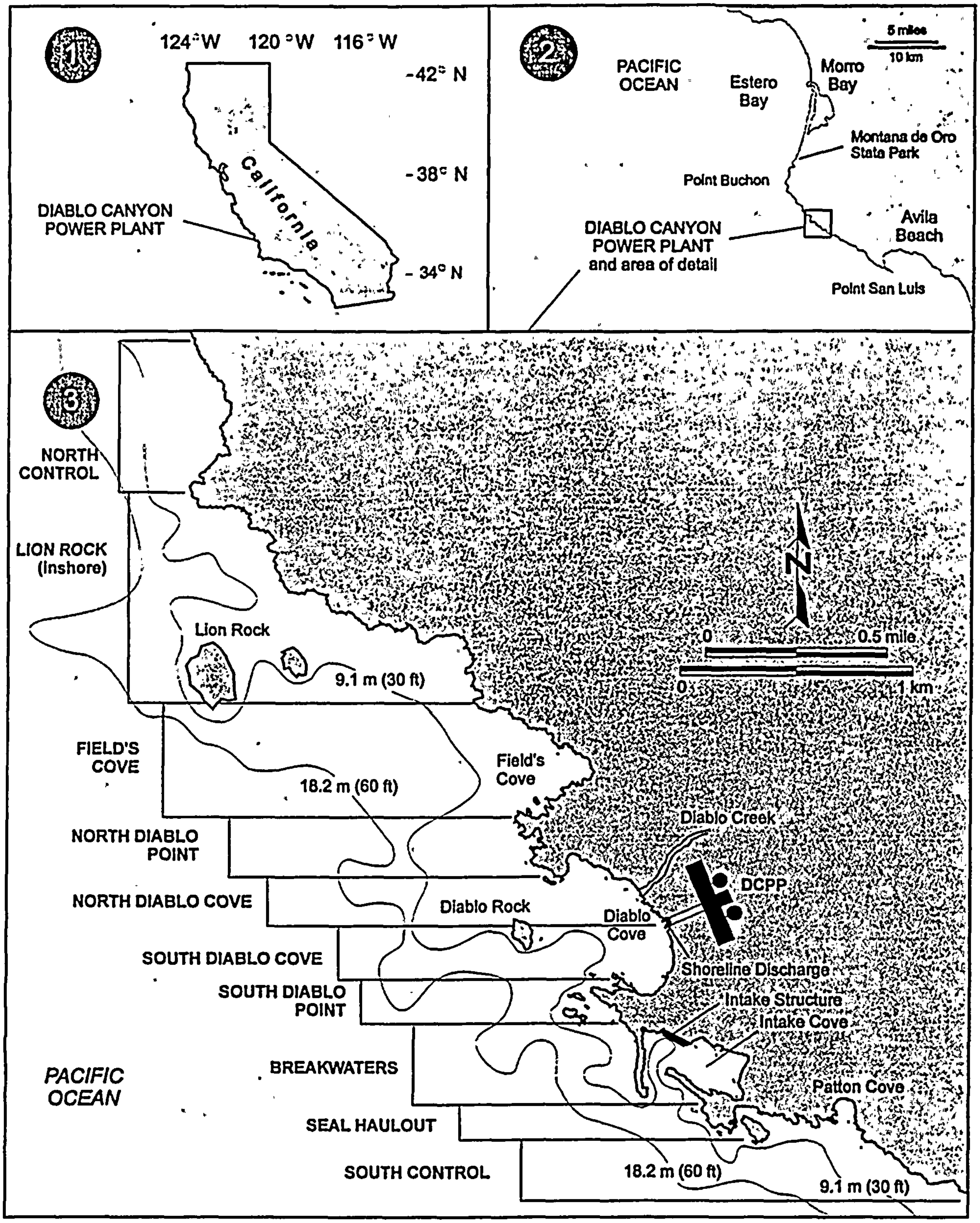


Figure 1. Location of the Diablo Canyon Power Plant (DCPP) and coastline segments surveyed for surfgrass.

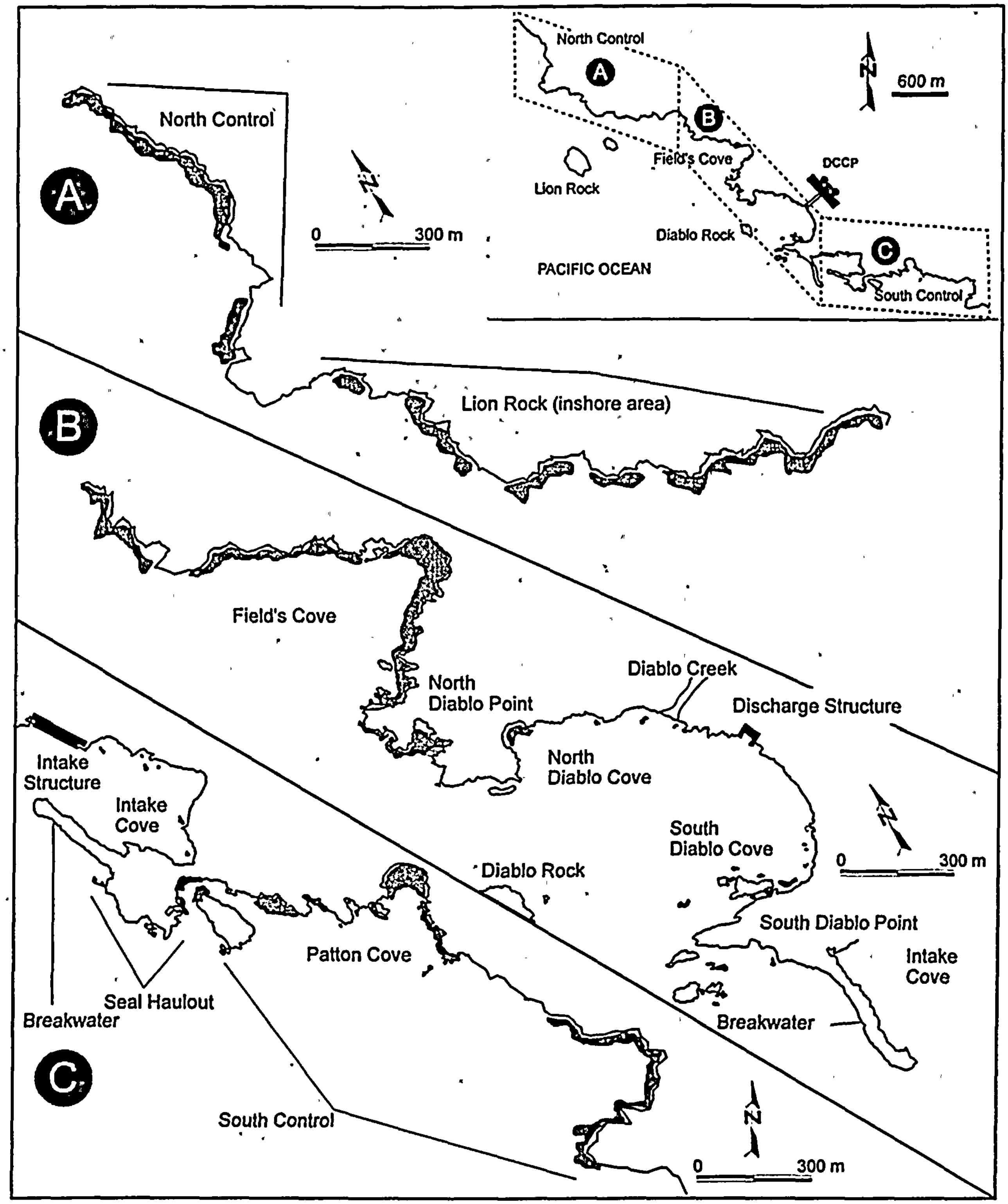


Figure 2. Map of the Diablo Canyon coastline and distribution of surfgrass from North Control to South Control from the 1997 summer/fall surveys. Areas that included surfgrass shown in dark shading. Areas outside Diablo Cove that lacked surfgrass were generally steep. Areas in Diablo Cove that lacked surfgrass were generally suitable for surfgrass in terms of substratum compostion and depth, but the areas were covered with algae.

zone of surfgrass was between approximately the zero MLLW tide level and -3 m (-10 ft) contours. The longest break in the shoreline distribution of surfgrass was within Diablo Cove.

Abundance

Phyllospadix scouleri was the predominant species, but several small patches of *P. torreyi* were present in the intertidal zone in Patton Cove located in the South Control area. Surfgrass was not present where steep vertical relief resulted in a narrow intertidal/shallow subtidal zone. Overall, surfgrass was least abundant in Diablo Cove. Patches of plants were present in both north and south Diablo Cove. Based on Geographic Information System (GIS) analysis, the coverage of surfgrass in Diablo Cove was about 0.1 hectare (0.25 acre). Surfgrass was more extensive outside Diablo Cove. Areas where surfgrass was sparse or absent, foliose red algae (primarily *Gigartina*, *Prionitis*, *Cryptopleura*, and articulated corallines) formed the predominant cover over the bottom. In Diablo Cove, the branched red alga *Gastroclonium subarticulatum* covered large areas in the surfgrass zone.

Condition

Surveys in Diablo Cove were conducted in August and again in October following a storm. Before the storm, surfgrass in Diablo Cove was covered with more epiphytes (mostly the foliose green algae *Ulva/Enteromorpha* spp.) than plants in Field's Cove and Patton Cove. The epiphytes were growing from near the distal ends of the surfgrass blades. In addition, the tips of nearly all surfgrass blades in Diablo Cove were generally more tattered than plants found outside the cove. Epiphytes typically grow on weakened host tissues, and therefore plants inside the cove appeared to be less healthy than plants outside the cove. After the storm, the blades of surfgrass in Diablo Cove had become noticeably shorter in length (change from about 1.0 m to about 0.5 m long), due to breakage at weakened tissue points. Although shorter, the remaining blade tissues were normal in color, had fewer epiphytes, and appeared relatively healthy. No change in the condition of surfgrass was observed outside Diablo Cove between surveys conducted before and after the storms. Blades were about one meter and greater in length. The lack of blade shortening from the storms was likely related to the plant tissues not being weakened by epiphytes. *Melobesia mediocris*, *Smithora naiadum*, and *Notoacmaea palacea* were not abundant on surfgrass blades in any area surveyed before or after the storms. No flower structures were observed during the surveys.

Previous Studies at DCPP

A number of previous studies at DCPP included recording the presence/absence or cover of surfgrass. Surfgrass thermal tolerance experiments were also completed at the PG&E on-site biological laboratory. The studies and findings are summarized in Table 2 and below.

North (1969) - Qualitative Subtidal Observations: The first biological dive surveys of Diablo Cove were done in 1966 and 1967 by North (1969). The qualitative study developed the cove's first species list and mapped the general distribution of the most conspicuous plant species in the cove. Subtidal surfgrass was noted as a principal plant species observed near the discharge in south Diablo Cove. No surveys were done outside Diablo Cove.

North et al. (1989) - Intertidal Vertical Band Transect Sampling: Sampling was conducted at four intertidal permanent locations from 1976 to 1987 (Figure 3). At each location a transect tape (about 50 meters long) was stretched from near the cliff base down to the water line (MLLW), running through permanent anchors. Sequentially placed 1m^2 quadrats were sampled along the tape. Sampling consisted of visual estimates of plant cover (including surfgrass) found in each quadrat.

North et al. (1989) recognized *Phyllospadix scouleri*, versus *P. torreyi*, as the more abundant of the two species. Data for surfgrass are shown in Figures 4 and 5. Surfgrass was absent at the Lion Rock (LCIX) transect, and therefore no

Table 2. Summary of surfgrass field and laboratory investigations at DCPP.

Investigating Organization or Author(s)	Report or Study Title	Duration	Zone Studied	Study Description	Findings
North (1969)	An Evaluation of the Marine Flora and Fauna in the Vicinity of Diablo Cove, California	1966-67	Subtidal	Qualitative surveys in Diablo Cove No surveys outside Diablo Cove	Surfgrass most abundant in south Diablo Cove in regions between about MLLW and -3 m (-10 ft)
North et al. (1989)	Wheeler J. North Ecological Studies at Diablo Canyon Power Plant	1976-87	Intertidal	Quantitative sampling at permanent vertical band transects in Diablo Cove No control population sampled	Large declines in surfgrass before power plant start-up due to 1982/83 storms and El Niño Additional declines in Diablo Cove late in the study, but no control for comparing changes to natural variation
Gotshall et al. (1984, 1986)	1984: A Quantitative Ecological Study of Selected Nearshore Marine Plants and Animals at the Diablo Canyon Power Plant Site 1986: Pre-Operational Basesine Studies of Selected Nearshore Biota at the Diablo Canyon Power Plant Site	1974-82	Intertidal	Fish and Game Studies: Quantitative random sampling within specific areas in Diablo Cove and at North Control	Increase in surfgrass abundance at all locations studied Study ended before the 1982/83 storms and El Niño
PG&E (1982)	Compendium of Thermal Effects Laboratory Studies	1979 and 1982	Lab	Thermal tolerance studies in 1979; reporting in 1982	Surfgrass tolerant to 24°C (75°F) for nine days and to 34°C (93°F) for three hours without deleterious effects
PG&E/Tenera (ongoing)	Thermal Effects Monitoring Program (TEMP) / Receiving Water Monitoring Program (RWMP)	1976 (ongoing)	Intertidal	Sampling at horizontal band transects	Declines in surfgrass in Diablo Cove after power plant start-up Surfgrass increased or remained unchanged outside Diablo Cove
			Intertidal	Sampling at vertical band transects in Diablo Cove for plant taxa beginning in 1979 Sampling at vertical band transects in Field's Cove for plant taxa beginning in 1985	Diablo Cove: declines in surfgrass after power plant start-up Field's Cove: surfgrass unchanged during power plant operation, but no pre-operation database for comparison
			Intertidal and Subtidal	Qualitative surveys and ancillary observations in Diablo Cove; none outside Diablo Cove	Surfgrass present as a nearly continous band around the shoreline of Diablo Cove, from about MLLW to -2 m (-6 ft) with some patches at -3 m (-10 ft) Large declines in 1982/83 from storm effects
			Subtidal	Sampling at benthic stations	Declines in surfgrass beginning in 1982/83 from storm effects and continued through power plant operation
Tenera, Inc. 1997	Changes in the Marine Environment Resulting from the Diablo Canyon Power Plant Discharge	Analysis of TEMP studies completed from 1976 to 1995	Intertidal	Analysis of TEMP horizontal band transect data	Statistically significant declines, relative to controls, at the upper zone of surfgrass in Diablo Cove, Field's Cove, and South Diablo Point
	Changes in the Marine Environment Resulting from the Diablo Canyon Power Plant Discharge	Analysis of TEMP studies completed from 1976 to 1995	Subtidal	Analysis of TEMP benthic station data	Statistically significant declines, relative to controls, at the lower zone of surfgrass in Diablo Cove

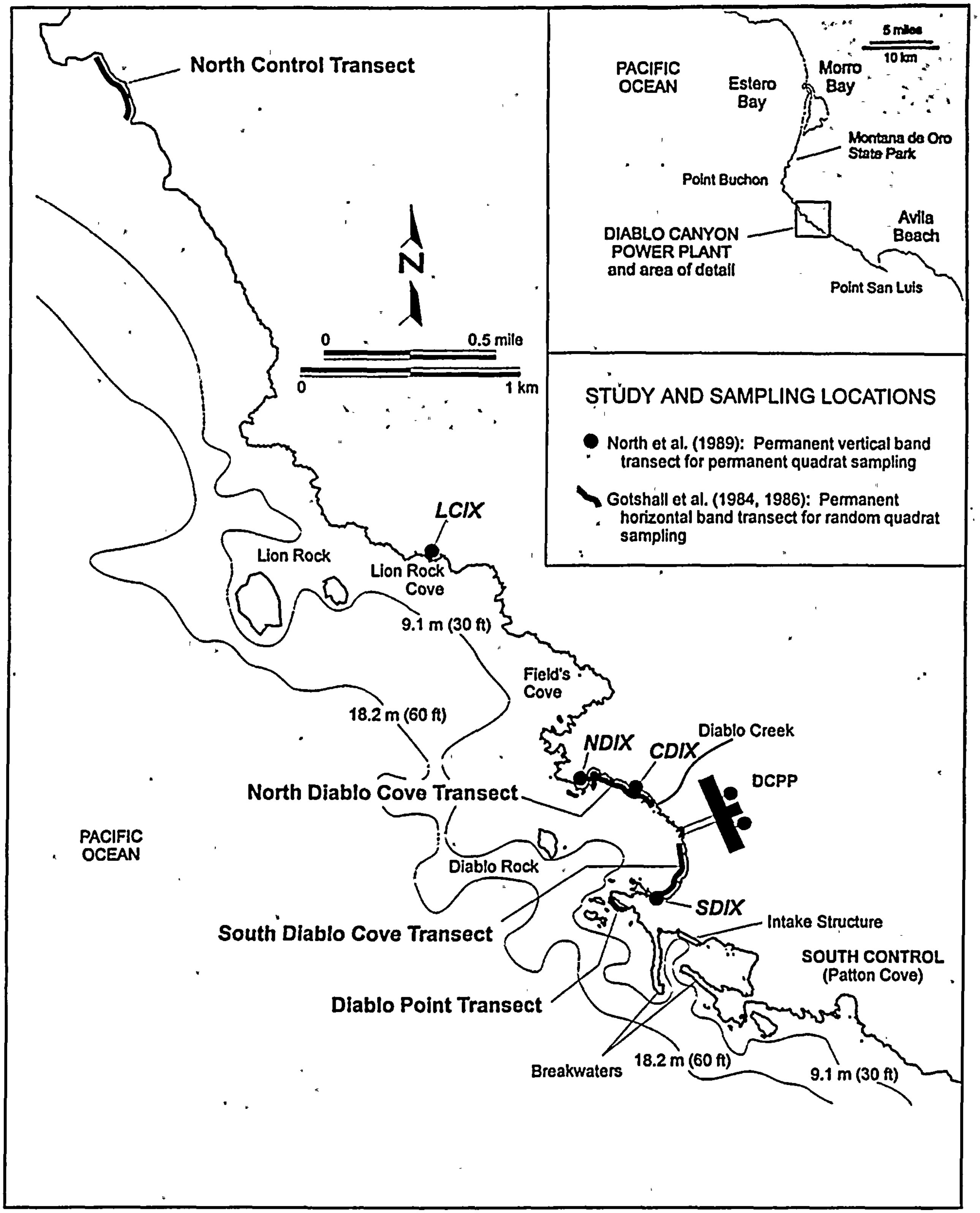


Figure 3. Locations of intertidal vertical band transects sampled by North et al. (1989) and transects of random quadrats sampled by Gotshall et al. (1984, 1986).

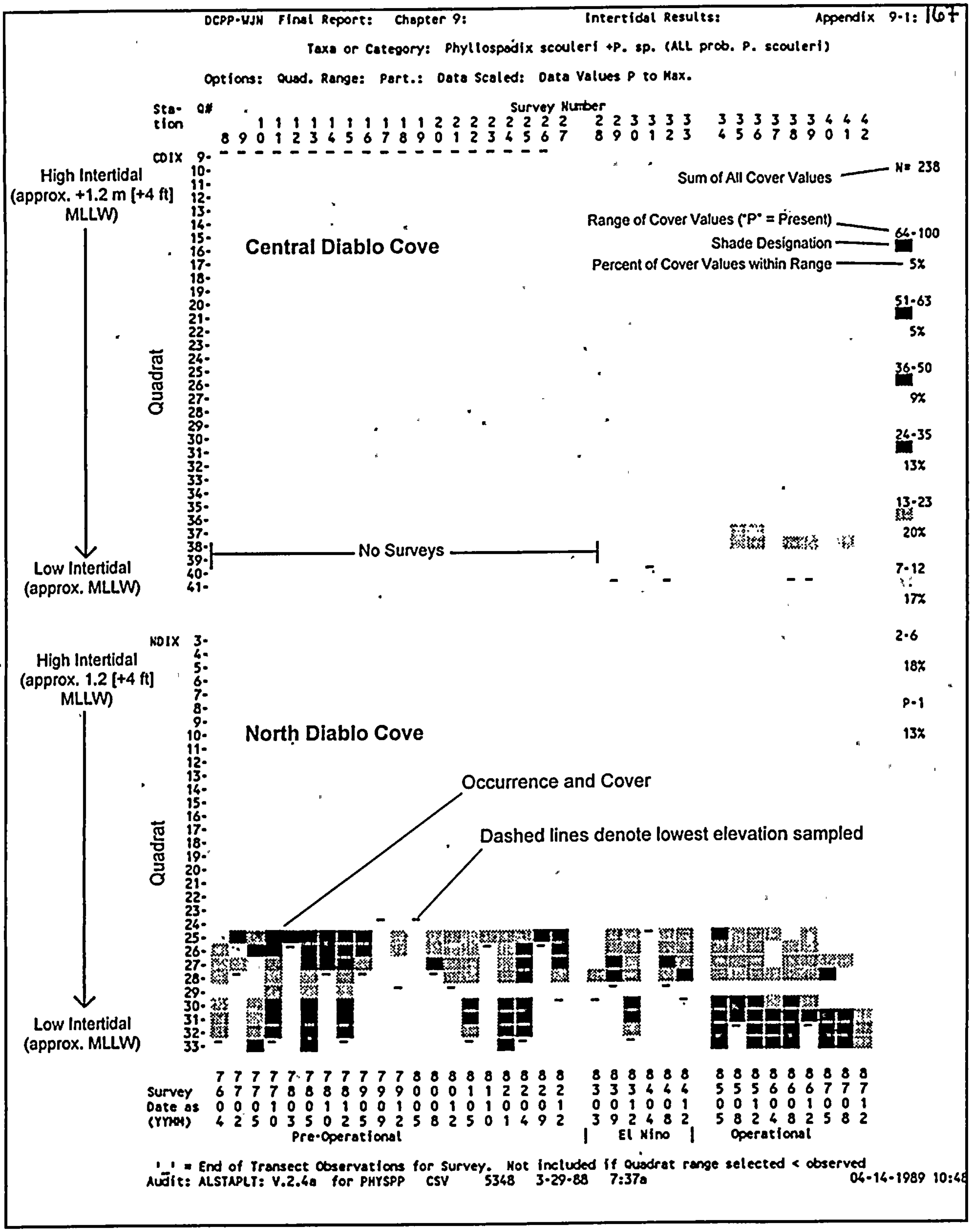


Figure 4. Graph from North et al. (1989) on changes in the occurrence and cover of surfgrass (*Phyllospadix*) at intertidal vertical transect stations CDIX (central Diablo Cove) and NDIX (north Diablo Cove). The darker the box shading the greater the observed cover. See Figure 4 for station locations.

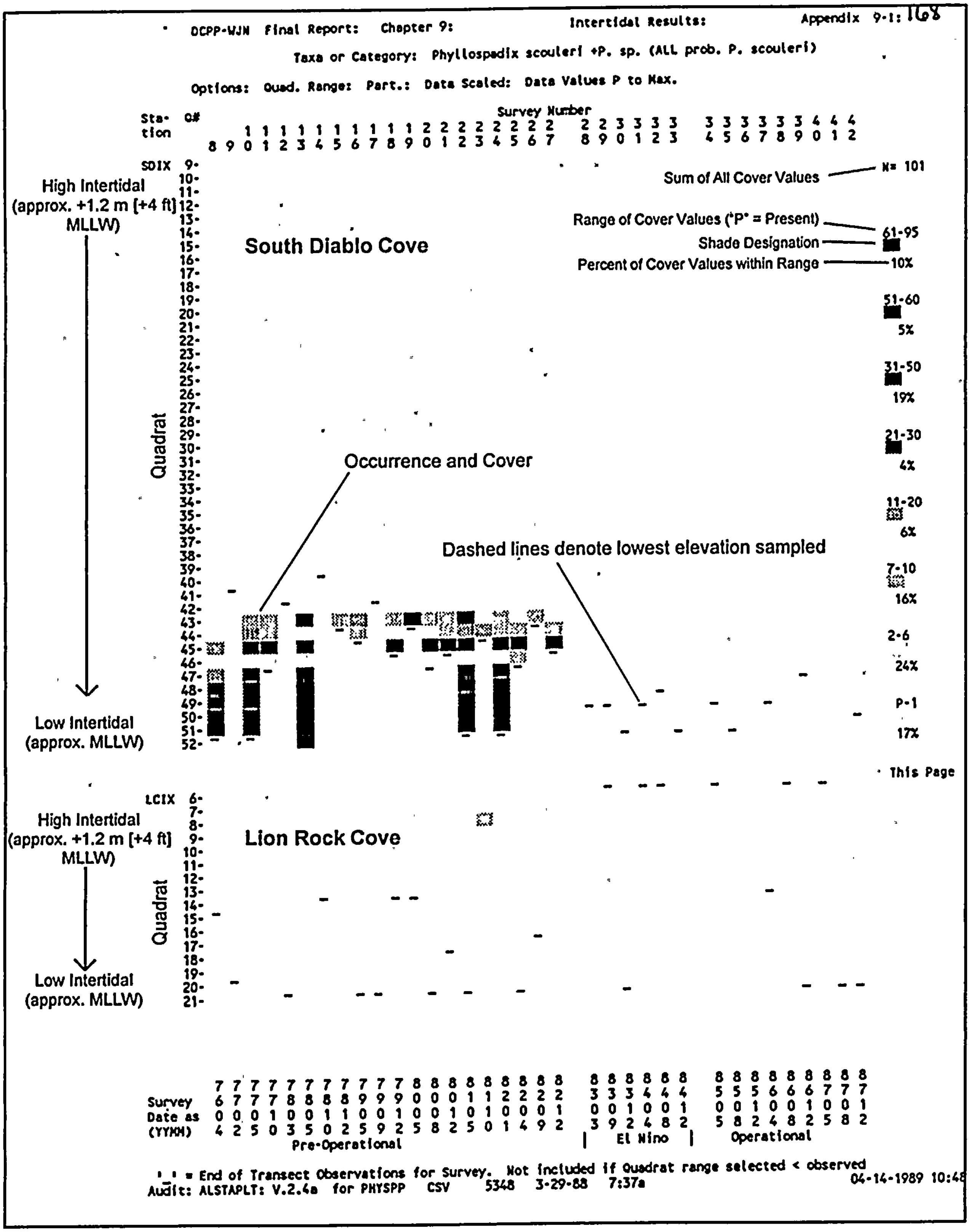


Figure 5. Graph from North et al. (1989) on changes in the occurrence and cover of surfgrass (*Phyllospadix*) at intertidal vertical transect stations SDIX (south Diablo Cove) and LCIX (Lion Rock Cove). The darker the box shading the greater the observed cover. See Figure 4 for station locations.

control population was sampled in this study. North et al. (1989) attributed a reduced abundance of surfgrass in Diablo Cove during power plant operation to reductions that occurred during the 1982/83 storms and El Niño.

Gotshall et al. (1984, 1986) - Intertidal Random Quadrat Sampling: Surfgrass was monitored as part of the California Department of Fish and Game intertidal study at DCPP. Surfgrass was absent at the South Diablo Point sampling area shown in Figure 3. The two species of surfgrass were not differentiated during sampling. In each area, the coverage of surfgrass was visually estimated in up to 40-0.25 m^2 quadrats randomly placed along transects near the zero MLLW tide level. The study began in 1974 and ended in 1982 just before power plant start-up and the 1982/83 El Niño and storms. During the study, surfgrass remained relatively abundant in each study area and generally increased in all areas from 1980 through 1982 (Figure 6). Surfgrass in the subtidal was not monitored by Gotshall et al. (1984, 1986).

Tenera, Inc. (1997) - TEMP Analysis Report, Intertidal Studies, Horizontal Band Transect Sampling: The primary intertidal results from 1976 to 1995 presented in Tenera, Inc. (1997) were based on the horizontal band transect study. In this study plant coverage was visually estimated for each taxa encountered in 10 fixed $1m^2$ quadrats positioned along permanent transect lines oriented parallel-to-shore. The transects were located at the +0.3 m (+1 ft) and +0.9 m (+3 ft) MLLW tide level in Diablo Cove and neighboring areas (Figure 7). Generally, a station consisted of both an upper and lower elevation transect. Surfgrass was present in some quadrats, although most quadrats were above the upper zone of surfgrass. *P. scouleri* was the more abundant of the two species.

Power plant effects on surfgrass were analyzed using data from the horizontal band transect study. Changes in surfgrass cover at all of the TEMP stations are shown in Figure 8. Only a subset of stations in Diablo Cove, Field's Cove, and South Diablo Point were suitable for statistical analysis (those with the greatest number of sampling completions over time and least physically damaged by the 1982/83 winter storms and 1983 El Niño). Analysis methods and station selection rationale were presented in the TEMP Analysis Report (Tenera, Inc., 1997).

Data for surfgrass in the horizontal band transect study did not meet the assumptions for analysis of variance, and were analyzed using the Fisher's exact test. The Fisher's exact test showed statistically significant declines in surfgrass cover ($p<0.1$), relative to controls for the station transects in Diablo Cove. The greatest declines occurred in north Diablo Cove, beginning in 1987 (Figure 8). In south Diablo Cove, surfgrass declined to near-absence before power plant start-up as a result of the 1982/83 storms and El Niño. The analysis also detected a significant decrease relative to the controls in Field's Cove and South Diablo Point. Surfgrass increased in abundance at the Field's Cove transect, but the increase was not as large as increases at the control transects, resulting in the significant difference. The South Diablo Point transects were not in a suitable area for surfgrass, as surfgrass remained absent at those transects both before and during power plant operation. The analysis detected the lack of change as a significant decrease relative to controls.

Tenera, Inc. (1997) - TEMP Analysis Report, Subtidal Studies, Benthic Station Sampling: In the TEMP subtidal study, the percentage cover of surfgrass was recorded at permanent benthic stations, $28m^2$ in area (Figure 9). The shallowest stations at -3 m (-10 ft) were at the lower depth limit of surfgrass. Percentage cover measurements were obtained using a random point contact sampling method. Two-hundred random points per station were sampled for the presence or absence of plants.

Surfgrass was present at only a few of the stations sampled, and declined in cover at those stations prior to power plant start-up during the 1982/83 winter storms and El Niño (Figure 10). Data from this study were statistically analyzed for power plant effects. The data were tested using a before-after/control-impact analysis of variance model (BACI analysis). The analysis showed statistically significant declines ($p<0.1$)

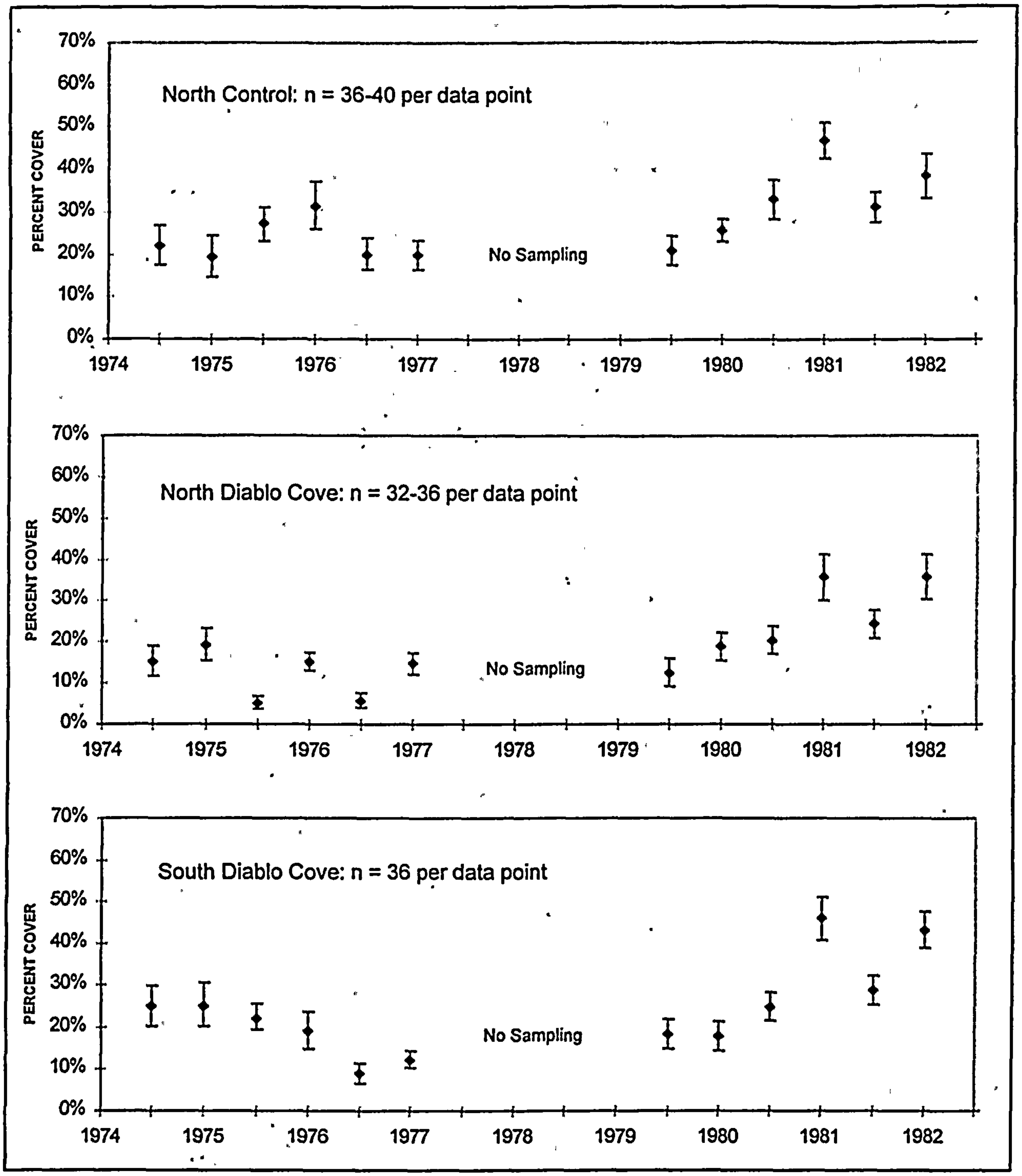


Figure 6. Changes in surfgrass cover from random $0.25m^2$ quadrat sampling at the MLLW tide elevation. Vertical bars are +/- one standard error. Data compiled from Gotshall et al. (1984, 1986). See Figure 3 for sampling areas.

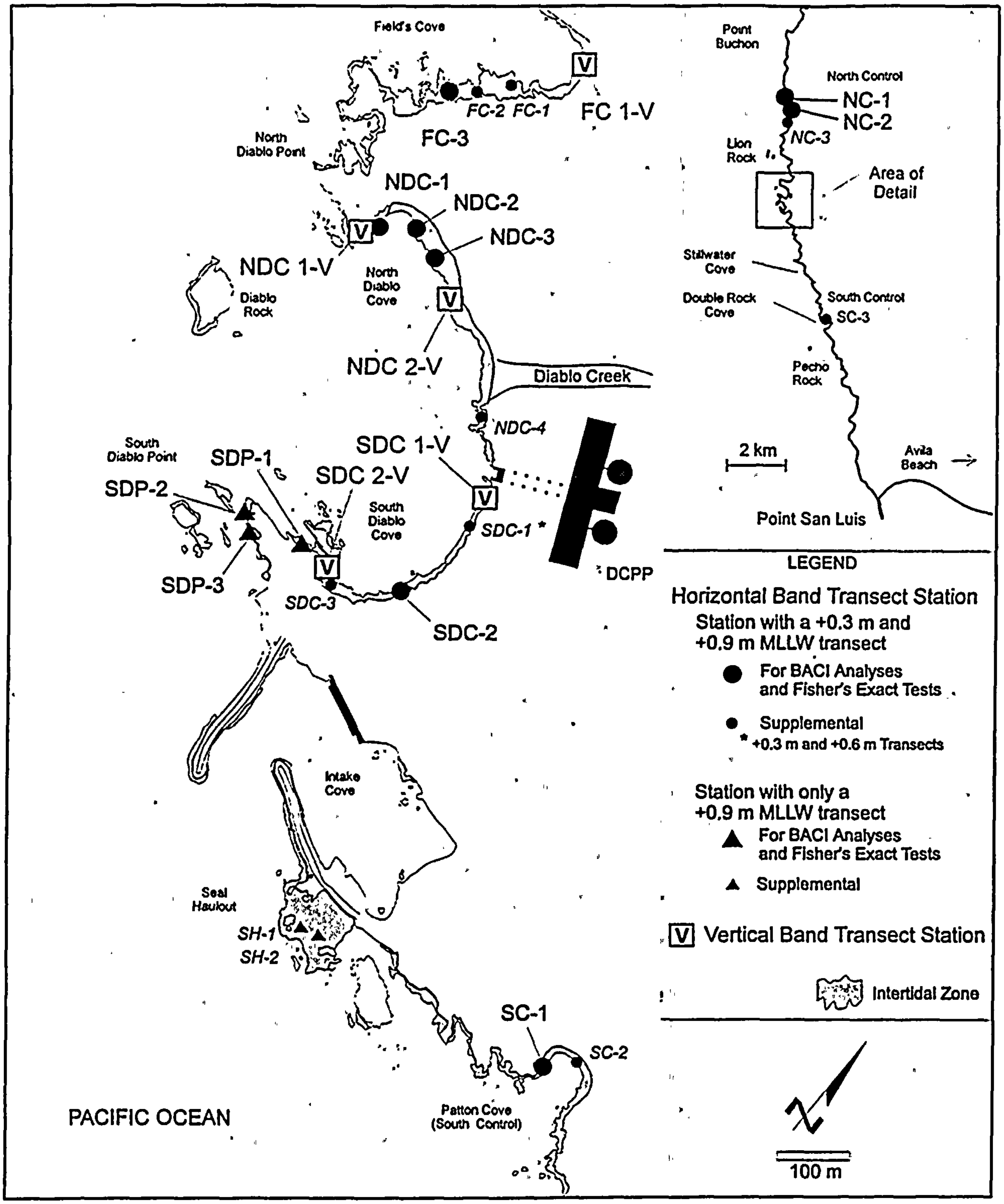


Figure 7. Locations of TEMP intertidal horizontal and vertical band transect stations.

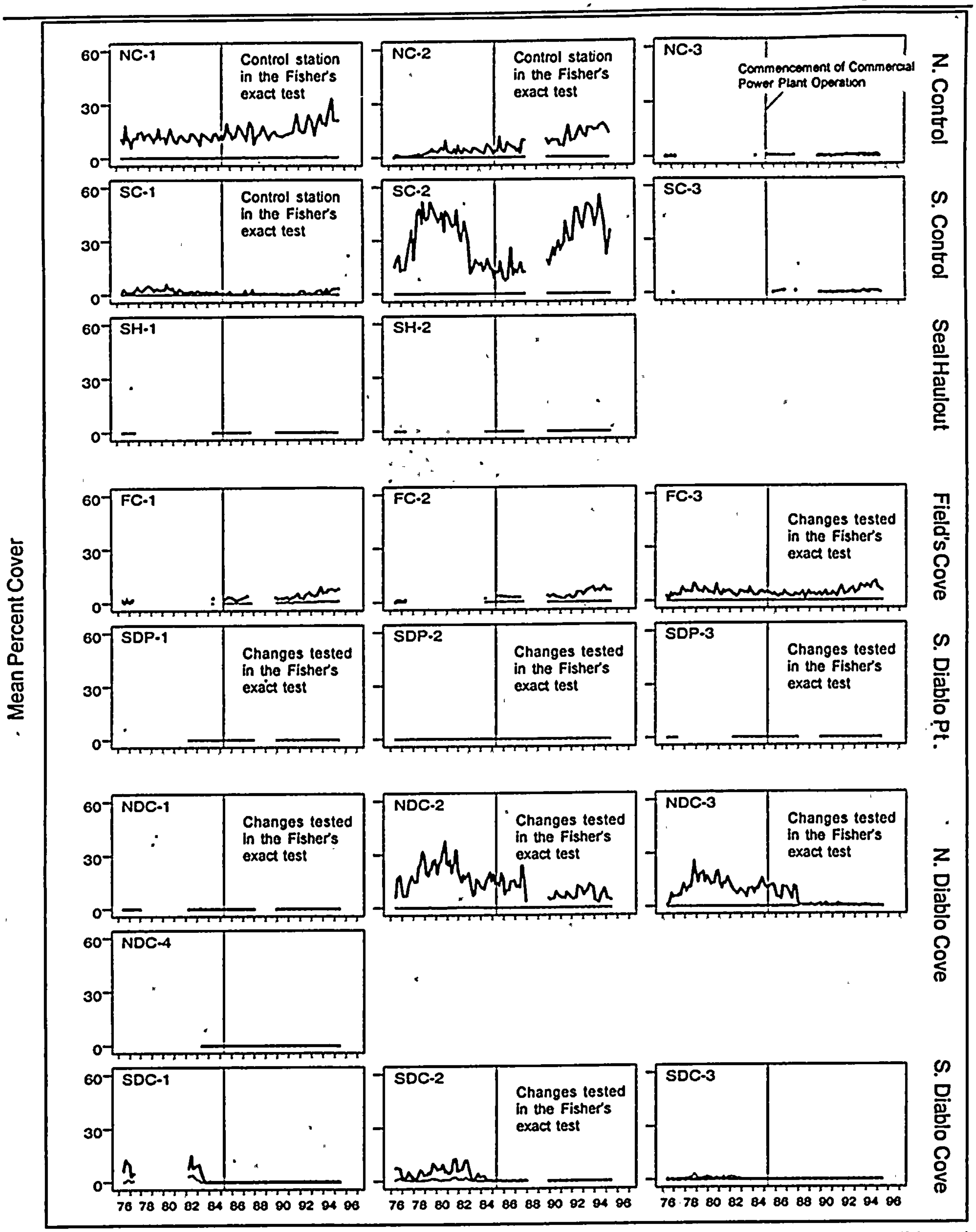


Figure 8. *Phyllospadix* spp.: changes in cover at the TEMP intertidal horizontal band transects. Wide and thin lines represent +0.3 m and +0.9 m MLLW transect data, respectively. See Figure 7 for transect locations. Note that before power plant start-up, *Phyllospadix* declined in abundance by about half in north Diablo Cove and to absence in south Diablo Cove from the 1982/83 storms and El Nino. Changes in Field's Cove were more similar to controls than to changes in Diablo Cove. *Phyllospadix* was generally always absent at all +0.9 m transects, including South Diablo Point. Graph from PG&E (1997).

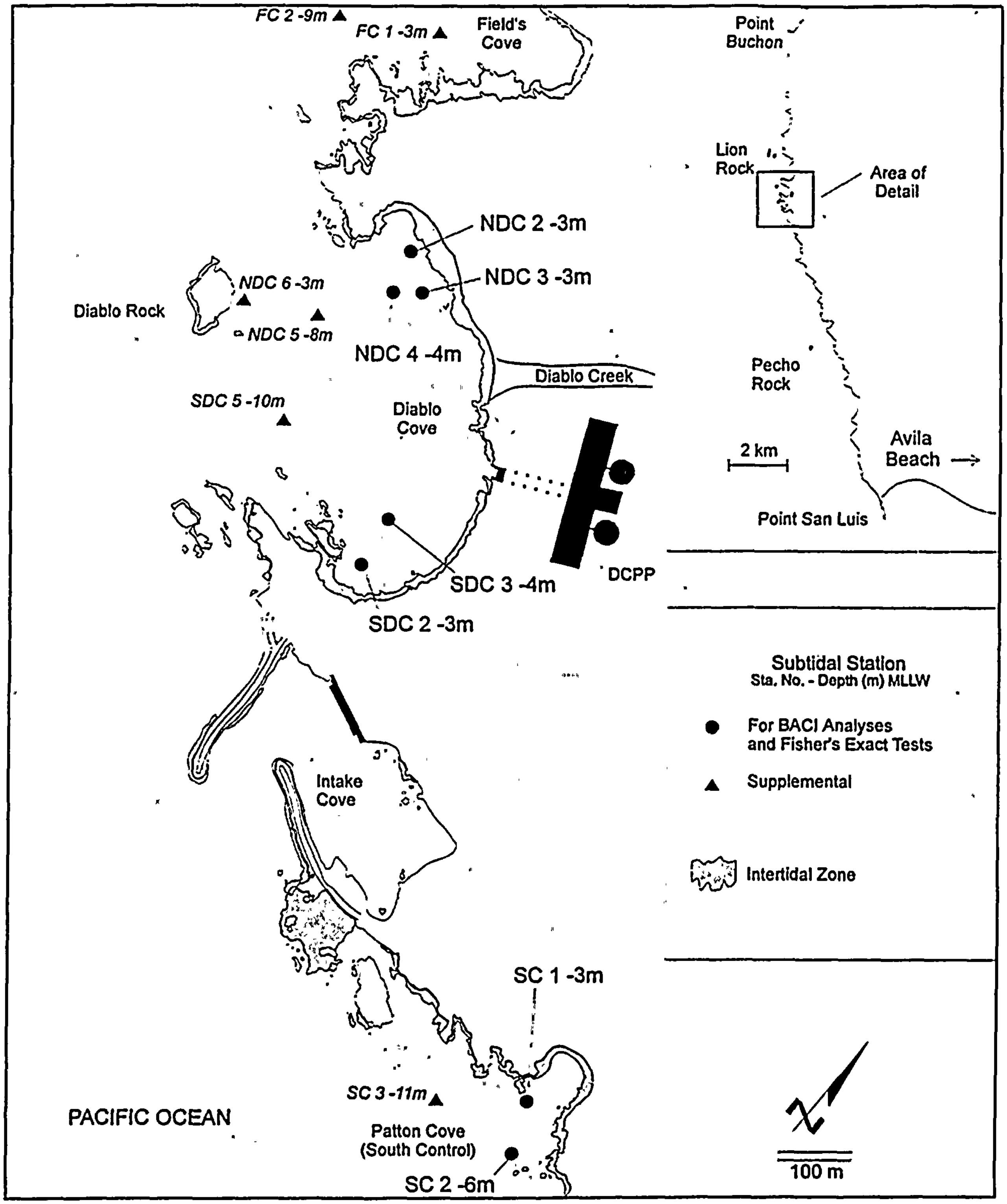


Figure 9. Locations of TEMP subtidal benthic stations.

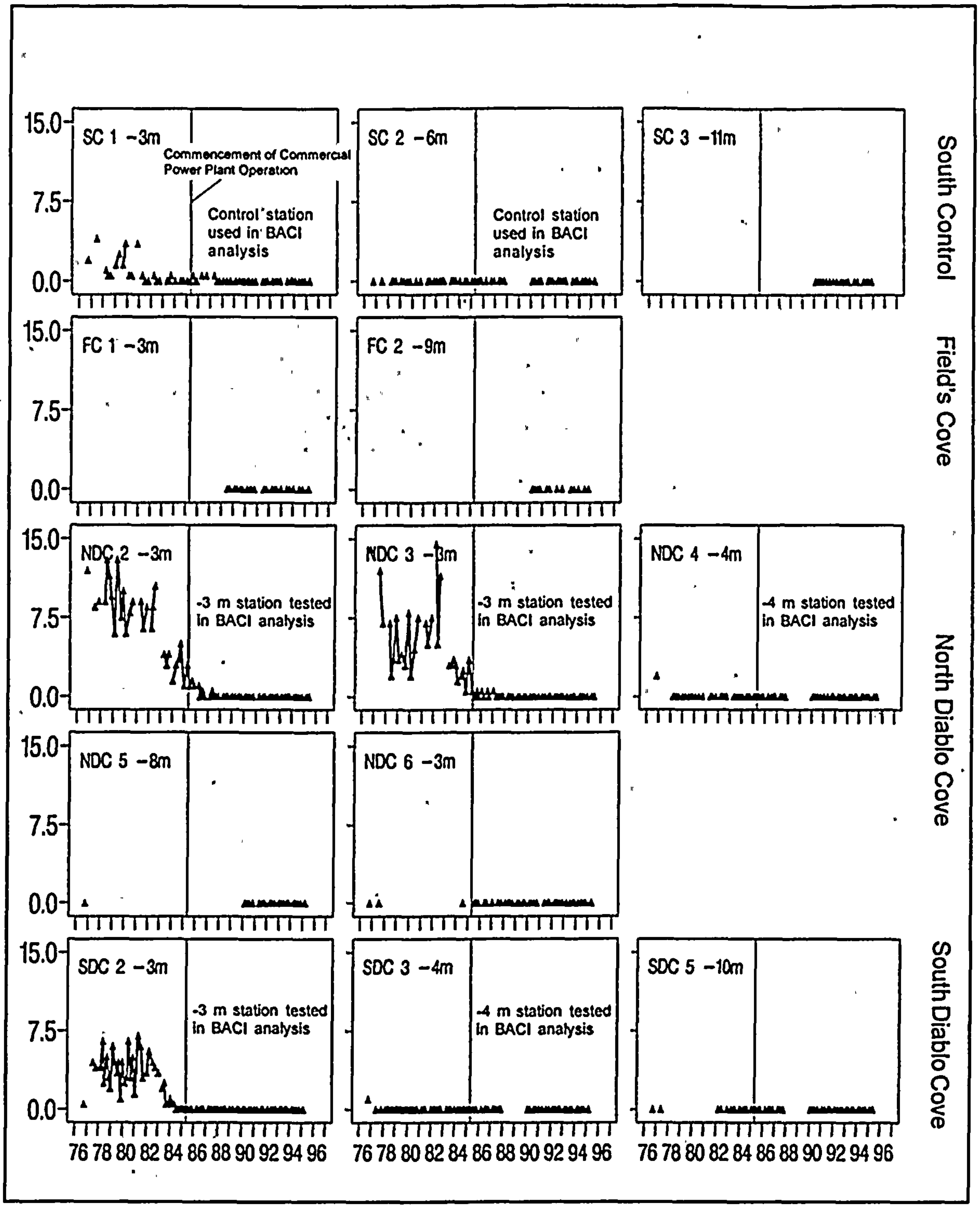


Figure 10. *Phyllospadix* spp.: changes in cover at the TEMP subtidal benthic stations. See Figure 9 for station locations. Changes in the control population were similar to changes at the Diablo Cove stations tested in the BACI analysis. Note that before power plant start-up, *Phyllospadix* declined in abundance from the 1982/83 storms and El Nino to about half the amount of previous abundances in north Diablo Cove and to absence in south Diablo Cove. *Phyllospadix* was generally always absent at the -4 m Diablo Cove stations tested in the BACI analysis. Graph from PG&E (1997).

at Diablo Cove -3 m (-10 ft) depth stations, relative to the control population, which also declined. Because the declines were largest at the Diablo Cove stations, the analysis interpreted the change as a significant relative decrease. In contrast, the analysis detected a significant increase for the -4 m (-15 ft) depth stations in Diablo Cove relative to the control. This was the result of surfgrass not occurring at the Diablo Cove -4 m (-15 ft) depth stations, and being compared to a declining control population (Figure 10) in the BACI analysis. (i.e., An unchanged surfgrass population in Diablo Cove was compared to a declining control population, resulting in a relative increase detected in the BACI analysis.)

TEMP - Intertidal Vertical Band Transect Sampling: In the vertical band transect study, the presence of plant species was recorded for 9-12 permanent 1m^2 quadrats sampled along permanent transects oriented perpendicular-to-shore. The transects ran from about the +1.2 m (+4 ft) MLLW tide level to MLLW. Three parallel transects (separated by several meters) were positioned at each station. Four stations were located in Diablo Cove and one station was in Field's Cove (Figure 7). Results from this study for plant taxa were not reported in the TEMP Analysis Report (Tenera, Inc., 1997), since the data could not be analyzed statistically. The only station outside Diablo Cove was located in Field's Cove, and plant taxa were not sampled there before power plant start-up. It was also found that the mean water temperature in Field's Cove was increased by about 1°C (2°F) above ambient conditions during power plant operation (Tenera, Inc., 1997). Therefore, there were no data from a control population sampled before and after power plant start-up for this study.

The data for the vertical band transects are included in the present report, because the study sampled lower intertidal elevations occupied by surfgrass (i.e., elevations below those sampled by the TEMP horizontal band transects). However, changes at the vertical band transect stations (Figure 11) were similar to those observed at the horizontal band transect stations (Figure 8) for the same areas sampled by the two studies. Although there are no pre-operation data for the Field's Cove station, surfgrass remained relatively unchanged in occurrence at the Field's Cove station during power plant operation. However, it declined in occurrence between the high and low intertidal zones at north Diablo Cove stations. Surfgrass declined in occurrence before power plant start-up at south Diablo Cove stations. These results are also similar to those of North et al. (1989) (Figures 4 and 5).

TEMP Qualitative Observations: Thousands of hours were spent completing the various field tasks of the TEMP. Reproductive surfgrass and germinating seedlings were only occasionally seen during these efforts before and after power plant start-up.

TEMP divers conducted a qualitative surfgrass survey in 1976-77, noting the distribution and abundance of surfgrass in Diablo Cove (J. Blecha, pers. comm.). Surfgrass was found forming a nearly a continuous band around the shoreline of Diablo Cove and was the predominant plant in the zone between about MLLW and -2 m (-6 ft) with plants occasionally at -3 m (-10 ft). However, surfgrass was absent or sparse in the region of Diablo Creek. Based on a GIS analysis of maps redrawn by Blecha (pers. comm.), the coverage of surfgrass in Diablo Cove in 1976-77 was approximately 2 hectares (5 acres). No areas outside Diablo Cove were surveyed in the 1976-77 surveys.

Substantial reductions in the abundance of surfgrass occurred over large areas in Diablo Cove, particularly in south Diablo Cove, during the 1982/83 winter storms and El Niño. The transport of large quantities of sand from the subtidal onto the intertidal in south Diablo Cove and the erosion of cliff sediments backing the south Diablo Cove intertidal zone scoured the surfgrass zone in nearly all of south Diablo Cove. Other portions of the surfgrass zone in south Diablo Cove became buried under rock fragments from a collapsed cliff. As a consequence, surfgrass throughout nearly all areas of south Diablo Cove declined in abundance. Impacts from the storms were evident at south Diablo Cove stations (Figures 9,

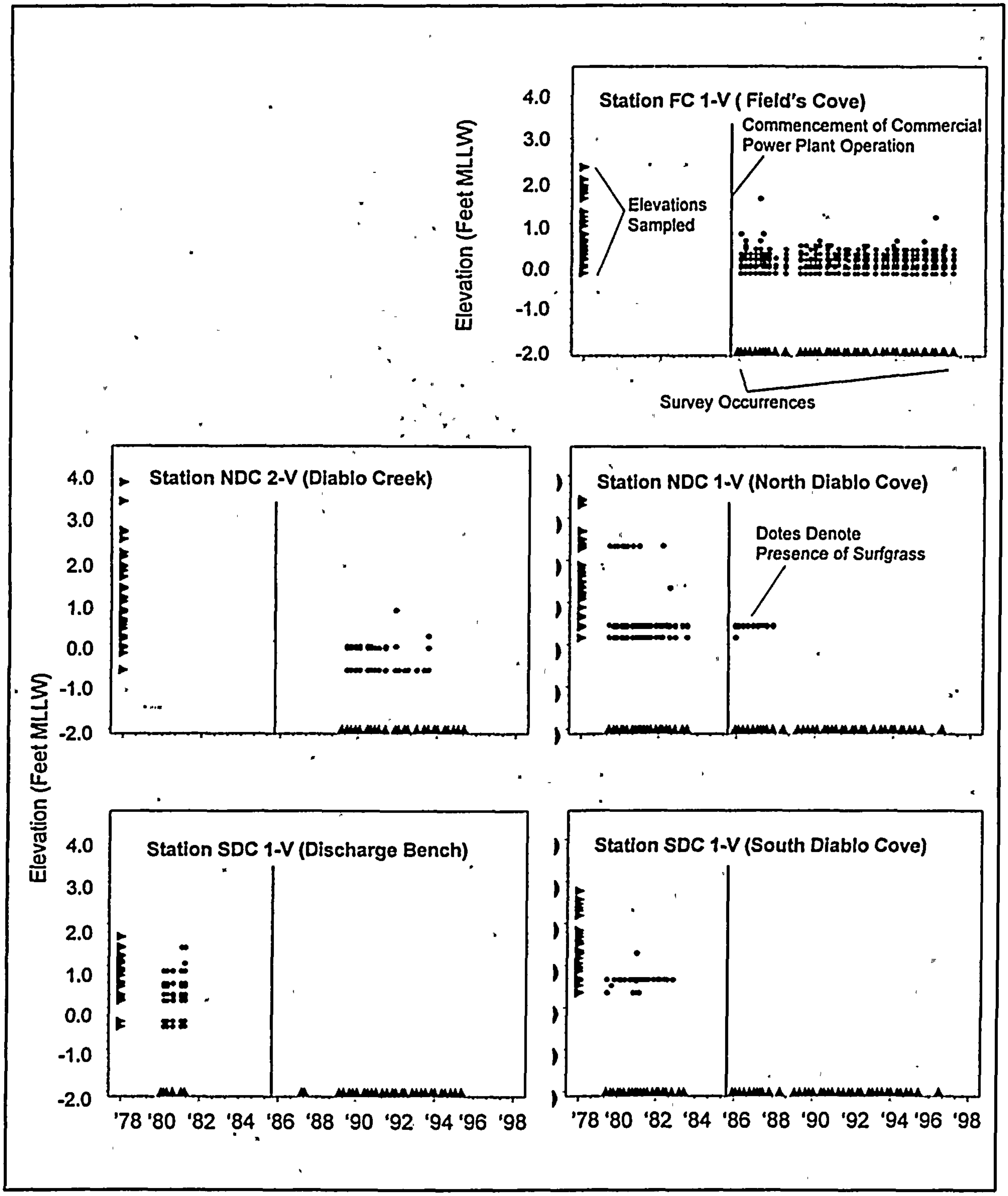


Figure 11. Changes in the vertidal distribution of surfgrass at the TEMP vertical band transect stations. Dots denote presence of surfgrass. Carrots along vertical axes represent elevations sampled. Carrots along horizontal axes denote survey occurrences. See Figure 7 for station locations. Years are positioned at January of each year.

10, 11). No observations were made outside the sampling stations to quantify storm impacts in other areas beyond Diablo Cove. In general, effects from the storms and El Niño were greatest in south Diablo Cove where surfgrass abundance was reduced to near-absence, while surfgrass in north Diablo Cove declined to about half from former levels of abundance.

PG&E (1982) - Thermal Effects Laboratory Studies: PG&E conducted a series of thermal tolerance studies on selected organisms. Surfgrass (*P. scouleri*) that was exposed to 75°F (24°C) for nine days did not exhibit any deleterious responses (tissue bleaching). Also, because a temperature controller malfunctioned during the experiment, the plants were exposed to 93°F (34°C) for three hours and were not adversely affected.

DISCUSSION

Results from surveys conducted during summer/fall 1997 show low surfgrass abundance in Diablo Cove compared to historical abundances and abundances in areas outside the cove (Figure 2). Changes in the amounts of surfgrass can be approximated from earlier TEMP qualitative descriptions, results from Gotshall et al. (1984, 1986), the summer/fall 1997 qualitative surveys, and statistical analysis results in the TEMP Analysis Report (Tenera, Inc., 1997).

Results from the TEMP qualitative surfgrass survey done during 1976-77 showed that surfgrass was abundant in Diablo Cove (estimated at 2 hectares; 5 acres). It occurred in various size patches around the perimeter of the cove but was largely absent in the region of Diablo Creek. Based on Gotshall et al. (1984, 1986) and other ancillary observations, surfgrass remained relatively constant at this level of abundance and may have increased through 1982, after which severe winter storms caused substantial reductions throughout the cove.

Using the results from the TEMP intertidal transect and subtidal benthic station studies, it is estimated that the storms removed about half of the surfgrass population in north Diablo Cove, and nearly the entire surfgrass population in south Diablo Cove. Thus, prior to power plant start-up, about 0.4 hectare (1 acre) of surfgrass was present in Diablo Cove, mostly in north Diablo Cove. Patches of surfgrass totaling about 0.1 hectare (0.25 acre) were observed in Diablo Cove during the 1997 summer/fall surveys, representing a loss of about 0.3 hectares (0.75 acres) of surfgrass in Diablo Cove during power plant operation. Lack of recovery to pre-storm abundances represents a potential loss of approximately 1.9 hectares (4.75 acres) of surfgrass in Diablo Cove.

Statistical analyses detected a significant decrease in surfgrass north and south of Diablo Cove for the high intertidal transect in Field's Cove and for transects analyzed for South Diablo Point. However, surfgrass was never abundant in these areas. The significant decline, relative to the control, occurred from the continued absence or near-absence of popula-tions in the high intertidal in Field's Cove and South Diablo Point being compared to increases in the control population (Figure 8).

Surfgrass in Field's Cove was common in the low intertidal and increased during power plant operation. However, the increase was not as large as increases observed at low intertidal control transects (Figure 8). Statistical analysis of the data detected the change as a significant decline in Field's Cove, relative to controls. Using the distance measurements of the TEMP Analysis Report, the spatial extent of documented effects should include partial reductions in surfgrass abundance in the low intertidal along 1.5 kilometers (0.9 miles) of shoreline, north from Diablo Cove and extending along the southern portion of Field's Cove.

No historical data was available to determine changes in subtidal surfgrass in Field's Cove, which occurs to depths of about -3 m (-10 ft). Increased water temperatures of about 1°C (1.8°F) above ambient have been recorded at -3 m in Field's Cove (Tenera, Inc., 1997). Therefore, there is the potential for effects on subtidal surfgrass in this region. However, the summer/fall 1997 dive surveys noted subtidal surfgrass in Field's Cove appeared similar in

abundance to other areas examined outside of Diablo Cove.

Although there has been a large decline in surfgrass mainly in Diablo Cove and mostly from the storms, it appears that the discharge caused further reductions in surfgrass in north and south Diablo Cove and may have directly or indirectly inhibited recovery. Statistically significant declines, relative to controls, were detected in intertidal surfgrass in Diablo Cove (Tenera, Inc., 1997). However, it is difficult to conclude from statistical analysis whether the declines in subtidal surfgrass in Diablo Cove after power plant start-up were the result of the discharge or continued effects from the 1982/83 storms (Figure 10). However, the 1997 summer/fall mapping surveys indicated the discharge has probably had some effect on subtidal surfgrass. Plants in Diablo Cove appeared more stressed than plants outside the cove, based on condition factors of shorter blade lengths and more epiphytes.

The mechanisms causing the decline in surfgrass in Diablo Cove during power plant operation are unknown. Currently, no conclusive evidence exists for effects on surfgrass from increased water temperature. Surfgrass is considered a warm water tolerant genus (Abbott and North, 1971), and laboratory experiments found that surfgrass can tolerate relatively high temperature exposures for short durations (PG&E, 1982). The temperature regimes used in the laboratory experiments rarely occur in Diablo Cove, except perhaps in a small area immediately in front of the discharge structure (Tenera Inc, 1997). Although surfgrass may be able to withstand these temperatures for short durations, nothing is known about the temperature tolerance of surfgrass when temperatures become only moderately warmed for longer periods. Both species of surfgrass occur in southern California where water temperatures are warmer than along the Diablo Canyon coast, but surfgrass in the vicinity of DCPP may be adapted to lower temperature regimes and unable to adjust to the new temperature regimes encountered in Diablo Cove.

The decline in surfgrass in Diablo Cove may have been the result of *Phyllospadix scouleri* and *P. torreyi* having different temperature tolerance thresholds, although both species have been categorized as warm water tolerant species (Abbott and North, 1971). Both can co-occur in mixed stands. They were not distinguished from one another in the quantitative studies, and therefore the two species cannot be analyzed separately for changes.

The decline in surfgrass abundance in Diablo Cove was probably not related to increased grazing. An increase in *Notoacmaea palacea*, a limpet grazer specific to surfgrass, was not observed in the TEMP study or during the 1997 summer/fall surveys. Development of sea urchin barrens (areas devoid of non-calcareous plants) in the intertidal and shallow subtidal in north Diablo Cove during the early 1990's occurred in areas previously covered with surfgrass (Tenera, Inc., 1997), but surfgrass had declined in those areas before the urchins became abundant (Figures 8 and 10). However, grazing from other limpet species and urchins that increased in abundance in Diablo Cove (Tenera, Inc., 1997) may have a role in hindering surfgrass recovery.

Flowering plants and germinating seedlings were rarely observed over the course of the TEMP studies. This suggests that the surfgrass population in Diablo Cove and neighboring areas is composed mainly of long-lived plants, which rely on vegetative growth of rhizomes and blades to replace old tissues as they degenerate and to expand in cover. Based on this theory, the potential for recovery may be low when disturbances remove plants and seed production and dispersal are affected in a negative manner.

Recovery in surfgrass has not occurred in areas of Diablo Cove where it was once abundant. In many of these areas, the branched red alga *Gastroclonium subarticulatum* has recruited and become the predominant plant. The inhibition of surfgrass recovery by algae is consistent with Turner (1985a,b), who found surfgrass slow to recover (over three years to recover) after algae became established. However, recovery potential is also related to

algae which function as "anchoring" structures for surfgrass seeds (Dawson, 1966). Nonetheless, surfgrass seeds were rarely observed in the study.

CONCLUSIONS

The scarcity of historical information, quantitative data, and descriptions of surfgrass in control areas make any assessment of changes in surfgrass from the power plant difficult. All of the available information obtained on surfgrass from the various studies at DCPP were integrated to create a reasonable scenario of changes. The TEMP qualitative surveys in 1976-77 and subsequent ancillary observations provided the only information for describing the aerial extent of surfgrass before power plant start-up, in which about 2 hectares (5 acres) of surfgrass was estimated to have been present in Diablo Cove. The 1982/83 storms and El Niño reduced the abundance to about 0.4 hectare (1 acre). The amount observed in 1997 was about 0.1 hectare (0.25 acre), representing a loss of about 0.3 hectares (0.75 acres) during power plant operation. Why surfgrass has not recovered from the storms, as observed outside Diablo Cove, is unexplained. The discharge may affect surfgrass by slowing vegetative growth, as well as hindering recruitment.

Although most effects to surfgrass were confined to Diablo Cove, the spatial description of documented effects includes partial reductions in surfgrass abundance in the low intertidal along 1.5 kilometers (0.9 miles) of shoreline, from Diablo Cove and extending along the southern portion of Field's Cove, considering shoreline indentations. No historical data were available to determine changes in subtidal surfgrass in this region, but the potential exists for effects on surfgrass to depths of -3 meters (-10 feet) in Field's Cove. No effects on surfgrass were observed in other areas examined outside of Diablo Cove.

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