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TO THE
CALIFORNIA COASTAL COMMISSION

K. Giant Kelp

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This report analyzes and presents the results of scientific studies of kelp carried out by Drs. Thomas A. Dean, Stephen C. Schroeter, and John D. Dixon. The reports that were the basis for the Final Technical Report are:

"The effects of the operation of the San Onofre Nuclear Generating Station on the giant kelp, *Macrocystis pyrifera*: Background information and the biology of kelp," December 1987

"The effects of the operation of the San Onofre Nuclear Generating Station on experimental populations of kelp," February 1987

"Changes in kelp populations in the vicinity of the San Onofre Nuclear Generating Station: 1981-87," January 1988

"Effects of the operation of SONGS Units 2 and 3 on patterns of kelp recruitment in the San Onofre kelp forest," February 1988

"Studies of fouling organisms on giant kelp," January 1988

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K. GIANT KELP

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Summary

The Marine Review Committee (MRC) 's studies of giant kelp were done over a ten year period and included sampling of natural populations, experimental manipulations and transplants in the field, and mechanistic studies both in the field and in the laboratory. These studies were combined with an extensive investigation of the effects of SONGS on the physical environment. In combination, these studies show that the operations of Units 2 and 3 of the San Onofre Nuclear Generating Station (SONGS) had substantial and adverse effects on the population of giant kelp in the San Onofre kelp forest (SOK). These results are summarized in Table 1. The operational period that was studied included years in which giant kelp was very successful in producing new plants and increasing its density and areal extent throughout southern California (e.g. 1986), and other years in which giant kelp did quite poorly (e.g. 1983). Because our studies encompassed such a broad range of conditions, the effects we have seen are quite likely representative of the average effects that will be seen in the future.

Extensive diver and shipboard SONAR surveys over the ten year period showed that both the areal extent and density of giant kelp in SOK were reduced below the levels they would have obtained in the absence of SONGS. By comparing the dynamics of giant kelp in SOK with those in the San Mateo kelp forest (SMK), we estimated that the area in SOK covered by moderate to high density stands of giant kelp was reduced by approximately 80 hectares (by about 60%). Density of adult giant kelp on areas of hard substrate was also reduced, particularly in the upcoast offshore portion of SOK, where losses reached nearly 80%. Throughout SOK, we estimated a loss in average standing stock of approximately 59,000 adult

and subadult plants that can be attributed to operations of SONGS. We emphasize that our estimates of losses in SOK are based on the dynamics of that forest, relative to SMK, and not just on the absolute densities of kelp in SOK. This is an important strength of the program since the past few years have been particularly good ones for kelp recruitment throughout southern California. If we had not been comparing SOK with a control bed, we might have mistakenly concluded that SOK was not impacted because of the recent production of new plants there.

Units 2 and 3 of SONGS affect adult giant kelp density by inhibiting the production of new adults. Two separate sampling programs showed that the decline in the production of adults was preceded by substantial declines in the production of small (10 cm to one m) sporophytes. During an intensive study of recruitment during 1986, higher mortality was seen in small sporophytes transplanted near the diffusers. During the operational period, fewer sporophytes were produced from gametophytes at experimental stations in SOK when those stations were exposed to plume water for a greater fraction of the time. Experimentally outplanted microscopic sporophytes also showed poorer performance when exposed to the plume water. The mechanisms for these impacts include an increase in seston flux and a decrease in irradiance. The relationships between biological characteristics of giant kelp and physical and chemical variables were established through laboratory experiments, and experiments in the field done over nearly all of the 10 year period. The initial production of microscopic sporophytes from the sexual stage (the microscopic gametophyte) is both positively related to irradiance and negatively related to high levels of seston flux. Higher seston flux values are also correlated with increased mortality rates of small sporophytes. In addition, the growth rates of all sporophyte stages are positively related to irradiance. Oceanographic studies have shown that the vertical flux (settling) of seston increased in the upcoast half of

SOK, and seston concentration near the bottom increased throughout the kelp forest. Irradiance reaching the bottom also declined throughout the kelp forest.

Overall, the effects we have seen on giant kelp follow the MRC's earlier predictions. The observed effects were most marked in the offshore and upcoast quadrant of the kelp forest, where they were predicted to be most severe. In addition, they were manifested by the early sporophyte stages, also in agreement with the predictions. Finally, our conclusion, that SONGS adversely affected giant kelp, is based on precisely the kind of evidence that the MRC argued, *a priori*, would indicate an effect: the density of giant kelp in the area downcoast of the diffusers became relatively lower, in comparison with densities in the San Mateo kelp forest, our control.

The effect of SONGS on giant kelp in SOK is likely to have indirect effects on other species. These include a decrease in the recruitment of some fish species, a reduction in the density of invertebrates that live on kelp fronds, and perhaps a decrease in the production of red sea urchins and other invertebrates, which depend upon drift giant kelp for food.

The studies of giant kelp by the MRC broke new ground in understanding the population biology of this species. By focussing on the mechanisms by which SONGS might influence the production of new plants, the results not only allowed an evaluation of effects of the power plant, but also will facilitate the study of potential impacts of other projects. We established quantitative relationships between physical variables such as light and seston flux, and the performance of microscopic and small macroscopic kelp stages. Much was also learned about the longevity of the microscopic stages and the dispersal of kelp spores. This information is of interest both for its inherent value and because it provides some of the tools needed to evaluate the consequences of the loss of a kelp forest, and to determine how such a forest might be reestablished.

1. Introduction

Populations of giant kelp, *Macrocystis pyrifera*, are one of the most extensive and valuable resources found off the California coast. Giant kelp is harvested and used in the manufacture of a wide range of products (Ashkenazy 1975, North 1976, American Gas Association 1977). In addition, forests of giant kelp are very productive ecological habitats that harbor a rich and complex biotic community (North 1971 and references therein, Rosenthal *et al.* 1974, Hobson and Chess 1976, Bernstein and Jung 1979, Coyer 1984, Foster and Schiel 1985, Coyer 1986). Giant kelp is the main structural component of kelp forest communities, and provides living space for hundreds of species of fishes, invertebrates and algae (North 1971). Many species of fish and invertebrates that comprise nearshore commercial and sport fisheries are intimately associated with *Macrocystis* forests at some point in their life history (Limbaugh 1955, Quast 1968, Burge and Schultz 1973, Miller and Giebel 1973, Feder *et al.* 1974, Ebeling *et al.* 1980, Dean *et al.* 1984, Harrold and Reed 1985, Hallacher and Roberts 1985, Bodkin 1986). There is also strong evidence that the abundance of some species of fishes is tied to the local abundance of giant kelp plants (Bray and Ebeling 1975, Larson and DeMartini 1983, Ambrose 1987, Ebeling and Laur 1988, Holbrook *et al. in press*, DeMartini and Roberts *submitted* (and Final Technical Report J), Bodkin 1988, Carr 1989). Further, the replenishment of local populations through larval recruitment is positively related to the presence of *Macrocystis* for several reef fishes (Larson and DeMartini 1983, Carr 1989).

Giant kelp has a complex, heteromorphic life history (Fig. 1). Adult sporophytes attain lengths of tens of meters. These plants are generally attached to hard substrate on the ocean's bottom by a holdfast, but most of the tissue is in the water column or at the surface where fronds often form a dense canopy, which reduces the light reaching the ocean floor. "Reproductive" adults (large sporophytes) release zoospores, a microscopic haploid stage. After dispersing, generally for a few to tens of meters, spores settle and develop into female or male gametophytes. These microscopic plants constitute the sexual generation of the kelp life history. Following fertilization of the microscopic female gametophyte, a microscopic diploid asexual sporophyte is produced. This tiny (about 45 microns in length) sporophyte grows into a small plant with a single blade, and is the first stage in the life cycle readily observable in nature. The single blade then grows and differentiates into two fronds. This can occur when plants are as small as 10 cm, but usually does not occur in the kelp forests near San Onofre until plants are about 40 cm in height. These small plants, with more than one frond, but less than a meter in length, were called juveniles. The plant continues to grow and produce new fronds, eventually reaching the water's surface.

This report evaluates the effects of the discharge from SONGS' Units 2 and 3 on giant kelp in the San Onofre kelp forest (SOK). Units 2 and 3 of the nuclear generating station use a once-through cooling system. Each unit takes in sea water at a single intake, pumps the water to the condensers where it is used to cool the secondary coolant, and then returns the seawater to the ocean through a diffuser with 63 separate ports (Interim Technical Report 1). At full operation, Units 2 and 3 in combination can circulate 1 x 10^7 m^3 per day. When the water is discharged through the diffusers, approximately 10 times this volume is secondarily entrained into the resulting the plume (Interim Technical Report 1, Final Technical Report L). Beyond 100 m from the diffusers, elevations in temperature are less than 0.5°C (Final Technical Report L). The diffuser system was designed to prevent large increases in temperature by rapidly diluting the cooling water by mixing it with ambient water (Interim Technical Report 1, Final Technical Report L). The resulting plume is often turbid, due to increased seston load, and predominantly moves towards the southeast (i.e. downcoast, Fig. 2) with prevailing currents (Final Technical Report L). The new Units began test pumping in 1980 and 1981, but did not reach full operational levels of water circulation until mid-1983 (Interim Technical Report 1).

In the vicinity of SONGS the coast is oriented northwest - southeast. Most of SOK is downcoast (southeast) of the diffusers, and prior to operations of Units 2 and 3, it extended to within 150 m of the diffusers (Dean 1980). SOK is located about 2 km offshore at the same depth as the diffusers, and extends 2-3 km downcoast from the diffusers. In 1980 SOK consisted of 80 ha of dense *Macrocystis* canopy, and an additional 60 ha of scattered plants. (Dean 1980). Because of SOK's location, the turbid plume from the diffusers of Units 2 and 3 reduces light reaching the bottom within SOK, on the order of 0.4 - 0.6 $E/m^2/d$ during the 60% of the time when the current moves downcoast (Appendix A, and Final Technical Report L). This reduction is equivalent to about 26% of average irradiance levels in SOK). SONGS may cause a somewhat smaller increase in irradiance within SOK when the current is moving northwest due to clearer "makeup" water being drawn inshore over the kelp forest. However, the evidence for this positive effect is less conclusive. Ignoring this possible positive effect, the average reduction in irradiance in SOK is about 16%, taking into account that the plume from the diffusers only moves southeast about 60% of the time. If we take the possible upstream positive effect into account (assumed to be half the magnitude of the downstream effect), the overall reduction within SOK is estimated to be 0.21 $E/m^2/d$, or approximately 12% of the average irradiance within SOK (Appendix A). There is also evidence that the turbid plume generated by SONGS leads to an increase in the vertical flux (settling) of seston (suspended particles) within upcoast SOK, and an increase in the concentration of seston near the bottom throughout the kelp forest (Appendix A).

Giant kelp forests have been uncommon in the vicinity of San Onofre. Over the period of the MRC's studies, there have been only three kelp forests in the general vicinity of the San Onofre Nuclear Generating Station (SONGS): the San Onofre (SOK), San Mateo (SMK), and Barn (BK) kelp forests. SMK is located approximately 4.5 km to the north, and BK is located approximately 11 km to the south of the generating station (Fig. 2). At times in the past, and in the past few years (1986-1989), giant kelp has appeared, in a patchily distributed fashion, especially inshore (i.e. 5-10 m depth), between these three kelp forests. However, based on the harsher physical conditions inshore, and past historical patterns, we expect these new areas with giant kelp to be less persistent than the SMK, SOK and BK kelp forests.

The SMK, BK, and SOK kelp forests differ from others in San Diego County in that a substantial proportion of the substrate consists of boulders, cobbles, and coarse sand, rather than consolidated reefs. Only the Barn kelp forest is located where there is also a substantial proportion of consolidated reef. All three of these beds consist of low relief substrate. The algal community consists of a canopy of giant kelp, and an understory composed primarily of the brown algae *Pterygophora californica*, *Cystoseira osmundacea*, *Laminaria farlowii* and occasionally *Desmarestia ligulata*, and the red alga *Acrosorium uncinatum*. Common macro-invertebrates include red and white sea urchins, gorgonian corals and a variety of molluscs (Final Technical Report F). The historical patterns in the persistence and areal extent of these three kelp forests in the San Onofre area are presented in more detail below

(Section 2).

The MRC's research on giant kelp proceeded along several lines. First, sampling studies were done to characterize the spatial and temporal patterns of kelp abundance in the field. A reduction in giant kelp abundance near SONGS during the After period relative to abundance at a control site or sites is regarded as circumstantial evidence for a SONGS effect (see Interim Technical Report 2). Both San Mateo and Barn kelp forests were considered as potential controls in the MRC studies. However, early in the MRC's studies it was recognized that simply sampling kelp in SOK and at a control location before and after SONGS began operating would not, alone, establish that SONGS had affected the kelp population. Although nearby kelp populations do tend to track one another in abundance and spatial extent (North 1971, Neushul 1981, Tegner and Dayton 1987), individual beds can demonstrate somewhat independent dynamics over a period of a few years (Dayton *et al.* 1984, North 1971, Nisbet and Bence 1989). For example, San Mateo and San Onofre kelp forests have generally tracked one another well, but Barn kelp has behaved quite differently (Section 2, and Dixon *et al.* 1988). The MRC kelp program was therefore also designed to identify the mechanisms of impacts.

Research on the effects of Unit 1 indicated that recruitment of microscopic stages of giant kelp was inhibited by an increase of turbidity and sedimentation (Deysher and Medler 1978). It is likely that these smaller stages would be more strongly influenced by a reduction in irradiance and an increase in sedimentation. This is because light must pass through the entire water column to reach small individuals located on the bottom, and these individuals experience more scouring over their entire surfaces than individuals that extend up into the water column (see also Deysher and Medler 1978, Dean 1980). Based on these and similar results, the

MRC predicted that a turbid plume emanating from the diffusers of Units 2 and 3 would adversely affect giant kelp populations, by limiting recruitment into the canopy-forming stage (Dean 1980). It was predicted that the maximum impact would be in the upcoast offshore portion of SOK where densities would be reduced 25 to 70 % (Murdoch *et al.* 1980, Dean 1980), because of proximity, and because physical models predicted that the turbid plume would pass over the offshore portion of SOK most of the time (Reitzel 1980). This prediction was made with some uncertainty because the extent and turbidity of the plume from Units 2 and 3 could not be predicted with great confidence, and because the extent to which density dependent processes might compensate for losses was unknown. It is possible, for example, that a reduction in the production of young plants would be compensated for by an increase in the fraction of the plants that were produced that survived to enter the adult population.

The original evidence, indicating that increases in turbidity or sedimentation would lead to a reduction in recruitment, was based on a relatively small number of samples of only one of the microscopic stages (gametophytes) of giant kelp (Dean 1980). The MRC's studies of giant kelp built upon these early data. One approach was laboratory experimentation in which irradiance and other physical factors were manipulated. The second approach was to outplant various stages of giant kelp at a Control site in SMK and at various locations in SOK. These outplants had two main purposes. First, mechanisms of effects could be identified by relating the performance of outplanted individuals to aspects of the physical environment (e.g. amount of irradiance, sedimentation rate). Second, effects could be linked to SONGS by comparing the performance of the outplants located in the plume to the performance of outplants that were outside the plume.

A third approach was to study intensively a recruitment episode to determine at what stage, if any, recruitment was interrupted by the power plant. This included transplanting cobbles bearing microscopic and small macroscopic stages of giant kelp to control and impact areas during periods when recruitment events seemed likely. This approach was used in 1985 and 1986, by which time the available evidence suggested that the plume from SONGS' Units 2 and 3 was impeding natural recruitment of macroscopic sporophytes.

The second and third approach can provide evidence for SONGS effects that might otherwise not be found in a reasonable time. However, our ultimate goal was to evaluate the effects of SONGS on the abundance of large plants. Thus, effects on individual life-stages needed to be related to the numbers of adults that were eventually produced. This was a difficult and not completely resolvable task, because there is evidence that mortality and growth within a cohort of giant kelp depends upon its own density (Dean *et al.* 1987 and *in press*, Reed *submitted*, Dayton *et al.* 1984) and the local canopy of adult kelp (Dean *et al.* 1987, Reed and Foster 1984, Santelices and Ojeda 1984). For this reason, sampling of the adult stage was essential.

Although we present the results of the studies on giant kelp as an integrated whole, information relevant to the biology of giant kelp and the effects of SONGS on this species comes from a variety of studies, some of which were concerned primarily with organisms other than kelp. For example, density of giant kelp has been estimated by the Kelp Ecology Project (KEP: directed by Dr. Tom Dean, University of California, Santa Barbara) along fixed transects, by the Kelp Invertebrate Project (KIP: directed by Drs. Stephen Schroeter and John Dixon, University of Southern California) in fixed quadrats as part of a study of benthic invertebrates and in widely distributed random quadrats as part of a study of sea urchins and kelp recruitment, and by Eco-systems Management Associates (Eco-M: directed by Mr. Karel Zabloudil and Dr. John Reitzel), using down-looking and side-scan SONAR. Much of the work on giant kelp has relied upon an extensive field study of the oceanography in the area by Eco-M. The field contractors reported their results in a series of final reports. This technical report further integrates these results. It is not the intent of this report to replace the extensive set of final reports submitted to the MRC. We refer to those reports for details on methods, and the details of the results that explored the basic biology of giant kelp. We present results and analyses in detail where they bear directly on the effects of SONGS.

2. Description of the Study Area

2.1 Characteristics of local kelp forests during the MRC's investigations

San Onofre kelp forest (SOK), and San Mateo kelp forest (SMK) (Figs. 2-4) are somewhat unusual in San Diego County in substrate composition (Table 2). A high proportion of the substrate in these two forests consists of cobbles and boulders, rather than consolidated reef (Table 2). To our knowledge, the only similar boulder field that supports a giant kelp population is offshore from Imperial Beach, just south of San Diego Harbor. A third kelp forest near San Onofre, Barn (BK) (Figs. 2 and 5) has extensive areas of both reef and cobble substrate, and is more similar to other kelp forests in Northern San Diego County (Table 2). Both SOK and SMK occur on fields of cobbles and boulders, which are set in a gravel and sand matrix. The substrate at SMK includes a greater proportion of very large boulders, which occur in large piles in parts of the bed. As a result, average bottom relief is higher at SMK than at SOK. Also, at SMK the large cobbles and boulders tend to be set in a matrix of gravel and small cobbles, whereas at SOK the boulders and cobbles are surrounded by coarse sand. As a result, there are more crevices that might provide shelter to invertebrates in SMK. Nevertheless SMK is the local kelp forest most similar to SOK.

Macrocystis pyrifera was the predominant surface canopy-forming alga within SOK and SMK. Of the understory algae that are generally found in southern California kelp forests, *Pterygophora californica* and *Cystoseira osmundacea* were often abundant at our study sites (Table 3). *Laminaria farlowii* was generally present in the shallower portions of SOK, but was not common. *Eisenia arborea* was rare. *Desmarestia ligulata*, an ephemeral species of brown algae, was occasionally extremely dense. Rock surfaces, especially in the shallower part of the beds, were generally dominated by encrusting coralline algae and a red algal turf, of which *Acrosorium uncinatum* was often a prominent member.

SMK and SOK were also somewhat unusual in that white sea urchins, *Lytechinus anamesus*, occurred in relatively large numbers (Table 4). From 1980-1987 red sea urchins, *Strongylocentrotus franciscanus*, were also abundant at SMK (Table 4), and in some portions of SOK.

In the early 1980's, commercial sea urchin divers found larger populations of red sea urchins in SOK and SMK than in any other kelp forests between San Onofre and Point Loma (Dave Rudy, *personal communication*). Feeding aggregations or "fronts" of red sea urchins formed in both of these kelp forests from time to time; however, intensive commercial harvesting from 1981 to 1984 reduced the density of red sea urchins in both beds. Purple sea urchins, *S. purpuratus*, were more numerous at SMK than at SOK, which was probably a reflection of the greater amount of cryptic habitat at the former site.

Prior to 1981 sea stars were common in all the kelp forests. The bat star, *Patiria (Asterina) miniata*, was particularly abundant, especially in SOK. In the summer and fall of each year from 1981 to 1984, sea star populations suffered catastrophic mortality from epizootics caused by a marine bacterium, *Vibrio patiriae* (Schroeter *et al.* 1988). After that time the density of sea stars was low.

The gorgonians *Lophogorgia chilensis*, *Muricea californica*, and *M. fruticosa* were found in all three kelp forests, but only *Muricea* spp. were abundant. *Muricea* populations were generally denser in SMK and BK than in SOK. Other abundant macro-invertebrates were the gastropods *Kelletia kelletii*, *Conus californica*, *Mitra idae*, *Pteropurpura festiva*, *Maxwellia gemma*, and *Murexiella santarosana* (Table 4, See also Final Technical Report F).

The assemblages of fish were similar in SOK and SMK prior to the operations of SONGS Units 2 and 3 (Final Technical Report J). Common species seen in the water column in both forests were kelp perch (*Brachyistus frenatus*), senorita (*Oxyjulis californica*), kelp bass (*Paralabrax clathratus*), halfmoon (*Medialuna califorianis*), and white sea perch (*Phanerodon furcatus*). Common species of fishes associated with the bottom substrate within both kelp forests were senorita (*Oxyjulis californica*), kelp bass (*Paralabrax clathratus*), California sheephead (*Semicossyphus pulcher*), white seaperch (*Phanerodon furcatus*), black perch (*Embiotoca jacksoni*), rock wrasse (*Halichoeres semicinctus*), pile perch (*Rhacochilus vacca*), blacksmith (*Chromis punctipinnis*), black croaker (*Cheilotrema saturnum*), and barred sand bass (*Paralabrax nebulifer*).

2.2 History of Giant Kelp Forests in San Diego County

Prior to the MRC studies, the kelp forests in the vicinity of SONGS had been mapped over the years using a variety of techniques, including surveys of canopy areas by sextant triangulation, aerial photography, and mapping of subsurface plants by means of side-scan and down-looking SONAR. These records allow a rough estimate of the location and approximate size of kelp forests in San Diego County at the times of the various surveys, which occurred sporadically over a period of about 75 years (Dixon *et al.* 1988).

In 1911, kelp forests were present at most locations along the coastline from San Diego to Point Conception where suitable substrate occurred. SOK, SMK and BK kelp forests existed then, and also at the time of surveys in 1934 and in the early 1950's.

Canopies at SOK and SMK disappeared completely during the 1958-1959 El Nino, and BK was reduced in size. It has been hypothesized that the die-off was related to either abnormally high water temperature (North 1971), or low nutrient concentrations associated with the high water temperatures (Jackson 1977).

The SMK and SOK kelp forests became reestablished in 1970 and 1972 respectively. The kelp forests generally flourished for the next several years until another partial die-off occurred in the summer of 1976. The size of other kelp forests in southern California also declined during that summer (R. McPeak, Kelco Div., Merck Inc., *personal communication*).

The SMK and SOK kelp forests began increasing in size again in 1977, and increased sharply in 1978 and 1979, following widespread recruitment events. During those periods, MRC investigators noted large numbers of small "blade-stage" (see Methods) *Macrocystis* throughout SOK and SMK (Tom Dean, *personal observation*).

From late 1979 until early 1982, both SOK and SMK declined slightly. However, the most striking event that occurred was the decline and disappearance of BK during 1980. The decline apparently began in the spring of that year, with the sharpest period of decline in population density between June and November, after which only a few scattered adult plants remained. For the most part, we stopped studying BK at that time.

We think that the most likely explanation for the die-off at BK in 1980 is that heavy sedimentation within the kelp forest inhibited recruitment and perhaps also killed adult plants. Rainfall was unusually heavy during 1978, 1979, and 1980 (Dixon *et al.* 1988, Fig. 32), and that led to high discharge volumes from creeks and streams. The discharge rate was so high during 1980 that the meter used to measure the flow rate was washed out of Las Flores Creek, which lies just inshore of BK (Dixon *et al.* 1988). What was unique in the vicinity of BK was that the heavy rains resulted in extensive landslide activity and cliff erosion along the shoreline adjacent to the bed in February 1978, and again in February 1980 (Kuhn and Shepard 1984). Enormous amounts of sediments were deposited offshore, creating a series of sand bars. We noted extensive sand movement onto several of our stations in BK during summer 1980. While some areas did not get covered with sand, a layer of fine sediments covered the kelp fronds and hard substrata throughout the bed. We suspect the loss of the BK forest resulted from an inhibition of recruitment due to the covering of much of the available hard substrata by sediments, and perhaps also by an increase in the mortality rate of adult plants. Once giant kelp was essentially extinct at BK, an early resurgence was probably prevented because no local source of spores remained. The BK forest did not become reestablished during the period of the MRC field studies, and not until 1987 did a substantial population of adult giant kelp again develop there.

The die-off of plants at BK was a very localized event, and we know of no other forests from Point Conception to San Diego that experienced such a decline at that time. Both before and after this period, the changes in the area of giant kelp at SOK and SMK tracked each other quite well. Consequently, we discontinued using BK as a "control" kelp forest and used SMK as our control. Because such large natural changes in kelp populations are possible, the MRC studies of giant kelp combined a study of mechanisms with the monitoring of natural populations.

3. METHODS

The MRC's studies of giant kelp incorporated a variety of different laboratory and field approaches, under the direction of several different principal investigators, over a ten year period. Here we summarize the methods that appear in the final reports of the original investigators, and refer the reader to those reports for additional details. When necessary, we present additional methodological details that were not included in previous reports.

Giant kelp has a complex life-history, and individuals range in size from microscopic to tens of meters in length. In addition to the microscopic gametophyte and sporophyte stages, we defined four macroscopic stages (blades, juveniles, subadults, and adults) corresponding roughly to size categories (Fig. 1). Blades were defined as plants with a single short stipe and a single lamina (blade) wrinkled at the base, which may have begun to split. Juveniles were plants less than one meter in height with at least two fronds. Subadults were plants greater than one meter in height with a primary dichotomy which was not overgrown by haptera (element of the holdfast). Adults were generally larger than subadults and had haptera above the primary dichotomy. They often formed a surface canopy, and most adults possessed reproductive blades termed sporophylls.

The MRC's studies fall into three groups: (1) field sampling of macroscopic stages of natural giant kelp through time, (2) examination of experimental kelp populations in the field, and (3) laboratory experiments. We present an overview of these three types of studies in the next three paragraphs, and then a more detailed accounting of the methods.

(1) A variety of different approaches was used to sample kelp in the field. Down-looking SONAR sampled relatively large areas and was therefore best at sampling the large but least numerous adult stage. Much smaller areas were sampled by divers to obtain accurate counts for the numerous blades and small juveniles following a recruitment episode. Finally, individual plants were marked by divers and followed through time providing information on mortality rates.

(2) Experimental kelp populations were used extensively. Included in this group were outplants, where gametophyte, microscopic sporophyte, and juvenile giant kelp were placed at standard locations in the field repeatedly over a period of years extending from before SONGS Units 2 and 3 began operating until well after operations began. Additional experiments were designed to study the 1986 recruitment episode. These included sampling of gametophytes by collecting cobbles and culturing them in the laboratory, transplanting of microscopic sporophytes that had recruited to natural cobbles, transplanting of blade-stage plants, and a more extensive than usual outplanting of juveniles. Adults were also transplanted near the diffusers where adult mortality had previously been high. Over the course of the MRC's studies a number of other field experiments was done that investigated how nutrient limitation or canopy shading influenced the preadult stages of giant kelp. These studies provided useful background information on the biology of giant kelp, and the methods and results are presented in detail in Dean *et al.* (1987).

(3) A number of laboratory experiments was done to identify the mechanisms by which SONGS might impact giant kelp. Irradiance, temperature, and nutrients were manipulated in these experiments. These experiments also

provided useful background information on the biology of giant kelp. Details of methods and results are in Dean *et al.* (1987).

Physical and chemical measurements were made during several of the kelp studies. Moreover, the MRC sponsored an extensive study of oceanographic processes in the San Onofre area. This work included a detailed study of how SONGS' plume reduced irradiance levels on the sea floor. Although these studies were to some extent integrated with, and motivated by the kelp studies, the details of this work are presented in the Final Technical Report on Oceanography (Report L), which we refer to when necessary. Some additional analyses of seston and irradiance data directly related to this report are included here as Appendix A.

Many field stations were used in the studies of giant kelp. To clarify the presentation of the results we have adopted the following naming conventions. The main portion of SOK, located downcoast (southeast) of the diffusers, was divided into four quadrants: SOKU35, SOKU45, SOKD35, and SOKD45 (Fig. 3). The two upcoast quadrants were designated as SOKU, and the two downcoast quadrants as SOKD. The ending '35' was attached to the inshore quadrants and the ending '45' was attached to the offshore quadrants, and refers to the approximate depth (in feet) of water in these areas. The patch of kelp a few hundred meters upcoast (northwest) of the diffusers was called SOKN. The offshore and inshore halves of SMK were called SMK45 and SMK35, respectively (Fig. 4). At times we also needed to identify individual sites within subareas of SOK or SMK (usually because multiple sites were being discussed within the same subarea). The names for these sites begin with L (for location) followed by the six character name for the general area of the site (e.g. SOKU45), and sometimes end with additional letters used to uniquely identify the site. For example LSOKU45CL is a specific site within the upcoast offshore quadrant in SOK. The locations of all the stations used in the studies reported in this report are given in Appendix B.

3.1 Studies of Natural Populations of Giant Kelp

3.1.1 Counts of Adults and Subadults

3.1.1.1 Down-looking SONAR Counts

We used down-looking SONAR as our primary method for assessing the density of the larger stages (subadults and adults) of giant kelp. This method was specifically developed to assess the density of giant kelp over large areas within SMK and SOK, a task that would have been prohibitively expensive by diver surveys.

Sonar surveys of kelp were conducted by Ecosystems Management Associates (Eco-M) in SOK and SMK. In our analyses we present results for SMK, SOK, and separately by quadrant within SOK. The areas surveyed correspond to those shown in Figs. 3 and 4. SOKN is included as part of SOK, and all analyses of SOK as a whole using down-looking SONAR included this subarea. Beginning in February 1982, SONAR estimates of kelp densities were made approximately every six months. Following the completion of the tenth survey under MRC auspices in September 1987, additional surveys were done by Eco-M under Southern California Edison (SCE) funding. Data from the additional surveys, through Feb. 1989, were processed by Eco-M and provided to the MRC in time to be included in this report.

The down-looking SONAR system consisted of a SONAR transponder attached to a small boat, a navigational system to record the boat's position at a given time, and a precision graphic recorder which recorded the SONAR echoes. Within each large block, the boat containing the SONAR equipment moved over a predetermined grid, with distances between transects of the grid at approximately 100 m intervals. The boat moved at a speed of approximately 2.7 m/sec, and its position was recorded at approximately 80 m intervals (i.e. every 30 s). These recorded boat positions are termed shot points. Kelp density was estimated in rectangles that were centered at these shot-points and were approximately 6 m wide (3 m on either side of the transect center line), and about 80 m long (the usual distance between shot points).

Adult and subadult kelp plants in a SONAR beam returned an echo that generally produced a distinctive linear trace on the record. Calibration studies (conducted by KIP and KEP in collaboration with Eco-M) determined that plants with less than eight stipes were often overlooked, but larger plants nearly always were counted. This size corresponds to a large subadult or young adult plant. The counts of kelp traces on SONAR records per meter length of the transect were related to kelp density in plants per square meter by using a mathematical model. The assumptions of the model were tested with field observations. The estimates of kelp density obtained by the model were in good agreement with those based on diver counts. Additional details of the methods used during SONAR surveys and to determine kelp densities at shot points from SONAR records are in Reitzel *et al.* (1987 a).

The results of the down-looking SONAR surveys, along with detailed substrate maps obtained from side-scan SONAR (Reitzel *et al.* 1987 b), were used to determine kelp density per unit area of hard substrate (i.e. > 10% cobble as indicated on side-scan SONAR maps), and to determine regions in which this kelp density exceeded a specified threshold value (e.g. greater than 4/100 m^2). Average kelp densities were calculated using only density records for shot points over hard substrate. Shot points were classified as being from areas of hard or soft substrate based on the substrate maps generated from side-scan SONAR surveys. Within a given region, the area for which kelp density exceeded specified values was determined simply as the proportion of all shot points on hard substrate for which density exceeded the specified value, times the total area of hard substrate within the region.

3.1.1.2 Transects

The Kelp Ecology Project (KEP) monitored the fate of giant kelp plants along permanent transects from 1978 through the end of 1986. They conducted surveys at approximately monthly intervals in 1978 and at quarterly intervals thereafter. Through May 1981, all *Macrocystis* that had reached the juvenile stage were marked and counted. Thereafter only new adult plants were marked.

We used data from the permanent transects to assess recruitment into and mortality of adult giant kelp populations. The transect data were well suited for this purpose because individual plants were marked and followed through time, starting in the Before period, both at SOK and at the control (SMK). Adult recruitment rate was estimated as the number of new adults that appeared during the interval from one census to the next, divided by the time period between censuses. Adult per capita mortality rate between survey i-1 and survey i, (M_i), was estimated as:

$$M_i = [\log(N_{i-1}) - \log(S_i)]/t_i \quad (1),$$

where N_{i-1} is the number of adults alive on survey i-1, S_i is the number of these adults still present and alive on survey i, and t_i is the time between the i-1th and ith survey. (Different letters are used to represent the initial number and their survivors since initially all adult plants were included, while at the next survey only those plants that had been present on the prior survey were included.)

We also used these data to assess temporal patterns in adult kelp population density. Although down-looking SONAR records produced estimates over larger areas, and therefore were more indicative of density in the kelp forest as a whole (see above), the density data from the transects were valuable because they have been recorded since 1978, while down-looking SONAR data are available only from 1982 onward. Kelp plants were counted by divers in other surveys described below, but the resulting data were generally not useful for assessing *adult* density, due to the smaller areas sampled.

There were 20 permanent transects in SOK, and four in SMK. Each transect was 50 m long by 6 m wide, and was marked with steel bars driven into the sea floor at 1-m intervals. Twelve transects were initially established in the SOK in the summer of 1978. Another transect was added in March 1979 to expand coverage of the forest. In 1981, two transects were established in SMK in order to provide a control stations at some distance from SONGS' diffusers. In December 1982, KEP established seven new transects in SOK and two in SMK to provide more complete coverage of both kelp forests.

Ten of the 20 transects in SOK and two of the four transects in SMK were initially established perpendicular to the edges of the kelp forest, with half of each of these transects on cobble substrate outside of the kelp forest, and half extending under the kelp canopy. These sites were chosen in order to monitor any expansion or contraction of these kelp forests. The other transects were established in dense patches of kelp that prior observations indicated had persisted for several years.

For the analyses presented here, transects were grouped by areas (SMK, SOKU35, SOKU45, SOKD35, SOKD45). In addition to the four transects in SMK, there were four to six transects within each of the subareas of SOK. We first estimated recruitment and mortality rates for each transect and then averaged these by areas. Additional details of the methods used on the transect surveys can be found in Dean *et al.* (1987, Sections 8 and 10), and Dixon *et al.* (1988, Section 3).

3.1.2 Counts of young giant kelp (blades and juveniles)

3.1.2.1 Bed-wide sampling of kelp recruitment

In September 1981, the Kelp Invertebrate Project (KIP) set up a grid of stations in both SOK and SMK to examine the distribution and abundance of sea urchins and newly recruited giant kelp. In these surveys, four stages of *Macrocystis* (blades, juveniles, subadults and adults) were counted, along with sea urchins and understory algae. Substrate characteristics were also recorded. We used data from these quadrats to assess recruitment of blade and juvenile kelp. Although larger plants were also counted, the area sampled was too small to accurately assess their density.

Originally, 24 stations were placed on hard substrate in SOK and 11 in SMK. In November 1985 six additional stations were placed in SOK, and two in SMK. Two new stations were also placed in SOKN at this time, but we do not use data from these stations in our analyses. In our analyses we group the quadrats into the following areas: SMK, SOKU35, SOKU45, SOKD35, and SOKD45. Prior to May 1984, counts were made in three 4-m^2 quadrats at each station, and in five 1-m^2 quadrats thereafter. Surveys were conducted quarterly except during 1983 and 1984 when they were done twice a year. A detailed description of the methods used to monitor these small quadrats is given in Schroeter *et al.* (1988).

3.1.2.2 Kelp counts from the study of benthic invertebrates

KIP also established a group of stations used primarily for the study of large benthic invertebrates (Final Technical Report F) in October 1980. Data from the SOKU45, SOKD45 and SMK45 subareas were analyzed for this report (additional data were collected in Barn Kelp Forest, see Final Technical Report F).

In these subareas the abundances of the four macroscopic stages of giant kelp (as well as a suite of invertebrates and understory algae) were estimated quarterly through December 1982, semiannually from January 1983 through May 1984, and quarterly thereafter through November 1986. The percent cover of various substrate types (e.g. sand, cobble, boulders, etc.) was also estimated in each quadrat. Prior to June 1981, only subadult and adult kelp were counted since smaller plants were either absent or very rare. Beginning in June 1981, following a recruitment episode, blades and juveniles were also counted. Each station consisted of a grid of 40 permanent 1-m^2 quadrats spaced 4 m apart along four 40-m transects.

The transects radiated from a center point to form a cross, centered on a 0.65 hectare plot.

We used these data, along with the data from the bed wide recruitment stations described above, to assess recruitment of blade and juvenile giant kelp. Additional detail on the sampling methods can be found in Final Technical Report F.

3.2 Studies of Experimental Giant Kelp Populations

3.2.1 Outplant and Transplant Techniques

3.2.1.1 Gametophyte Outplants

KEP examined the production of sporophytes from gametophytes by outplanting known densities of gametophytes on nylon lines and sampling these lines six weeks later to determine the number of sporophytes produced. Gametophyte outplants were placed in the field on a total of 39 dates in the Before period (November 1977 - August 1982) at one to five stations, and on 24 dates in the After period (May 1984 - July 1986), at three to five stations. Procedures for culturing gametophytes on lines in the laboratory, outplanting, and counting the number of sporophytes produced are described in detail in Dean *et al.* (1987), and are briefly summarized below.

Sporophylls were collected from adult sporophytes in SOK and were returned to the laboratory. Spores were then released from the sporophylls to make an inoculation solution which consisted of a known density of spores in filtered seawater. Plastic plates with nylon line substrates were placed in the inoculation solution overnight. The next day one line was removed from each plate and the densities of gametophytes on the lines were estimated. The plates with the remaining lines were outplanted onto PVC racks at field sites in SOK and SMK. After six weeks in the field, the plates were collected and returned to the laboratory where the number of sporophytes per line was estimated. The proportion of gametophytes producing sporophytes was then calculated as the ratio of sporophyte density at the end of the outplant to the initial female gametophyte density (assumed to be half the initial gametophyte density). Over the range of gametophyte densities used, initial density did not influence the proportion of gametophytes producing sporophytes (Dean *et al.* 1987, see also Reed *in press*). A six-week exposure period was used because previous studies had indicated that the maximum density of sporophytes was generally reached after this period in the field (Dean *et al.* 1987, Section 5.0).

The number of substrate plates and the number of lines per plate varied as the experimental design evolved. Generally, two plates with seven lines per plate were outplanted to the sea floor and 2 m above the sea floor at each station (Appendix G to Dean *et al.* 1987). In addition, plates were also placed at 4 m and 6 m above the bottom in SMK45 during 1981 and 1982. Substrates were placed in the water column to provide a wider range of physicochemical regimes.

The instruments used to measure the physical factors were attached to the same racks holding the plates. Temperature, irradiation, seston flux (accumulation of sediments in plastic tubes), and nitrogen concentrations ($NO_2^- + NO_3^- + NH_4^+$) were measured. Details on their measurement are in Appendix C to Dean *et al.*

(1987). Nitrogen values were not used in analyses because they were measured too infrequently. Instead, we used temperature as a proxy for nutrient status because nitrogen concentration was well correlated (negatively) with temperature, and because low temperatures are indicative of nutrient rich upwelled waters (Zimmerman and Kremer 1984, Final Technical Report L).

A number of stations in SOK and SMK was used in the gametophyte outplants (See Appendix G to Dean *et al.* 1987 for a complete list of stations). A station in SOKD45 was used continuously since 1977, a station in SOKU45 was added in June, 1979. An additional station in SOKD35, and two in SMK45 were added in August, 1981, and a station at SOKU35 (LSOKU35) was added in October, 1985. Note that outplants were placed at one of the two SMK45 stations only on a subset of surveys, and consequently this site is not used as a second control site.

In addition to the standard outplants described above, an additional set of outplants was done during a time when physical conditions made the production of sporophytes unlikely. These outplants were intended to determine whether older gametophytes enter a "resting stage" with low mortality rates. This was of interest because of the hypothesis that such a resting stage might allow a kelp forest to recover after all adults had died, without a source of recruits from outside the local area. The methods and results of these outplants are described in detail in Dean *et al.* (1987).

3.2.1.2 Microscopic Sporophyte Outplants.

The growth and survival of microscopic sporophytes was examined by outplanting known densities of newly recruited sporophytes on nylon lines attached to substrate plates, and examining these lines after three weeks to determine the size of sporophytes and the number of survivors. Lines were inoculated with gametophytes, in the same way as for the gametophyte outplants described above (Section 3.2.1.1), kept in laboratory culture under optimal conditions for two weeks until sporophytes were produced, and then outplanted to field sites. Laboratory culture conditions used for sporophytes are given in detail in Dean *et al.* (1987, Section 6.0).

Transport and attachment of experimental substrates, the set of stations used, and the measurement of physical factors were the same as for the gametophyte outplants. In outplants since 1981, substrates were placed at the bottom at up to six field stations. During earlier outplants (1979-1981) substrates were also placed two m above the sea floor. Immediately prior to outplanting, one line from each plate was selected at random and removed to determine initial densities and lengths. Two to three lines from two substrates were sampled after the plates had been in the field for approximately three weeks. Sporophyte outplants were placed in the field on 15 dates during the Before period (September 1979 - September 1982) at two to six stations, and on 11 dates during the After period (July 1984 - July 1986) at three to five stations.

Sporophyte growth was defined as the instantaneous rate of change in length as a proportion of initial length, and was estimated as the difference between final and initial log transformed lengths divided by the outplant duration; i.e. by:

$$g = [\log(l_{final}) - \log(l_{inital})]/\text{duration} \quad (2),$$

where l_{final} and $l_{initial}$ are the final and initial lengths and duration is the duration (in days) of the outplant period. Mortality rate was estimated as the difference between the initial and final log transformed densities, divided by the outplant duration (after Eqn. 1).

3.2.2 Cobble transplants and sampling

Cobbles were transplanted as part of the detailed study of the heavy recruitment episode in 1986. Gametophyte availability was monitored by collecting cobbles, returning them to the lab, culturing them, and counting the number of sporophytes that were produced. We assumed that differences in sporophyte densities following culturing reflected differences in gametophyte densities in the field.

Cobbles were collected from one station in SMK (in SMK45) and four stations in SOK (one each in SOKU45, SOKD45, SOKU35, and SOKD35) at approximately monthly intervals between November 1985 and July 1986. Beginning in May 1986 the standing stock of microscopic sporophytes was assessed by counting the number of sporophytes on cobbles immediately after their collection at these same stations. During this same time period (November 1985 - July 1986), and at these same stations, slides were placed in the field at approximately monthly intervals and left in place for two week periods. These slides were then collected, cultured in the lab, and the numbers of resulting sporophytes were counted. The slides were used to determine whether patterns seen in standing stock of gametophytes corresponded to the numbers of gametophytes that accumulated (i.e.

settled and survived) over two week periods. Detailed methods of collection and culturing are in Dean *et al.* (1987).

The survival and growth of newly recruited microscopic laminarian sporophytes was assessed in a transplant experiment. (At these early stages it was not possible to distinguish *Macrocystis* from other laminarian species.) Many of these plants were *Macrocystis*, as indicated by the subsequent heavy recruitment of giant kelp. Others were the understory algae, *Pterygophora californica*. Details of the methods used in this transplant experiment are in Schroeter *et al.* (1988, Section 4.1), and are summarized here. Approximately one week after high densities of sporophytes were seen at SMK, on May 16, 1986, cobbles were collected at SMK and transplanted to six transplant sites: two in SMK45, and one each in SOKU45, SOKU35, SOKD45, and SOKD35. The overlaying canopy of *Macrocystis* and understory algae had been cleared from all of these sites to equalize conditions at the different locations.

Six trays were placed at each site, with four cobbles in each tray. Three trays at each site were secured to the sea floor with T-shaped steel bars. Three other trays were held approximately 20 cm above the sea floor on T-shaped bars partially driven into the sea floor. The latter treatment was used to exclude sea urchins.

After eight weeks the cobbles were collected and returned to the laboratory where all sporophytes on the cobbles were counted and measured. In order to determine sporophyte densities, an index of the surface area of each cobble was obtained by tracing its outline onto paper, and then measuring the outlined area with a planimeter.

With the exception of one of the stations in SMK45, irradiation, temperature, and seston flux were measured at each station during the course of the experiment. Details of the methods used to measure these physical factors are given in Schroeter *et al.* (1988, Section 2.1).

3.2.3 Blade Stage Transplants

The main blade-stage transplant experiment was done from August 18, 1986 to January 11, 1987 as part of the detailed study of the 1986 kelp recruitment episode. Details of the methods of this experiment are in Schroeter *et al.* (1988, Section 5), and are summarized here. One hundred blade-stage kelp plants 10-15 cm in length were transplanted on small cobbles from the upcoast portion of SMK to a station in SMK35, and to each of three locations in SOK (one station each in SOKU35, SOKU45, SOKD35) and to shallow SOKN (LSOKN35), and fifty blade stage plants were transplanted to a station in SOKU45. The transplanted cobbles were secured by cable ties to chains that were fastened to the bottom with steel bars. Except for SMK35, seston flux and light were measured at each station or, in the case of the station in SOKN, at a nearby location. The site near to SOKN used to measure seston was in a sand plain and consequently seston flux on the bottom was overwhelmed at this location by sand movement. Therefore comparisons of seston flux between SOKN and the control site in SMK45 were based on data collected 2 m above the sea floor.

One other manipulative experiment with blades was done in 1986, which overlapped in time with the above experiment, and used similar methods. To examine the effect of the canopy of adult giant kelp on the growth of blade-stage plants, some blades were transplanted into canopy areas and their growth was compared to that of others transplanted into clearings. A similar "natural experiment" was done in 1983 when the growth of blade-stage individuals was monitored in canopy and non-canopy areas. The methods and results of these other blade experiments are presented in detail in Dean *et al.* (1987, Section 5).

3.2.4 Juvenile Transplants

Juvenile sporophytes, about 40 cm in height, were transplanted to various locations in SOK and SMK, and temperature, irradiance, and seston flux were concurrently measured. Each plant was measured immediately after transplanting, and after six weeks the remaining plants were remeasured. The transplanting was done because juveniles were not always available when and where they were needed. Also, transplanting enabled plants to be placed so that they experienced a wide range of physical conditions.

Nine juvenile transplant experiments were done during the Before period (October 1978 - September 1982) at two to four stations. There were seven juvenile transplant experiments in the After period (July 1984 - August 1986) at three to six stations. Prior to 1986, six stations located in SOK and SMK were used at various times in these transplants. A complete tabulation of the dates for each transplant and the stations used is given in Dean *et al.* (1987, Table 9.1). These six stations were located within 50 m of adult kelp populations that persisted for the length of the study, and all were at a depth range of 13.2 to 14.4 m. At three stations (LSMK45CAN, LSOKD45CAN, LSOKU45CAN) transplants were placed under a stand of adult *Macrocystis pyrifera*. At the other (standard) stations (LSOKD45, LSOKU45, and LSMK45), all adult plants within approximately 10 m of the transplant racks were removed. During the After period experiments were done at the standard stations without adult canopy.

Following a recruitment event in spring 1986, juveniles were transplanted twice to three additional locations in the shallower areas of the kelp forests (SOKU35, SOKD35, SMK35). The results of these inshore transplants were analyzed separately from the other transplant data.

Details of transplant techniques are given in Dean *et al.* (1987), Section 9. Briefly, plants were either taken from naturally recruited stocks growing in SOK, SMK, or other nearby kelp forests, or were reared to the blade stage in the laboratory and then grown to juvenile size in the field, at either SMK or SOK. The juvenile plants were transplanted by divers onto sawhorse-like racks. The racks held the plants about 1 m above the bottom.

Growth rates were calculated for each individual plant, and then averaged by station. Growth rates were calculated as the difference in log transformed final and initial lengths divided by the duration of the experiment (i.e. by eqn. 2).

3.2.5 Adult transplants

In 1984, there was extremely high adult mortality on the transect located closest to the Unit 3 diffuser in about 12 m of water. All adult plants in that area died in place over a period of about four months (Schroeter *et al.* 1988, pp. 56-57). An adult transplant experiment was done in 1986 to determine whether any new adults that might recruit to that area would suffer such severe mortality.

On August 20 - 23, 1986, adult *Macrocystis* were transplanted from downcoast SMK to three control plots in SMK35 and to three experimental plots in SOKU35. Each plot was 25 m x 15 m, with boundaries marked with steel rods. All adult kelp was removed from these plots prior to the transplant. Twenty adult kelp plants averaging 19 fronds per plant were transplanted to each plot for a total of 60 plants in SMK35 and 60 plants in SOKU35. Each plant was attached to a 60 lb. concrete block which was anchored to the bottom and uniquely numbered.

The transplant plots were revisited between September 2 and September 5, at which time there were between 17 and 20 plants at each plot. This survey was designated the start of the transplant experiment, and the number of fronds on each plant were counted. The transplant plots were revisited on 29 September 1986, 30 October 1986, 25 November 1986, and 21 January 1987. On each visit any missing plants were noted, and on the final visit the number of fronds per plant on the remaining plants was noted.

3.2.6 Nutrient addition experiments

There were two sets of nutrient addition experiments. In the first (done in 1981), nutrient levels were elevated above ambient in the vicinity of one (of two) sets of gametophyte outplants. The effect of nutrients on juvenile growth rate was examined in the second set of field experiments, in 1984. The details of the methods and results of both of these are included in Dean *et al.* (1987).

3.3 Laboratory Experiments

Laboratory experiments were done to determine the effects of light, temperature, and nutrients on sporophyte production from gametophytes, and microscopic sporophyte growth. The methods and results of these experiments are presented in detail in Dean *et al.* (1987).

In 1980 the relationship between irradiance and the production of sporophytes from gametophytes was examined. The primary goal of this study was to determine the lower critical light requirements for gametogenesis. During 1984, the combined effects of temperature and irradiance on sporophyte production from gametophytes was examined. In these experiments irradiance and temperature were varied among treatments in a factorial design, to test for an interaction between these two factors. A series of three laboratory experiments explored the effects of nutrients on the production of sporophytes from gametophytes. Two sets of laboratory experiments examined the relationship between sporophyte growth and irradiance.

3.4 Analytical Methods

Commonly used statistical procedures are described when they are used in the Results section. The programs used in our analyses are documented in Appendix C. Here we present less well-known methods that we used repeatedly.

3.4.1 Tests for relative changes at an impact site

In many of the MRC's investigations, including the studies of giant kelp, samples were collected repeatedly through time at a control station and at one or more impact stations. By sampling both Before and After SONGS Units 2 and 3 began operating at normal levels, and by sampling in Control and Impact areas, many temporal and spatial variations unrelated to the operations of SONGS were controlled for. For the analyses we first calculated the differences between each of the Impact and Control values collected on a given survey. We tested for a relative change in the Impact area in the After period by determining whether these differences ("deltas") had changed significantly from Before to After. More detail on the rationale behind this Before-After-Control-Impact-Pairs (BACIP) design is presented in Interim Technical Report 2.

For this report we used three variants of the BACIP design, and we describe each of these below, and then turn to the details of the analyses.

3.4.1.1 A single impact site

In this case there was a single impact site that was being compared with a single control. This is the design described in detail in Interim Technical Report 2. We analyzed the difference between Impact and Control values (possibly transformed, see Section 3.4.1.4 below). We then determined whether the mean value of these deltas in the After period was significantly ($p < 0.05$) different from the mean for the Before period using a 2-sample t-test.

3.4.1.2 Two impact sites

When there was more than one impact site one could perform separate analyses for each impact site as described for the single site case above. Alternatively, one could analyze the data from the multiple impact sites in a unified manner. For this report we used both approaches, depending upon the structure of the data. When the different impact stations had substantially different sampling histories (e.g. one of the impact stations was established years before the other) we analyzed them separately, so as to be able to use more of the data. In this case we also tested for a differential effect at the two impact stations by calling the "far" impact station a Control and comparing it with the "near" impact station using the usual BACIP approach described above.

In those cases where the different impact sites were generally sampled at about the same times, we analyzed the data from both Impact stations simultaneously using repeated-measures Analysis of Variance. For each survey we first calculated the difference between the values at each Impact station and the control station. In this analysis, a significant main effect of period indicates that the deltas, averaged over the two impact stations, had changed from Before to After SONGS Units 2 and 3 began operating. A significant location by period interaction indicates that the two Impact sites had changed differentially from Before to After.

Repeated measures ANOVA was also used in our study of the effects of SONGS on large benthic invertebrates in the San Onofre kelp forest (Final Technical Report F). A more detailed discussion of the analysis, including the model specification, is in that report.

3.4.1.3 Limited Before sampling

In some cases only a few surveys were done in the Before period, beginning toward the end of that period. In these cases we did not test whether the Impact-Control difference (delta) had changed from Before to After. Instead, we tested for trends in the deltas through time by regressing the delta for each survey against time. This may indicate an effect that had "accumulated" through time. It is a test which is more likely to falsely implicate SONGS than one comparing mean Before and After values, because a trend might be a continuation of a pattern already in evidence before operations of the new Units of the generating station began. With sufficient Before data we could test for a trend during that period (see below).

3.4.1.4 Details of the analyses

In our analyses we defined the "After" period as starting on May 1, 1983. Since SONGS Units 2 and 3 were not simply turned on, but increased their operating levels gradually through time, some judgement was exercised in choosing this as the break between the Before and After periods. However, Units 2 and 3 (and SONGS as a whole) clearly operated at higher levels after this date, over the period of our investigations (Table 5). The choice of a date is only of concern for the surveys of natural populations since no outplants were made from the end of 1982 until May 1984. One exception to the May 1983 break-point was our analysis of YOY recruitment at the bed-wide stations where we included the fourth survey (begun in July 1983) in the Before period.

The most critical assumptions underlying our statistical tests are additivity, lack of serial correlations, and absence of trends in the Before period. When possible we tested for violations of each of these assumptions. We tested for lack of additivity using the Tukey one-degree of freedom test, for serial correlation using the Durbin-Watson statistic, and for trends by regressing deltas against time in the Before period. Details on these assumption tests are included in Interim Technical Report 2. Tests of assumptions for the repeated measures ANOVA are described in Final Technical Report F. In some cases, there were too few Before data to conduct assumption tests. This was true for studies on blade and juvenile densities (young-of-the-year recruitment), and for the down-looking SONAR data.

Violations of assumptions may sometimes be avoided by transforming the raw data before analysis. In our analyses, we generally used log transformations. We preferred log transformations because we expected SONGS to have a multiplicative effect (i.e. to change values to some *fraction* of what their unaffected values would be). For kelp forest area and for mortality rate we preferred not to transform the data. Mortality rate is already a derived variable based on log transformed values, and we had no *a priori* expectation that kelp forest area wouid be affected by loss of a fraction of its original size. In the case of log transformations we first added a constant because the log of zero is undefined. The constant added was 1 for kelp densities determined from down-looking SONAR, and 0.025 for young-of-the-year recruitment based on diver surveys. For other data 1/6 of the mean value in the Before period was tried as the constant. If the tests of the assumptions on the data using the preferred transformation indicated violations (especially of additivity), we then turned to alternative data treatments (i.e. a different constant or the use of untransformed data). If the log transformation using

1/6 of the mean violated the test assumptions, the Before mean value was considered as a possible constant before untransformed data was tried.

For large data sets (on the order of 50 sampling times or more) the presence of serial correlation can be adjusted for in the BACIP t-test. The procedure we adopted was to model the residual variation about the period means as an autoregressive (AR) process. We used this procedure in our comparison of seston flux in upcoast and downcoast SOK (reported in Appendix A). In these analyses we used an AR(1) (order one) process, and treated periods of more than three months between observations as breaks in the time series. We chose an AR(1) model because preliminary analyses indicated that higher order terms were not significant. Additional details on this procedure are in Final Technical Report L, where it was used in BACIP tests on irradiance.

In some applications other than the BACIP t-test we also modelled residual variations as autoregressive processes. In particular we used this method when we compared irradiance or temperature between two sites over a defined period of time. In those analyses we took the difference between the two stations and tested whether the average difference was significantly different from zero, which would indicate that the mean values at the two stations differed. In this case, our test was a time-series version of the one-sample t-test. For station differences of both irradiance and temperature we used an AR(1) process to model the residual variation about the mean delta.

$\frac{SOK_A}{SmK_A} \frac{SmK_B}{SOK_B}$ · $\frac{SOK_B}{SmK_B} \cdot \frac{SMK_A}{SmK_B}$

3.4.2 Estimating the area and number of plants lost

For variables used in BACI analyses estimates of relative percent change are given, and these were estimated using the methods given in Interim Technical Report 2. Here we describe the methods used to estimate the changes in the area, density, and numbers of giant kelp in SOK based on down-looking SONAR data.

As a first step in calculating the numbers of giant kelp plants (adults and subadults) lost, we estimated the multiplicative factor S, defined by $SOK_A = S \times Predicted_A$, where SOK_A and $Predicted_A$ are the densities (per unit area of suitable substrate) actually seen in SOK, and predicted given no impact, respectively, during the After period. We estimated S using the equation derived in Final Technical Report J: $S = (SOK_A/SOK_B)/(SMK_B/SMK_A)$. The terms on the right hand side of the equation represent the mean densities in a given kelp forest during a given period, and the subscripts A and B refer to the After and Before periods, respectively. Thus, SOK_B represents the mean density of kelp plants per unit area of suitable substrate in SOK during the Before period. We can express the observed changes as relative percent changes which equal 100 x (1-S).

We converted our estimate of S to a number of plants lost by first calculating the decline in density that could be attributed to SONGS, and then multiplying this by the average area of suitable substrate (i.e. >10% cobble on side-scan SONAR maps) that had existed in SOK over the course of the MRC studies. The change in density that could be attributed to SONGS was calculated as $SOK_A - SOK_A/S$, since $SOK_A/S = Predicted_A$.

$$\frac{\left(\frac{I_A}{C_A}\right)}{\frac{I_B}{C_B}} = \frac{I_A \, C_B}{I_B \, C_A}$$

~~$\frac{SOK_A}{SmK_A} \Big/ \frac{SOK_B}{SmK_B}$ $SOK_A \, SmK$~~

$\frac{SOK_A}{SOK_B} \cdot \frac{SmK_A}{SmK_B}$

We estimated losses in area covered by moderate to high densities (i.e. >4 plants per 100 m^2) of giant kelp as follows. First we calculated the proportion of suitable substrate covered by moderate to high densities of giant kelp for each kelp forest and period, as the mean area for that forest and period, divided by the mean area of suitable substrate in that kelp forest. We then took the difference between the proportion for SOK and SMK (SOK - SMK) in each period, and then took the difference between the differences seen in the Before and After periods (Before - After). This double difference is our estimate of the change in the proportion of hard substrate occupied that can be attributed to SONGS. We can convert this to area by simply multiplying it by the average area of hard substrate in SOK. We take the sum of this change and the actual area occupied in SOK during the after period as an estimate of the area that would be occupied if SONGS did not exist. Thus, the percentage change is simply our estimate of the change, divided by the area that would have been covered in the absence of SONGS, times 100.

We used the method described above for calculating changes in area that could be attributed to SONGS, rather than a simple multiplicative model, or other methods that did not take into account the area of suitable substrate, because these other methods estimated losses greater than the average amount of free space in the After period. Even the method described above, when applied to areas with *any* kelp present, estimated a larger loss than is physically possible. This occurred because in the After period SMK became nearly saturated with giant kelp. In the Before period 39% of the suitable substrate had some kelp in SMK and 73% had some kelp in SOK. In the After period, the value rose to 93% in SMK and remained unchanged in SOK. The saturation in SMK was less extreme for the moderate to high density kelp category. In the Before period 24% of the suitable

oK SMK $\Delta_A - \Delta_B$
.73 .39 .34 -.54
.73 .93 .20

			Δ	$\Delta_A - \Delta_B$
B	.37	.24	.13	-.44
	.32	.63	-.31	

substrate had this much kelp in SMK, and 37% of the suitable substrate had this much kelp in SOK. In the After period the percentage occupied rose to 63 in SMK, but fell to 32 in SOK.

In our calculations of both areas and numbers lost we used the first three surveys (February 1982 - July 1983) as the "Before" period, and the last six surveys (January 1987 - February 1989) as the "After" period. We did this, rather than using the standard Before and After periods because there were few data from before May 1, 1983, and because there were trends in the deltas, so we wished to estimate losses for an "After" period when the differences between SOK and SMK appeared to no longer be changing systematically through time.

3.4.3 Regressions of outplant results against physical and chemical variables

The relationship between the production of sporophytes from gametophytes, microscopic sporophyte growth and mortality rates, and juvenile growth rates and physical variables (irradiance, temperature, and seston flux) was evaluated using multiple regression. As part of the outplant studies, temperature and irradiance were recorded continuously, and seston flux was estimated from accumulation in tubes over several week periods. The instantaneous concentration of nitrogen was estimated for locations near the outplants on some dates. Because there were few data on nitrogen, however, we did not use this variable in our analyses, instead we used temperature because low temperature is associated with nutrient rich upwelled water (Final Technical Report L). In our regressions we used the average daily value at an outplant station, over the period of the outplant. Thus, we calculated an average for each day at a station, then averaged these daily values over all days an outplant was in the field.

In general, we linearly regressed a given log transformed biological variable against the log transformed physical variables. Extensive preliminary analyses indicated that these models generally had smaller mean square errors and fit the data better than linear models fit to untransformed data (Dean *et al.* 1987). Furthermore, preliminary nonlinear regressions of growth rates against irradiance using a von Bertalanffy equation provided little or no improvement in fit over the linear regressions using log transformed data. The one exception to our use of log transforms was for irradiance in the model for sporophyte production from gametophytes. Extensive laboratory experiments (see Dean *et al.* 1987) suggested that sporophyte production responded to irradiance as a step function, rising abruptly from a low to an asymptotic value. Consequently, we created an indicator variable, and assigned it a value of one when irradiance was above a threshold, and zero when it was below that threshold, and used this variable in our analyses. Laboratory results suggested that a threshold value of about 0.4 $E/m^2/d$ would be appropriate. The indicator variable, using this threshold, outperformed a range of different thresholds, as well as log transformed irradiance in preliminary analyses (i.e. it explained more of the variation, see also Dean *et al.* 1987).

We developed a single model for each biological variable, using data from all stations and depths. For stations in SOK we used only data collected in the Before period, to eliminate any confounding influence of a SONGS effect operating through processes independent of these variables. We also excluded data collected in the After period on the bottom at SMK45 because this site (and SOKD45) experienced a substantial increase in sea urchin densities that may have influenced results on the bottom during the After period (see Results).

For each biological variable we first fitted a multiple regression model using the three (transformed) physical variables as the independent variables. The results from this model were examined, and a second model was then fit including only independent variables for which the slope parameter attained a significance level of 0.1 or less in the first analysis.

3.4.4 Plume analyses

We analyzed the microscopic outplant data by testing whether the performance of these outplants was related to the fraction of time a station was classified as being in SONGS' plume. For every hour during an outplant we classified each station as being in or out of the plume using an oceanographic model that took into account current vectors and diffusion (see Final Technical Report L). We then calculated the fraction of hours each transplant was exposed to plume waters.

In our analyses, the dependent variables were the differences between the values of the biological variables (possibly transformed) at the various Impact sites and the value at the Control site (SMK45). We used the same transformations as were used in the BACIP tests described above. We linearly regressed these "deltas" against the fraction of time a station was classified as in the plume, and included in our analyses the impact station identities as "dummy variables". This is equivalent to analysis of covariance (ANCOVA), with station as the treatment and fraction of time in the plume as the covariate.

4. Results

Throughout the results section, we distinguish different areas within SOK and SMK (see Methods). In particular, we divide the main portion of SOK that lies downcoast (southeast) of the diffusers into four quadrants: SOKU35, SOKU45, SOKD35, and SOKD45. SOKU45, for example, is the offshore and furthest upcoast quadrant of the main SOK kelp forest and lies immediately downcoast from the diffusers (Fig. 3). One other area of SOK, SOKN, is distinguished. This area lies northwest (upcoast) from the diffusers, and therefore is exposed to SONGS' plume less often than is the main SOK bed (Final Technical Report L).

4.1 Effects of SONGS on Natural Populations

4.1.1 Trends in adult and subadult populations

The spatially most comprehensive data on population density of subadult and adult giant kelp in SOK and SMK come from down-looking SONAR, but those surveys did not begin until February 1982. Because there are very few data from the Before period we tested for temporal trends in the deltas between the impact site (SOK or subareas of SOK) and the control (SMK) by regressing these differences against date. We analyzed both the area of the kelp bed and the density of kelp on hard substrate. We considered three categories of areas: the area where any kelp is present, the area where kelp density exceeds 4 plants per 100 m^2, and the area where kelp density exceeds 16 plants per 100 m^2. For both density and area, a decline through time indicates a decline at the impact site relative to the control which we regard as circumstantial evidence for an effect of SONGS.

There was a general decline in the area supporting any giant kelp in SOK relative to SMK from 1982 through 1989 (Fig. 6). The relative decline in area was significant for SOK as a whole, which includes SOKN (Table 6). A similar pattern is seen when we consider the area with moderate kelp, i.e. more than four plants per 100 m^2 (Table 6). There was also a significant relative decline in the area in SOK with dense kelp, i.e. greater than 16 plants per 100 m^2 (Table 6). The relative declines in areas with some or moderate kelp were largely the result of absolute declines in SOK from 1982 through 1985. After 1985 SOK tracked SMK, with areas increasing in both forests, but did not recover its earlier losses relative to SMK. For areas of high kelp density, the relative loss at SOK resulted both from a decrease to near zero at SOK by 1985, and a failure to increase as much as SMK did starting in 1986 (Fig. 6).

We estimated a decline in the area with moderate to high density kelp (i.e. > 4 plants / 100 m^2) within SOK relative to SMK of 80 hectares, corresponding to 57% of the area in SOK that would have had this much kelp, if SOK had changed in the same way as SMK did. This estimate was calculated using the first three surveys (February 1982 - July 1983) as the "Before" period and the last three surveys (January 1987 - February 1989) as the "After" period (see Methods). It is worth noting that this relative decrease in area in SOK corresponds to a relative decrease in the percentage of the hard substrate covered with moderate to high density kelp. In the "Before" period 24% and 37% of the hard substrate in SMK and SOK, respectively, were occupied by moderate to high density kelp. In the "After" period the percentage declined to 32% in SOK, but increased to 63% in SMK. As discussed in the Methods section, calculating the area with any kelp that was lost in SOK is complicated by the fact that nearly all substrate in SMK was covered by at least some kelp during the "After" period. Our best estimate of the area with at least some kelp that was lost in SOK is simply the total area of hard substrate that was not occupied there, equaling 50 ha.

In addition to its use in producing substrate maps, side-scan SONAR records were used to produce maps on which areas of different kelp density categories were demarcated. These maps were digitized, and used to estimate areas with moderate to high density of giant kelp, as part of the kelp bed fish analyses (Final Technical Report J). By comparing kelp areas at SOK and SMK during the times of the kelp bed fish Before and After surveys, it was estimated that 76% of the area supporting moderate to high kelp density was lost. Although side-scan maps have not been quantitatively calibrated against diver counts, these records were used in the kelp bed fish analyses since down-looking SONAR surveys did not begin until after the Before fish sampling was completed. In Appendix D we provide analyses of all the side-scan data, which encompass 25 surveys from 1978 through 1989 on which areas of both SOK and SMK were estimated. These results are qualitatively consistent with the analyses of down-looking SONAR presented here, and the analyses of a subset of the side-scan SONAR presented in Final Technical Report J. A significant decline in the area with moderate to high density kelp was detected. This decline was estimated as 54% of the area that would have supported such densities of kelp if SONGS were not operating.

Based on down-looking SONAR, there was a decline in the density of giant kelp in offshore SOK beginning in 1983 (Fig. 7). The declines at both SOKU45 and SOKD45 were statistically significant (Table 7). At inshore SOK the density of giant kelp initially declined relative to SMK then increased markedly in 1987 (Fig. 7). Overall there was no significant correlation between the deltas and time for the inshore quadrants (Table 7). The overall trend was for a relative decline in the density of giant kelp in SOK, but this was not quite significant (Table 7, p=0.06). Giant kelp density in the area immediately upcoast of the diffusers (SOKN) showed a nonsignificant negative trend (Table 7).

From the down-looking SONAR data we estimated a decline in density of giant kelp within SOK relative to SMK of 60% (Table 8). This decline was due to losses in the offshore portion of SOK, especially in the upcoast quadrant, where density was initially highest, and declined by 80% (Table 8). These percentage losses correspond to a total of 59,000 plants lost from the average standing stock in SOK. These estimates were calculated using the first three surveys (February 1982 - July 1983) as a "Before" period and the last three surveys (January 1987 - February 1989) as an "After" period (see Methods).

In the Before period the abundance of adult giant kelp was estimated in permanent transects over a longer time than with down-looking SONAR. We were therefore able to statistically compare the differences between SMK and SOK for a Before (prior to May 1, 1983) and an After (May 1, 1983 and after) period using the BACI procedure. This analysis excludes the downcoast inshore quadrant of SOK (SOKD35) because few Before data were collected there.

Density on the transects declined strikingly in SOK relative to SMK from the Before to the After period (Fig. 8). The decline was statistically significant in both offshore and inshore SOK, with declines of 45% and 55% offshore, and 92% inshore (Tables 9 and 10). We were only able to compare the declines in upcoast and downcoast SOK for the offshore quadrants, and there was no evidence for a *smaller* effect in downcoast SOK (Table 9). It is possible that some of the decline seen in downcoast SOK was due to white sea urchins that increased in that area (Final Technical Report J).

The relative decline in adult density seen in the transects in SOK was largely due to a relative reduction in recruitment rate into adult populations (Fig. 9), and not to an increase in mortality of adults (Fig. 10). In offshore SOK neither the recruitment rate of adults nor their mortality rates changed significantly relative to SMK, but the relative decline in recruitment rate in SOK was substantial in size (on the order of 90%, Tables 9 and 10), while changes in mortality rates were small and in the opposite direction needed to explain the changes in adult density (Table 9). Our failure to detect a significant decline in adult recruitment is not surprising given the low power of the tests (Tables 9 and 10). While the relative decline in recruitment rate was also large in upcoast inshore SOK, we were not able to statistically evaluate mortality rate in this quadrant. This is because all the plants on the transects in SOKU35 died in place over a four month period in 1984 (see Fig. 8), and as a consequence mortality rates either could not be estimated (or were based on the survival of a single plant that subsequently recruited) over much of the After period.

Based on Unit 1 studies, it was predicted that the cover of fouling organisms on adult kelp would increase in SOK, and would result in increased mortality rates. However, neither such an increase in fouling (Dixon *et al.* 1987), nor the resulting general increase in mortality rates was seen. As noted above, however, nearly all the adult plants in the upcoast inshore quadrant of SOK (SOKU35) died over a four month period in 1984. We return to this subject below, when we evaluate the results of an adult transplant experiment.

There was a striking decline in the density of giant kelp on transects throughout SOK relative to SMK. This pattern was not evident for inshore SOK in the down-looking SONAR surveys. The difference between the SONAR and the transect results stems from the fact that SONAR sampling was continued after the end of 1986, when the transect sampling stopped. In September of 1987 there was substantial recruitment in SOK, especially in the upcoast inshore portion, which made temporal trends non-significant at the inshore quadrants for the down-looking SONAR data. These plants have persisted, and a substantial giant kelp population existed inshore at SOK as of February 1989.

We believe that the giant kelp that appeared in the down-looking SONAR surveys in September 1987 were produced from gametophytes during the last half of January 1987, a period when Unit 3 (the Unit with its diffuser further inshore) was shut-down. Supporting evidence in favor of this hypothesis is presented at the end of the Results section along with other information critical to the argument.

4.1.2 Effects of SONGS on Blade and Juvenile Kelp

Lower recruitment into the adult population at SOK was strongly linked to the reduced recruitment of blade-stage and juvenile kelp (referred to as young-of-the-year or YOY) 6 to 8 months earlier (see also Schroeter *et al.* 1988). Very little recruitment of YOY was seen in SOK during the After period, while substantial recruitment was seen in SMK (Figs. 11 and 12).

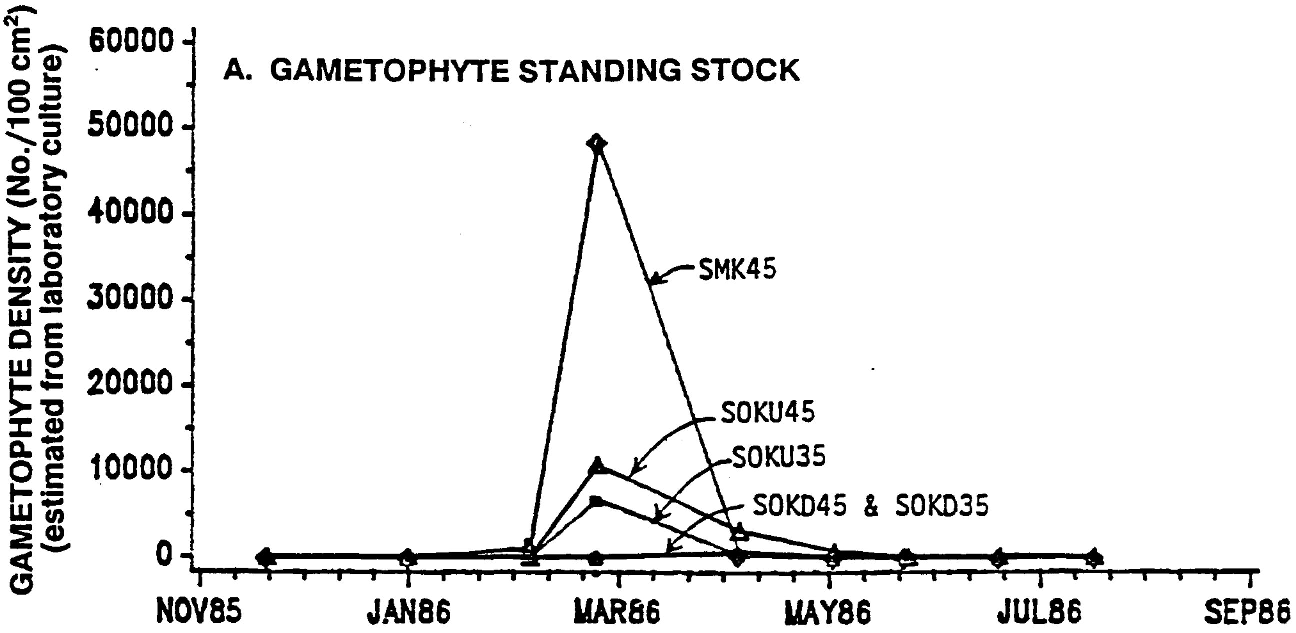
Repeated-measures ANOVAs comparing Before and After differences between SOK (or subareas in SOK) and SMK indicated relative declines in the recruitment of kelp YOY in SOK during the operational period (Table 11).

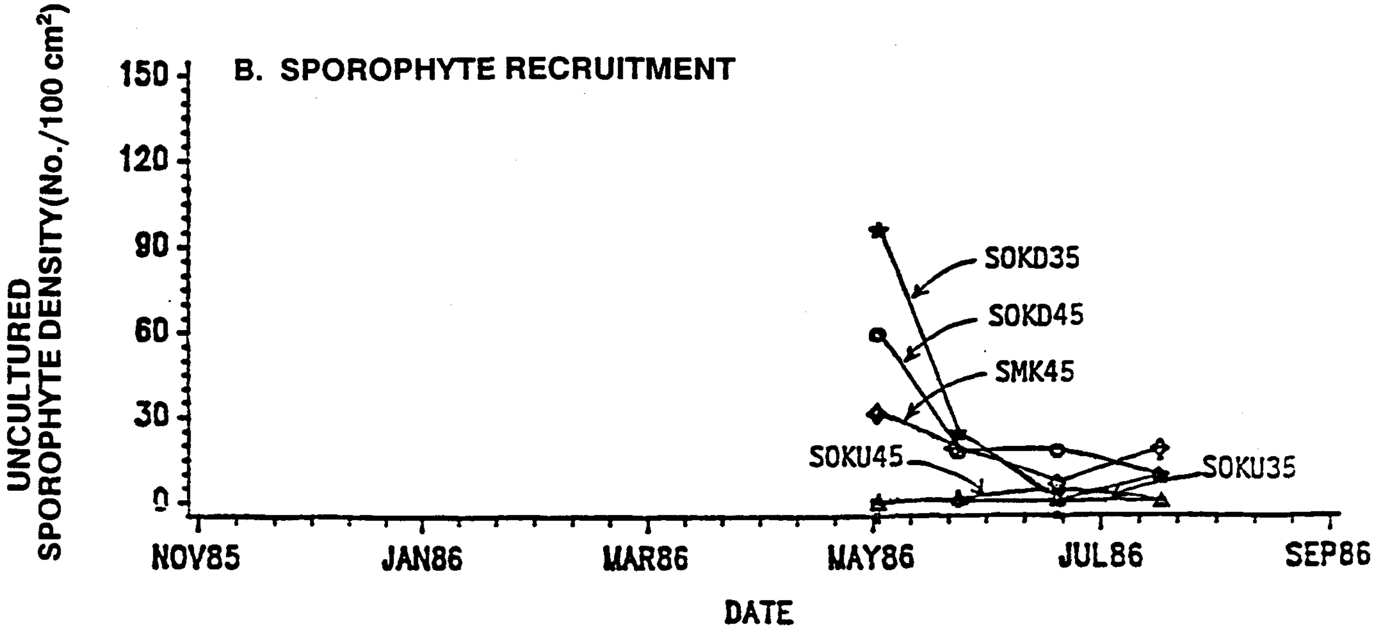
Analyses done on "kelp recruitment" stations in SOK and SMK indicate a statistically significant relative decline throughout SOK of about 75% with no difference between the upcoast and downcoast halves of the bed, as indicated by the nonsignificant period x location interaction (Table 11). A similar pattern was seen when the bed was split into inshore (35 ft. depth) and offshore halves (45 ft. depth). However, the relative decline was slightly greater in the inshore than the offshore half of the bed, and was not statistically significant in the latter (Table 11). All the tests for effects in SOK had, however, quite low power (Table 11), and even quite large effects could have gone undetected.

Additional sampling of YOY was done at two stations in the offshore portions of SOK (within the SOKU45 and SOKD45 quadrants) and one station in the offshore half of SMK (in SMK45) that were also used to monitor populations of kelp forest invertebrates (see Technical Report J). A less accurate picture of recruitment results from these samples because less area was sampled. Nonetheless, results from these stations are similar to "kelp recruitment" stations in the offshore half of SOK: a relative decline in YOY in offshore SOK which was not statistically significant (Fig. 12, Table 11).

4.2 Recruitment of Microscopic Stages of Giant Kelp

The last two sections showed that declines in giant kelp populations in SOK (relative to SMK) were strongly influenced by patterns of recruitment into the adult population. In turn, the lower recruitment rate seen for adults was also seen in the sub-canopy juvenile and blade stages (YOY). This strongly suggests that failure of adult recruitment in SOK during the After period resulted from events affecting the microscopic or blade stages. Failure to recruit to the blade stage (the smallest


A. GAMETOPHYTE STANDING STOCK
GAMETOPHYTE DENSITY (No./100 cm²) (estimated from laboratory culture)
60000
50000
40000
30000
20000
10000
0
SMK45
SOKU45
SOKU35
SOKD45 & SOKD35
NOV85
JAN86
MAR86
MAY86
JUL86
SEP86


B. SPOROPHYTE RECRUITMENT
UNCULTURED SPOROPHYTE DENSITY(No./100 cm²)
150
120
90
60
30
0
SOKD35
SOKD45
SMK45
SOKU45
SOKU35
NOV85
JAN86
MAR86
MAY86
JUL86
SEP86
DATE

above. During the spring recruitment period of 1986, seston flux was higher and irradiance was lower in the upcoast portion of SOK than in SMK or downcoast SOK (Table 13). For seston flux the difference was significant at the SOKU35 station versus SMK45 and nearly significant at SOKU45 versus SMK45 (Table 13). For irradiance no differences were significant; however, the SOKU45 vs SMK45 comparison was nearly so (Table 13). Although there were significant differences in temperature between all sites (Table 13), temperatures were low enough at all sites so that associated nutrients were probably not limiting during the time period of this experiment (Dean *et al.* 1987).

4.2.2 Production of sporophytes from gametophytes

Because gametophytes were not in short supply at any of the stations, while microscopic sporophytes were scarce at the stations nearest the diffusers, our attention now focuses on the production of microscopic sporophytes from gametophytes, and the survival of these sporophytes once produced.

The production of sporophytes from naturally recruited gametophytes was not measured. However, the production of gametophytes from sporophytes was assayed in an extensive series of field outplants (Methods). The relationship between the production of sporophytes in these outplants and the physical environment was examined by use of a multiple regression model (see Methods for details of model formulation). The results of these regressions indicated that the production of sporophytes was higher at higher irradiance values, lower when seston flux was higher, and lower when temperature was high (indicating that nitrogen and other nutrients were at low concentrations, Final Technical Report L) (Table 14).

Of special interest are the relationships with irradiance and seston flux, since SONGS appears to influence both these variables.

To directly assess SONGS' effects, we tested, during the After period, whether sporophyte production at an impact station was related to the proportion of the time a station was designated as in the plume by a plume model (see Analytical Methods). On the bottom the production of sporophytes from gametophytes was generally low for all outplants and sites during the operational period. Although the production of sporophytes was lower when a station was in the plume more, the effect was not significant (Table 15). At two meters above the bottom, where there was appreciable production of sporophytes at times, the production of sporophytes was significantly and negatively related to percent time in the plume (Table 15).

4.2.3 Microscopic sporophyte survival

Mortality of microscopic sporophytes almost certainly contributed to the observed recruitment failure near SONGS. During an experiment done as part of the intensive study of the 1986 recruitment episode, cobbles with microscopic sporophytes that had naturally recruited on them were transplanted to stations in SMK and SOK. The numbers of surviving sporophytes was lower on cobbles transplanted to stations in SOK (especially the upcoast stations nearest the diffusers) in comparison with the control station in SMK (Table 16). In this experiment, cobbles were either transplanted on the bottom or on a tray raised off the bottom to protect them from grazing. These two treatments were pooled because a preliminary analysis indicated no effect of the treatment (Schroeter *et al.* 1988: Table 25). Station had a significant effect (One-way ANOVA, $F_{5,138}=2.28$, $P=0.05$), and the numbers surviving at the upcoast stations in SOK (SOKU35 and

SOKU45) were significantly lower than the numbers surviving at the two stations in SMK (Table 16).

The density of surviving sporophytes was positively correlated with mean irradiance ($n=5$, $r^2=0.71$, $p=0.07$) and negatively correlated with mean seston flux ($n=5$, $r^2=0.92$, $p=0.02$) during this experiment, but there was no apparent relationship with temperature ($p=0.92$). During the experiment irradiance was lower at all stations within SOK than in SMK45 (irradiance was not measured in SOKU35), and these differences were statistically significant for three of the four stations in SOK (Table 17). Seston flux was higher at all stations within SOK than at SMK and was especially high at the upcoast station. However, only the differences between the downcoast stations in SOK and SMK were significant (Table 17). The lack of significance for the upcoast stations in SOK resulted from high variability among the three samples at each of these stations, as the mean seston flux at these stations was actually higher than in downcoast SOK (Table 17).

The mortality rate of microscopic sporophytes was also assessed from an extensive series of outplants. During the After period, mortality rates were directly related to the fraction of the time a station was classified as being in SONGS' plume (Table 18).

Based on the results of the above analyses, we cannot distinguish between the negative effects of high seston flux and low irradiance. However, the outplant data suggest that increased seston flux may have been the primary cause of the low survival rates seen in upcoast SOK. The relationship between the survival (and growth) of this stage, and the physical environment was explored through the use of multiple regression models (see Methods for details on model development).

Survival was significantly lower when seston flux was high (Table 19). Although survival was also negatively correlated with irradiance, this was weaker than that with seston flux, and the addition of irradiance did not explain a significant amount of additional variability in the mortality rates over that explained by seston flux alone. Furthermore, increases in seston flux provide a plausible mechanism for increased mortality since burial by sediments has been shown to reduce survival of microscopic kelp in lab experiments (Devinny and Volse 1978). However, because irradiance and seston concentrations are correlated in the physical-chemical data collected as part of these outplants (Appendix A), we cannot rule out some influence of irradiance on microscopic sporophyte survival rates.

4.2.4 Growth of microscopic sporophytes

Effects of SONGS on growth of the microscopic sporophyte stage are also of interest. Mortality rates for this stage are higher than for larger sporophytes, and if growth rate is reduced, an individual plant will remain in this high risk stage for a longer period of time.

During the 1986 cobble transplant experiment, the final length of surviving sporophytes was measured, and was taken as a measure of the growth rate over the course of the experiment. The results for growth from this experiment do not present clear evidence for a power plant effect. The station to which cobbles were transplanted to did not significantly influence length, but there was a significant interaction between station and height off the bottom (Table 20). Lengths of sporophytes were not significantly correlated with any of the physical factors that were measured.

Although growth during the cobble transplant experiment was not correlated with irradiance levels, outplant results showed that growth of the microscopic stage was, in general, positively related to irradiance level, and negatively related to seston flux (Table 21). Although effects of both irradiance and seston flux were significant, and together these two variables explained 50% of the variability, the partial r^2s for both variables were low (Table 21). This indicates that although together these variables were important, we could not distinguish between their effects. Either very little or a substantial portion of the variability in growth rates could be attributed to either of these physical factors alone.

Growth rate of microscopic sporophytes, like mortality rate, was related to the proportion of the time a station was classified as being in SONGS' plume. Growth rates were inversely related to the fraction of the time a station was classified as in the plume (Table 18).

4.2.5 BACIP Analyses on Microscopic Outplants

Gametophyte and microscopic sporophyte outplants were placed at a control site (in SMK45), a near impact site (in SOKU45), and a far impact site (in SOKD45) repeatedly both before SONGS Unit's 2 and 3 began operations and after operations began. By examining the change, from Before to After, in the difference between impact and control stations we tested for effects using the Before-After-Control-Impact-Pairs (BACIP) approach (see Interim Technical Report 2 for details).

The results of these tests are presented in Tables 22 (Production of gametophytes from sporophytes), 23 (growth of outplanted microscopic sporophytes), and 24 (mortality rate of microscopic sporophytes). To control for depth, tests were only done comparing SOKU45 and SOKD45 with the control at SMK45. We did not test for differences in sporophyte production at 0 m (on the bottom) at SOKU45 because sporophyte production at that site was zero or near zero on nearly all dates both in the Before and After period. With the exception of some tests on mortality of the microscopic sporophyte outplants, these tests had very low power (less than 20%), and were not statistically significant. Because of their low power, these BACIP tests on the microscopic outplants do not constitute a strong test of SONGS effects.

There was one statistically significant effect. The mortality rate of microscopic sporophytes was significantly *lower* at SOKU45 in comparison with SMK45 in the After period relative to the Before period (Table 24). A nearly significant difference was seen in the SOKU45 vs SOKD45 comparison, again with a relative decrease in mortality rates at SOKU45, the station closest to the diffusers (Table 24). These effects were due to increases in mortality rate from Before to After at the control (SMK) and far impact (SOKD45) sites.

The BACIP results for mortality of the outplanted microscopic sporophytes do not agree with the patterns observed for natural recruitment, nor with the results of the cobble transplant, nor with the relationship between microscopic mortality and percent time in SONGS' plume. These other lines of evidence all suggested that SONGS had adverse effects on microscopic stages of giant kelp. We believe that the reduction in mortality of microscopic sporophytes in upcoast SOK indicated by the BACIP analysis of the outplant data was anomalous, and not indicative of what natural kelp populations have experienced throughout the SOKU45 quadrant. The apparent reduction in mortality rate may have stemmed from a Period by Site interaction at the specific sites used in these outplants. In contrast with our bed-wide monitoring of natural populations, the outplants at each station were placed within a relatively small area (less than 1 m^2), and it is possible that they were strongly influenced by very local events. For example, a large increase in white sea urchin *(Lytechinus)* density occurred at or near the outplant sites in SOKD45 and SMK45, and the white sea urchin is a known grazer on giant kelp, and can inhibit recruitment of small stages (Dean *et al.* 1984). Although not sampled for sea urchins, it is known that the area used for these outplants in SMK became an urchin barrens during the After period (S. Schroeter, *personal observation*). White sea urchin densities near the SOKU45 and SOKD45 outplant sites were estimated as part of the MRC's study of hard benthic invertebrates (Final Technical Report F). The densities increased substantially near the outplant site in downcoast SOK, relative to the increase near the outplant station in upcoast SOK (Table 25) in the After period. The increase near the outplant site in SOKD45 (LSOKD45) relative to the outplant site in SOKU45 (LSOKU45) is approximately six fold (Table 25). While there was a general increase in the density of white sea urchins in the SOKD45 quadrant relative to the SOKU45 quadrant, this overall increase, less than a doubling (Final Technical Report F), was substantially less than was seen at the outplant sites. This is of course, just one logical explanation for the results. Another is that mortality rates increased at the control site due to increased abrasion from drift kelp. During the After period drift kelp was more often observed tangled with the outplant racks in SMK (Tom Dean, *personal observation*).

4.3 Performance of Macroscopic Plants

4.3.1 Blade stage transplants

Results from experiments that compared the growth of blade-stage individuals under an adult kelp with growth in clearings demonstrate that under field conditions growth is generally lower when irradiance levels are reduced (Dean *et al.* 1987).

An additional blade-stage transplant experiment was done in 1986. In it blade-stage plants were placed in various stations in SOK and in SMK, and their growth and survival was monitored over a four month period. Mortality rates during the experiment were higher in each area of the main part of SOK than they were in either SMK or in the area of kelp northwest of the diffusers (SOKN) (Fig. 14). Mortality was significantly higher in the inshore downcoast portion of SOK than in SMK (Table 26), and was actually significantly lower in the area of kelp upcoast of SONGS diffusers (SOKN) than in SMK (Table 26). Mortality at all sites in SOK, downcoast of the diffusers, combined, was significantly higher than at the two sites upcoast of the diffusers (SMK and SOKN) combined ($X^2_1 = 26.7$, $p < 0.0001$).

The higher mortality rates seen in SOK compared to SMK were generally associated with higher seston flux on the bottom in the SOK kelp bed than in the SMK bed during this experiment (Table 26), but the correlation between log transformed mortality rate and log transformed seston flux did not reach statistical significance ($r^2=0.60$, $p=0.12$, $n=5$). In contrast, there is no evidence that high mortality rates were associated with low irradiance (Table 26). In fact, irradiance levels were somewhat higher in SOK than in SMK during the experiment (Table 26).

Although growth rates of blade stage plants varied significantly among stations during this transplant experiment, they were not generally lower in SOK than in SMK, and no individual SOK station had a growth rate that differed significantly from that seen at SMK (Table 26). There was no obvious relationship between growth rate and irradiance or seston flux. For example, SOKU45 had the lowest irradiance and the highest seston flux, and yet the second highest growth rate (Table 26). This is not to say that growth rate is generally unrelated to irradiance. It should be noted that within SMK an experiment overlapping in time with this one showed that blade stage individuals under adult giant kelp canopy (and experiencing 30% lower irradiance) grew slower than individuals in clearings (Dean *et al.* 1987).

There is some suggestion in the results of the blade transplant experiment that mortality rates were higher and growth rates lower at stations with lower bottom temperatures. The station with the lowest temperature had the lowest mortality rate and the highest growth rate, and the two stations with the highest temperatures had the lowest growth rates and the highest mortality rates. The correlation between log transformed growth and log transformed temperature was negative ($r^2=0.67$, $p=0.09$, $n=5$), and the correlation between log transformed mortality and log transformed temperature was positive ($r^2=0.69$, $p=0.08$, $n=5$), although neither of these correlations was quite statistically significant. However, evidence from a 1983 experiment with blade-stage individuals argues against a direct effect of temperature or the low nutrient concentrations associated with high temperatures. At the time of that experiment, the average temperature was substantially higher (17.5 °C) than at any station during the 1986 experiment, yet growth rates were higher during the 1983 experiment than in 1986, and especially high mortality was not noted in 1983 (Dean *et al.* 1987). Clearly the role of nutrient limitation on growth of the blade-stage is an area for future research.

4.3.2 Juvenile transplants

We used data from juvenile transplants to assess SONGS' effects on juvenile growth rate. Overall, the juvenile transplant results do not provide convincing evidence that SONGS acts to reduce growth rates. For juveniles we do not have the information necessary to evaluate SONGS' effects on mortality. On transects individual juveniles were marked *in situ* only during the Before period. Although there were data for transplanted juveniles for both the Before and the After periods, they were secured to racks and raised off the bottom, a procedure that eliminated the most significant sources of mortality to juvenile plants in nature.

During 1986, juveniles were transplanted to additional inshore stations within SOK and SMK (SOKD35, SOKU35, SMK35), along with the offshore areas used throughout the study (SOKD45, SOKU45, SMK45). These additional stations were added during two transplants as part of the intensive study of the 1986 recruitment episode. The first of these two transplants was started on 24 June, about the time when the first natural recruits reached the juvenile stage. The second transplant was started on 7 August, at a time when many natural recruits had reached the juvenile stage.

Among the inshore transplants during 1986, growth rates were lowest nearest the SONGS diffusers (Table 27). For these inshore stations growth rates differed significantly among stations and were ordered as SMK35 > SOKD35 > SOKU35 and SMK35 = SOKD35 > SOKU35 in the 24 June and 7 August transplantings, respectively (Table 27). There were no consistent spatial trends in growth rates among the offshore sites (Table 28), although growth was significantly lower in SOKD45 than in SMK45 in the 24 June transplant.

Differences in growth rates at the inshore sites appeared unrelated to irradiance or temperature. In fact, at these inshore stations, irradiance was generally higher at SOK, even though growth was lower there (Table 29). Temperatures did not differ significantly among inshore sites during either experiment, and the only difference seen offshore was significantly lower temperatures at SOKU45 in comparison with SMK45 during the 7 August transplant (Table 29).

Inshore, growth rates of transplanted juveniles were lower at the sites with a higher percent cover of fouling organisms. Among the inshore sites the highest levels of fouling were observed at the inshore site closest to the diffusers (SOKU35) followed by SOKD35 and SMK35 (Table 30). The spatial pattern at the offshore stations was opposite, however, with fouling quite high in SMK and low in upcoast SOK, and spanned the same range as was seen inshore (Table 30). Taken together these results suggest that the negative relationship seen between fouling and growth inshore may be spurious, or that fouling affects kelp differently inshore than it does offshore. Early studies demonstrated lower growth and higher mortality associated with increased fouling of giant kelp plants transplanted near the outfall of Unit 1 (Murdoch *et al.* 1980). This work was also done inshore (because of the location Unit 1's outfall).

The transplants during 1986 did not indicate that variation in irradiance or temperature among sites contributed to differences in growth rates. A more extensive series of transplants done only at the offshore sites demonstrated that in general juveniles grow faster when irradiance is high and when temperatures are low. Together these two physical factors explained 56% of the variation in growth rates with partial r^2s of 0.49 and 0.27 for temperature and irradiance respectively (Table 31).

Because juveniles tended to grow more slowly when irradiance was lower, and irradiance tended to be lower in the After period in SOK relative to SMK due to SONGS' turbid plume, it was reasonable to suppose that the operations of SONGS would lead to a reduction in growth rate. There is no direct support for this prediction based on a Before-After/Control-Impact evaluation of the juvenile transplant data. In fact, in comparison with the Before period, growth rates were actually higher at SOKU45 relative to SMK45 or SOKD45 during the After period, with the comparison with SOKD45 being significant (Table 32). We suspect that no negative effects occurred because the absolute values of irradiance were high in the After period, and were probably above the level necessary for saturation of growth at all stations (Dean *et al.* 1987).

4.3.3 Adult transplants

Our observations of natural populations of adults indicated that adult mortality rate was relatively constant, and that mortality rates did not generally increase in SOK relative to SMK during the After period (see Section 4.1.1). However, especially high mortality occurred in shallow water near SONGS' diffusers in 1984. Consequently, kelp disappeared from this portion of the bed. This motivated the transplanting of adult kelp to this area and to a control site in SMK in Fall 1986.

During the three months the experiment was monitored, only two of the transplanted adults died. However, there was a significant decrease in the number of fronds per plant in SOKU35 relative to SMK35 (Table 33). The adults at SMK gained an average of three fronds per plant, while those at SOK lost an average of three fronds per kelp plant (Table 33). A continuation of this trend would lead to a loss of the plants at SOKU35. It is possible that this difference between inshore SMK and SOK was accentuated in 1984 under El Nino conditions.

4.3.4 An Investigation of the Fall 1987 Recruitment of Adult Kelp

The MRC's studies of giant kelp, through the end of 1986, showed a striking pattern. Recruitment of immature giant kelp declined substantially in SOK relative to SMK after SONGS Units 2 and 3 began operating. In July 1987, as in June 1986, there was much lower recruitment of blade and juvenile kelp in SOK relative to SMK (see Fig. 11). We were surprised, then, to see a substantial increase in density of large (subadult or adult) kelp recorded in the down-looking SONAR survey of SOK in September 1987 (Fig. 7). We have no reason to believe that survival of young giant kelp should have been much higher in SOK during 1987 than it was in 1986, and the number of young recruits we counted during the July 1987 survey does not seem sufficient to account for the increase in adult and subadult density recorded in the SONAR survey in September, 1987.

To help pin-point the time period that the giant kelp seen in the September 1987 survey were produced from gametophytes, we estimated size (and approximate age) of plants recorded by SONAR in September 1987 by measuring the traces on the SONAR records. In addition, in December 1987 we counted the fronds of all plants in a 70 m^2 area near the Unit 3 diffusers in SOKU35 (a temporary quadrat set up near "transect 1"), and in a 100 m^2 area of SMK45 (in two temporary quadrats, one 70 m^2 and the other 30 m^2, both between "transects 14 and 15"). We estimated that in September the largest plants near the Unit 3 diffusers were about 8 m long, and most plants were late juveniles or early subadults. In December essentially all the plants in SOK were young subadults with fewer than seven fronds (Fig. 15). Most had two or three fronds which did not reach the surface in 12 m of water.

We can identify the time period during which these sporophytes were produced from gametophytes, with fairly high confidence, as being during the last three weeks of January 1987. We can do this by combining information on the size of these plants, earlier SONAR and diving survey data, the maximum development rate of giant kelp in the San Onofre area, and data on the physical environment.

First, the 8 m long plants seen in September 1987 must have been produced from gametophytes at least seven months earlier. This conclusion is based on maximum growth rates for each stage of giant kelp in the San Onofre area (Schroeter *et al.* 1988). Second, few of the plants observed in SOK by SONAR in September 1987 could have resulted from recruitment at SOK in 1986, which was light. Finally, it is unlikely that the plants were produced from gametophytes during Fall 1986 since water temperatures were high most of the time, and it is unlikely that there were sufficient nutrients for gametogenesis and sporophyte production. The light and nutrient conditions required for sporophyte production were probably not met until after the first week of January 1987 (Fig. 16). We have therefore bracketed the production of these sporophytes between early to mid-January, when physical conditions became favorable, and the beginning of February after which even maximum growth rates would have been insufficient for them to reach the size they had attained by September. The January timing of sporophyte production explains why these sporophytes did not show up in large numbers during the July 1987 bed wide survey for YOY. The sporophytes produced in January would have been large juveniles or small subadults by July. Our surveys of bed-wide recruitment were not suited for estimating the relatively low densities of large juveniles and subadults because small areas were examined (1-m^2 quadrats) in those surveys.

The significance of the production of sporophytes during January 1987 is that Unit 3, the Unit with an inshore diffuser, was not pumping water after the beginning of January until the end of February 1987 (Fig. 16).

5. Discussion

The results of the MRC's studies on giant kelp show that SONGS has caused reductions in the area of the San Onofre kelp forest, and of the density of giant kelp within the forest. Results of both mechanistic and sampling studies indicate that the adverse effects of SONGS Units 2 and 3 occur by substantially reducing recruitment to the adult stage. Much of the effect appears to have already occurred by the time plants reach the blade-stage.

The argument in favor of a SONGS effect is especially strong because there are multiple, independent, lines of supporting evidence. This evidence is summarized in Table 1. It includes patterns in natural populations based on five separate sets of sampling data that were collected using different methods and on different dates. Two sets of data, one based on down-looking SONAR done over the period 1982 to 1989, and another based on diver counts of marked plants on transects done over the period 1978 to 1986, showed similar declines (55 - 60%) in the density of adult giant kelp in the San Onofre kelp forest, relative to densities in the control San Mateo kelp forest. Study of the marked plants on transects showed that the decline in density was caused by a reduction in the production of adult plants, and not an increase in their mortality. Two separate sampling programs showed that reduced recruitment of adults was preceded by a reduction in the production of small (10 cm to 1 m) sporophytes. During an intensive study of recruitment during 1986, there was higher mortality of small sporophytes transplanted downcoast of the diffusers. Fewer sporophytes were produced from gametophytes at experimental stations in SOK when those stations were exposed to plume water for a greater fraction of the time. Experimentally outplanted microscopic sporophytes also showed poorer performance during experiments when they were exposed to more plume water. When they were more often exposed to the plume, their mortality rate was higher and their growth rate was lower.

Information on how SONGS has changed the physical environment, and on how giant kelp responds to the physical environment, also argue for adverse effects of SONGS. SONGS reduced the amount of light reaching the sea-floor throughout SOK. We found an increase in vertical seston flux (settling particles) in the upcoast portion of SOK, and evidence for an increase in seston concentration near the bottom throughout SOK. During our studies, the production of sporophytes from gametophytes was positively related to irradiance and negatively related to vertical seston flux; the growth of small sporophytes was higher when light levels were higher; finally, the survival of small sporophytes was negatively associated with the rate of vertical seston flux. The results of other studies are in agreement with these results. Sedimentation and seston flux can adversely impact microscopic stages of giant kelp (Devinny and Volse 1978), as well as the microscopic stages of other benthic organisms (see references in Foster and Schiel 1985). There is no question that light level, within the range observed in kelp forests, is an important determinant of growth rates for the preadult sporophyte stages of giant kelp and other laminarian algae (e.g. Luning and Neushul 1978, Luning 1980, Luning 1981, Neushul 1981, Murray and Fain 1982, Deysher 1984). Furthermore, recruitment and growth of small sporophytes is reduced under giant kelp canopy (e.g. Pearse and Hines 1979, Reed and Foster 1984, Dayton *et al.* 1984, Dean and Jacobsen 1984, Santileces and Ojeda 1984) and canopy of giant kelp can reduce irradiance by 90% or more (e.g. Neushul 1971, Gerard 1984, Dean 1985).

In addition, an unexpected change in the environment that could well have been influencing giant kelp populations was the appearance of fine sediments with unusual bulk properties in SOK in 1985 (Final Technical Report B). Although the effect of these sediments on giant kelp was not studied explicitly, it was probably adverse. The presence of these sediments acted to reduce the densities of both macro-invertebrates (Final Technical Reports B and F), and understory algae (Final Technical Report B). If nothing else, kelp is unlikely to successfully recruit to areas where the hard substrate has been buried with these sediments. As of July 1988, these sediments covered about 30 hectares (15% of the cobble area underlying SOK). The timing of their appearance, and their concentration in the areas of SOK closest to the diffusers suggested that SONGS may have been responsible for these sediments; however, the mechanisms responsible for the production and transport of this material are still under investigation, and the results of these studies will be included in the final draft of Technical Report B. It should be noted that although these sediments could be responsible for a portion of the lost kelp in SOK, the case for SONGS effects does not rest on them. Much more area has been affected than the total covered by these sediments.

The changes in the SOK giant kelp population we have seen match, in many regards, the changes that were predicted prior to the beginning of operations by SONGS Units 2 and 3. Reductions in both density and areal extent were predicted, and it was also predicted that this would occur because of a reduction in recruitment of small sporophytes. Furthermore, the evidence that led to our conclusion that SONGS adversely affected the SOK kelp forest is exactly the kind of information that the MRC had thought would indicate an effect when the studies were planned. For example, in the Technical Appendix to the MRC's predictions (Dean 1980) it was stated that:

> The upcoast margin of SOK, especially in the offshore-upcoast area, should be studied carefully since it is closest to the diffuser lines and has proven to be one of the most persistent portions of the SOK bed. Any drastic reduction in high density frond area near the Units 2 and 3 diffuser lines without obvious natural causes such as heavy storms, urchin invasions, or loss of substrate, or without concurrent changes in the SMK bed would indicate adverse impacts of SONGS.

And it was this portion of the SOK kelp forest that showed the greatest relative decline in density, of nearly 80%.

Two aspects of our results need further discussion. First, in contrast with the results during the After period when the MRC did most of its field studies (which ended in December 1986), down-looking SONAR recorded substantial recruitment of subadult kelp in inshore SOK in September 1987, and relatively high densities there through 1989. On first consideration this seems to argue against SONGS having effects on the giant kelp populations. However, it is important to keep in mind that our evaluations of SONGS effects come by comparing the impact area with a control area. The resurgence of giant kelp seen in SOK starting in 1987 was paralleled by even greater recruitment of kelp in SMK during the same period. Thus, over this period, when kelp recruited well throughout California, we estimate that there were, on average, 59,000 fewer large kelp plants in SOK, and there were 80 fewer ha of moderate to high kelp density than there would have been if SONGS were not operating. However, the effects that seemed evident throughout SOK during the After period were restricted to the offshore portion of the kelp forest when the period from 1987 onward is considered. The largest increase in kelp density inshore was in September 1987. These plants appear to have resulted from sporophytes that were produced from gametophytes in January 1987, a time when Unit 3 (with the furthest inshore diffuser) was not pumping any water. There has been additional recruitment of adult giant kelp in SOK, especially inshore, since

September 1987. Some of these adults may represent remaining recruits from 1987 that had not reached the canopy (perhaps due to overshading), and began growing rapidly following a severe storm on January 17, 1988, that removed canopy. However, production of new sporophytes did occur inshore after January 1987, especially in the downcoast portion of SOK. This is indicated by the results of the final survey for young of the year kelp recruits in July 1988. One possible explanation for this result is that the increase in the concentration of seston caused by SONGS is greater offshore, so that effects are less severe inshore, and perhaps are only evident during more marginal recruitment periods. There is no evidence for such a spatial difference in physical effects, however (Appendix A). A second possibility is that effects are on average the same inshore as they are offshore, and that we have simply seen a chance deviation from the long term average. A third possibility is that conditions are generally better for giant kelp recruitment in the inshore quadrants than in the offshore quadrants of SOK, and as a result the same physical effects inshore interrupt recruitment only during some of the times that offshore recruitment is impeded. These are possibilities that can not be distinguished given the existing data, but may be by continued sampling of the San Onofre and San Mateo populations of giant kelp by down-looking SONAR.

Second, it could be argued that SONGS has not adversely impacted giant kelp because BACIP tests did not show such effects on outplanted microscopic or juvenile stages. We think this is a weak argument. These BACIP tests had low statistical power (that is, even large effects could go undetected). In addition, the data used in these outplants came from extremely localized sites, and the BACIP results do not reflect the patterns seen in natural populations. Thus a very localized event at these stations could strongly influence the BACIP results for the outplants. One such localized event was a substantial increase in white sea urchin densities during the After period at two of the outplant stations. Finally, using the same outplant data in an analysis different from the BACIP, we have shown that microscopic kelp performs more poorly when exposed to more plume water.

The body of results presented in this report strongly suggests that temporal variation in recruitment (rather than in adult mortality) was the major force driving fluctuations in adult densities in the kelp forests near San Onofre. The resurgence of giant kelp in inshore SOK, resulting from a burst of recruitment during a less than two month period when Unit 3 was shut down, emphasizes that episodic recruitment events are crucial to the population dynamics of giant kelp. A kelp forest can be dominated for a year or more by plants that recruited during a period of a month or less. These results do not mean that adult mortality will never be an important structuring force for giant kelp populations. For example, storm induced mortality of adult kelp had striking effects on a kelp forest near Santa Barbara, California (Ebeling *et al.* 1985).

The long-term effect of SONGS on SOK will depend in part on how often SONGS' operating schedule, or particularly good conditions that mask SONGS' effects, permit successful recruitment of giant kelp to the adult stage. A kelp forest can reach a "maximum" adult density even after missing several episodes of adult recruitment, given that the period between successful adult recruitment episodes is not so long that local extinction results. This is not unexpected given the strong density dependent effects of adult giant kelp on recruitment of small sporophytes (see citations above), and the predicted consequences of such delayed density dependence on population dynamics (e.g. Nisbet and Bence, 1989). Recovery from low densities of adults depends crucially on the lengths of time between successful recruitment events. If these time periods are too long, a local giant kelp population may go extinct, and once this happens it can take many years for a recovery to occur. This was the case for SOK and SMK following a die-off in the late 1950's, and at Barn kelp forest after a die-off in 1980.

One potential method to mitigate SONGS' effects on giant kelp would be to schedule down-time for the January-May period, when the production of new giant kelp sporophytes often occurs. Standing in the way of successful implementation of such a plan is the highly unpredictable timing of production of new giant kelp sporophytes. On the other hand, even if such rescheduling did not allow substantial production of sporophytes during all potential "windows" when physical conditions were appropriate, it might increase the probability of successful recruitment.

There are of course many other potential methods to mitigate SONGS' effects on giant kelp, and these are discussed at length elsewhere (Final Technical Report H). One such method would be the construction of an artificial reef. If located in the San Onofre area, care will be needed to locate such a reef so that the substantial adverse effects of SONGS on giant kelp that we saw in SOK do not occur there also. One possible location would be upcoast (northwest) of SONGS diffusers, which now is largely a sand plane. The available population data suggest that SONGS did not reduce the density of giant kelp on a patch of hard substrate immediately upcoast of SONGS' diffusers. It is possible that SONGS does not substantially affect kelp in this area because it is generally upstream of the diffusers, and on average only experiences a small reduction in irradiance (Appendix A). However, caution should be exercised in locating a kelp forest in this area, since potential SONGS' effects were not studied in the detail there that they were downcoast of the diffusers. It is possible, for example, that SONGS might increase seston flux in this area, leading to higher mortality rates of small plants. Such possibilities would need to be considered if this area were chosen as the site of an artificial reef.

Because giant kelp is such an important component of the kelp forest community, losses in giant kelp populations have consequences to other components of the community. Of particular interest is that decreases in areas covered by giant kelp, or the density of kelp within an area, can lead to declines in the abundance of some species of fish. As it turns out, over the short-term, the effect of decreased area covered by kelp in SOK was an increase in the density of the mid-water fish in the remaining area of kelp as the fish become "concentrated" into that area (Final Technical Report J). Whether or not losses in areas with kelp lead directly to losses of bottom fish is unclear. Over the long term, however, total numbers of fish may decline either if mortality rates increase, or more likely, if total recruitment of young fish declines. Support for this speculation comes from the observation that reefs with higher kelp densities tend to have more fish (Final Technical Report J). (Note that the numbers of bottom fish in SOK have declined relative to SMK, but this decline was at least partly independent of changes in the density of giant kelp (see Final Technical Report J).)

Giant kelp populations are also of importance to some invertebrates. For example both the red sea urchin and abalone feed primarily upon drifting fronds of *Macrocystis*. It is worth noting that the red sea urchin is now one of the most important commercial fisheries in southern California (Reed, *personal communication*). One estimate of such detrital production was made during the Before period (December 1978), when it was estimated that 9,000 kg of drift kelp was released by SOK per day, which is equivalent to 18 g/m^2/d (Dean 1980). Gerard (1976) studied the material dynamics of the Point Cabrillo kelp forest in

Monterey Bay, California in detail. She estimated that 70% of the production entered the drift kelp pathway, and that of this, 40% was used by foragers within the kelp forest. Clearly organisms that live directly on giant kelp plants (e.g. fouling organisms) will be lost when the plants are lost. We suspect that at least some species that are less obligatorily dependent upon giant kelp also experienced reductions in abundance as giant kelp became less abundant in SOK. However, we have no direct evidence for this, and in general such losses were probably not catastrophic for large benthic invertebrates. For example, we could detect no obvious density response of large benthic invertebrates living in Barn kelp forest after the giant kelp population there went extinct in 1980 (Final Technical Report F). Again, it is worth noting that we have seen declines in the density of macroinvertebrates in SOK since SONGS began operating, but these losses do not seem to be tightly linked to the declines in giant kelp (Final Technical Report F).

In summary then, following the start of operations by the new Units, SONGS appears to have substantially reduced the production of new adult giant kelp plants in SOK. This led to a decline of about 60% in density of adult kelp in SOK relative to SMK, and the loss of approximately 80 ha of moderate to high density stands of kelp. This overall decline occurred in the face of substantial adult recruitment in inshore SOK during fall of 1987. Our estimates of overall reductions in area and density in SOK due to SONGS are reasonable long-term ones. This is in view of the fact that the oceanographic setting of the After period has spanned the range from very good (e.g. 1986, 1988) to very bad (1983) conditions for kelp recruitment and growth.

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7. TABLES

Table 1

SUMMARY OF EVIDENCE FOR A SONGS EFFECT ON GIANT KELP

- **Patterns in natural populations**
    - Adult density and areal extent declined in SOK relative to SMK
    - Recruitment rate of adults declined in SOK relative to SMK. Decline was very large but not significant (low power)
    - Recruitment rate of blade-stage/juveniles declined in SOK relative to SMK
- **Studies of the 1986 Recruitment Episode**
    - Gametophytes present in adequate numbers
    - Microscopic sporophytes scarce near SONGS' diffusers
    - High mortality rate of microscopic sporophytes transplanted near diffusers
    - High mortality rate of blade-stage sporophytes transplanted downcoast of diffusers
- **Mechanistic studies**
    - SONGS' plume acts to reduce irradiance and increase seston flux
    - Microscopic sporophyte production lower when:
        - irradiance low or seston flux high
        - plume is present more
    - Microscopic sporophyte survival lower when:
        - seston flux higher
        - plume is present more
    - Microscopic sporophyte growth lower when:
        - irradiance lower or seston flux higher
        - plume is present more
    - All pre-adult stages grow more slowly when irradiance lower

Table 2

Average cover (%) of various substrates in kelp forests in San Diego county in November/December 1984. Estimates were made at a single site in each area. 40 1-m^2 quadrats were examined at SMK, SOKU, SOKD, and BK. 20 quadrats were used in the other kelp forests. SMK = San Mateo; SOKU = Upcoast San Onofre; SOKD = Downcoast San Onofre; BK = Barn kelp; CSB = Cardiff State Beach; LEU = Leucadia; SWA = Swami's; CAR = Carlsbad; LJ = La Jolla. Substrate categories defined by Wentworth scale (Inman 1963). Based on Table 1, Dixon <u>et al.</u> 1988.

	KELP FOREST								
SUBSTRATE	SMK	SOKU	SOKD	BK	CSB	LEU	SWA	CAR	LJ
Reef	0.0	0.0	0.0	54	65	70	60	97	93
Boulder	24	21	12	2.7	0.0	1.1	0.0	0.7	1.4
Cobble	53	32	47	24	0.0	1.7	2.2	1.8	1.5
Gravel	11	7.7	14	2.7	0.0	0.4	3.4	0.0	0.4
Sand	12	40	27	17	35	27	34	0.0	4.3

Table 3

Average density (no./m^2) of various algae in kelp forests in San Diego county in November/December 1984. Estimates were made at a single site in each area. 40 1-m^2 quadrats were examined at SMK, SOKU, SOKD, and BK. 20 quadrats were used in the other kelp forests. SMK = San Mateo; SOKU = Upcoast San Onofre; SOKD = Downcoast San Onofre; BK = Barn kelp; CSB = Cardiff State Beach; LEU = Leucadia; SWA = Swami's; CAR = Carlsbad; LJ = La Jolla. Based on Table 2, Dixon et al. 1988.

	KELP FOREST								
SPECIES	SMK	SOKU	SOKD	BK	CSB	LEU	SWA	CAR	LJ
Macrocystis pyrifera (adult)	0.8	>0.1	>0.1	>0.1	0.1	0.5	0.2	0.4	0.1
Laminaria farlowii	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	2.3
Cystoseira osmundacea	0.3	0.3	0.1	0.4	0.0	0.0	3.2	0.1	13
Desmarestia ligulata	0.2	0.1	0.3	0.4	0.0	0.1	0.7	0.0	0.0
Egregia menziessi	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.1	1.5
Eisenia arborea	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	2.8
Pterygophora caifornica	0.1	0.0	0.1	0.0	0.0	0.0	0.7	0.1	2.9

Table 4

Average density (no./m^2) of various benthic invertebrates in kelp forests in San Diego county in November/December 1984. Estimates were made at a single site in each area. 40 1-m^2 quadrats were examined at SMK, SOKU, SOKD, and BK. 20 quadrats were used in the other kelp forests. SMK = San Mateo; SOKU = Upcoast San Onofre; SOKD = Downcoast San Onofre; BK = Barn kelp; CSB = Cardiff State Beach; LEU = Leucadia; SWA = Swami's; CAR = Carlsbad; LJ = La Jolla. Based on Table 3, Dixon <u>et al.</u> 1988.

	Kelp Forest								
Species	SMK	SOKU	SOKD	BK	CSB	LEU	SWA	CAR	LJ
Tethya aurantia	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Muricea californica	9.5	3.4	9.3	9.8	4.4	9.6	1.1	1.6	0.4
Muricea fruticosa	2.4	0.2	0.5	3.1	0.8	0.8	0.1	0.5	0.0
Astraea undosa	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.1
Cypraea spadicea	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Maxwellia gemma	0.3	0.3	0.1	0.0	0.1	0.1	0.1	0.0	1.5
Murexiella santarosana	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.0
Pteropurpura festiva	0.2	0.6	0.9	0.2	0.7	0.1	0.1	0.0	0.0
Kelletia kelletii	2.3	1.0	0.8	0.2	0.6	0.9	0.3	0.3	0.6
Mitra idae	0.0	1.3	0.7	0.0	0.3	0.1	0.7	0.1	0.3
Conus californicus	1.1	2.2	2.8	0.3	1.9	0.6	0.3	0.2	0.8
Lytechinus anamesus	4.3	17	36	0.6	0.5	0.4	1.1	0.0	0.1
Strongylocentrotus franciscanus	0.4	0.1	0.0	0.0	0.0	0.0	0.0	1.2	0.3
Strongylocentrotus purpuratus	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3

Table 5

Average flow volume and power production (as a percent of maximum possible) for "Before" (January 1, 1978 - April 30, 1983) and "After" (May 1, 1983 - July 20, 1988) periods. (Note that July 20, 1988 is the last date for which the MRC updated the data bases containing data on SONGS operations before the closing of the Encinitas computer facility.)

PERIOD	FLOW VOLUME OF UNITS 2 & 3 (M^3D^{-1})	% POWER PRODUCTION OF UNITS 2 & 3
Before	1.0×10^7	0.4
After	7.1×10^7	59.0

Table 6

Tests of trends in deltas (Impact - SMK) of areas in meters exceeding threshold kelp densities. Data were not transformed.

TYPE OF AREA (THRESHOLD)	SLOPE	R^2	P
Area with kelp present	-292	0.47	0.006
Area with kelp density exceeding 4/100 m^2	-251	0.58	0.003
Area with kelp density exceeding 16/100 m^2	-61	0.63	0.001

Table 7

Trends of deltas (Impact - SMK) for kelp density estimated by downlooking SONAR. Data were log transformed.

IMPACT AREA	SLOPE	R^2	P
SOK	-0.0001	0.29	0.06
SOKU45	-0.0003	0.78	0.0001
SOKD45	-0.0001	0.48	0.009
SOKU35	-0.0001	0.11	0.28
SOKD35	-0.00002	0.01	0.78
SOKN	-0.00007	0.14	0.21

Table 8

Estimated percentage changes of kelp area and density in SOK (relative to SMK) from the Before to the After period based on down-looking SONAR data. * indicates results supported by trends ($p < 0.1$) in deltas through time.

VARIABLE	PERCENT CHANGE
Area (>4 plants/100m2) of SOK	-57*
Density in SOK	-60*
Density in SOKU45	-78*
Density in SOKD45	-55*
Density in SOKU35	+60
Density in SOKD35	-13
Density in SOKN	-40

Table 9

Results of repeated-measures BACI analysis for adult kelp on transects.

Estimated percent changes in the SOKU45 (near impact) and SOKD45 (far impact) quadrants relative to the values in the control kelp forest, SMK, and the results of repeated measures analyses. Data were log transformed before analysis.

	% CHANGE		PERIOD		PERIOD X LOCATION		POWER (%)	POWER (%)
	SOKU45	SOKD45	F(DF)	P	F(DF)	P	MAIN	PERIOD X LOCATION
Density	-44.9	-55.4	7.95(18)	0.011	3.64(18)	0.073	47.6	99.9
Recruitment	-83.9	-89.7	2.23(13)	0.159	0.41(13)	0.534	7.7	25.8
Mortality	-4.3	-19.0	0.47(17)	0.502	0.34(17)	0.566	38.8	29.0

Table 10

BACIP tests on adult kelp on transects at SOKU35. SMK was used as the Control. Transformations were chosen to induce additivity. Power is 100 x the probability of detecting a 50% change at the impact site testing at the 0.05 level. Tests of serial correlations could not be done for recruitment rate, because there were only three Before observations.

VARIABLE	TRANS-FORMATION	MEAN VALUES BEFORE CONTROL		MEAN VALUES AFTER CONTROL		P	POWER (%)	% CHANGE
		CONTROL	IMPACT	CONTROL	IMPACT			
Density	log(x)	0.137	0.052	0.179	0.006	<0.0001	32.5	-91.5
		(n = 4)		(n = 14)				
Recrutiment	log(x+0.00314)	0.052	0.010	0.078	0.001	0.295	5.6	-78.4
		(n = 3)		(n = 8)				

Table 11

Results of repeated-measures BACI analysis for young-of-year kelp.

	% CHANGE		PERIOD		PERIOD X LOCATION		POWER (%)	POWER (%)
	SOKU~~45~~	SOKD~~45~~	F(DF)	P	F(DF)	P	MAIN	PERIOD X LOCATION
45' Recruitment stations	-76.5	-72.8	3.28(15)	0.09	0.04(15)	0.84	8.5	8.6
35' Recruitment stations	-77.1	-87.1	6.55(15)	0.02	0.87(15)	0.37	9.7	6.7
Both depths combined (recruitment stations)	-71.9	-82.9	4.58(15)	0.049	0.96(15)	0.34	10.4	11.6
45' invertebrate sampling stations	-46.5	-81.1	1.50(14)	0.24	0.77(14)	0.39	6.1	6.0

Table 12

Mean densities of gametophytes and sporophytes on cobbles during periods of peak abundance in 1986. Letters indicate groups of means that were not significantly different at $p < 0.05$ based on Duncan's multiple range test. Gametophyte density is based on numbers of sporophytes produced after culturing under optimal conditions in the laboratory. Based on Table 17, Schroeter et al. (1988).

STATIONS	MEAN GAMETOPHYTE DENSITY (NO./100 CM^2)				MEAN SPOROPHYTE DENSITY (NO./100 CM^2) ON UNCULTURTED COBBLES			
	27 FEB 1987		10 APR 1987		08 MAY 1987		21 MAY 1987	
SMK45	A	48,550	A	402	A	32	A	20
SOKU45	A	10,662	A	3,131	B	0	A	1
SOKU35	A	6,701	A	233	B	0	A	0
SOKD45	B	1	A	552	A	60	A	18
SOKD35	B	0	A	693	A	97	A	25

Table 13

The mean values for irradiance, seston flux, and temperature for the period 27 Feb 86 to 8 May 86. The irradiance value for SOKU35 is from the period 31 March 86 to 8 May 86, since data prior to 31 March 86 were missing. Based on Tables 18-21, Schroeter et al. (1988).

A. Mean Values

STATIONS	IRRADIANCE ($E/M^2/D$)	SESTON FLUX (MM/D)	TEMPERATURE (°C)
SOKD35	1.13	6.8	14.3
SOKD45	0.88	8.9	14.1
SMK45	0.85	5.5	13.3
SOKU45	0.48	10.0	13.8
SOKU35	0.68	14.5	13.9

B. Pairwise comparison of stations for seston flux, irradiance, and bottom temperature by t-tests.

	IRRADIANCE			SESTON FLUX			BOTTOM TEMPERATURE		
STATIONS	N	T	PR > T	N	T	PR > T	N	T	PR > T
SOKD45 SMK45	67 67	-0.09	0.93	9 9	-0.88	0.39	71 71	-4.81	<0.01
SOKD35 SMK45	68 68	-1.40	0.17	7 9	-0.26	0.80	71 71	-3.19	<0.01
SOKU45 SMK45	68 68	1.80	0.08	9 9	-1.78	0.09	71 71	-2.17	<0.03
SOKU35 SMK45	50 50	1.34	0.19	9 9	-2.38	0.04	52 52	-7.20	<0.01

Table 14

Regression of log transformed production of sporophytes from gametophytes against log transformed seston flux, log transformed temperature, and a "dummy" variable, taking values of 1 where irradiance exceeded 0.4 $E/m^2/d$ and 0 otherwise. Included are all data collected before 1983, and data from SMK after 1983 for outplants at depths other than 0 meters.

PARAMETER	PARAMETER ESTIMATE	P	PARTIAL R^2
Intercept	41.25	0.0001	--
Slopes			
Log (seston flux)	-0.56	0.0005	0.045
Log (temperature)	-19.81	0.0001	0.21
Irradiance dummy variable	3.12	0.0001	0.09

Total R^2 = 0.35
P for model = 0.0001

Table 15

Results of regressions of deltas (Impact - SMK45) for sporophyte production from gametophytes against the proportion of time a station was classifed in the plume. After data from impact stations in SOKU45, SOKU35, SOKD45, and SOKD35 were used, and station was included as a dummy variable. Data were log(x + 0.003) transformed before calculating deltas.

HEIGHT	SLOPE VS. PROPORTION TIME IN PLUME	P VALUE FOR PROPORTION TIME IN PLUME	P VALUE FOR STATION EFFECT	N
0 m	-0.89	0.41	0.10	42
2 m	-5.06	0.003	0.006	47

Table 16

One-way analysis of variance testing for differences in log-transformed densities of sporophytes on cobbles experimentally transplanted to different stations. Cobbles from all trays and depths at a station were treated as replicates. Duncan's multiple range tests were used to examine differences among individual stations. Means with same letters are not significantly different at $p < 0.05$. Untransformed means are tabulated. The experiment ran from 16 May to 04 June 86. From Table 26, Schroeter et al. 1988.

SOURCE	DF	TYPE III SS	F	PR > F
Station	5	10.01	2.28	0.05
Error	138	121.08		
Total	143	131.09		

STATION		MEAN DENSITY (#/100 CM^2)	N
SMK45CL	A	10.5	24
SMK45	A	9.7	24
SOKD35	B A	4.8	24
SOKD45	B A	2.7	24
SOKU35	B	2.7	24
SOKU45	B	2.6	24

Table 17

The mean values for irradiance, seston flux, and temperature for the period 16 May to 4 June, 1986. Based on Tables 27-29, Schroeter et al. (1988).

A. Mean Values

STATIONS	IRRADIANCE ($E/M^2/D$)	SESTON FLUX (MM/D)	TEMPERATURE (°C)
SOKD35	1.76	4.24	15.7
SOKD45	1.10	6.35	14.7
SOKU35	0.93	13.46	15.8
SOKU45	0.80	8.80	14.3
SMK45	2.12	1.50	14.9

B. Pairwise comparison of stations for seston flux, irradiance, and bottom temperature by t-tests.

	IRRADIANCE			SESTON FLUX			BOTTOM TEMPERATURE		
STATIONS	N	T	PR>T	N	T	PR>T	N	T	PR>T
SOKD45 SMK45	20 20	2.32	0.03	3 3	-7.95	<0.01	20 20	1.27	0.22
SOKD35 SMK45	20 20	1.17	0.26	3 3	-2.85	0.05	20 20	-6.13	<0.01
SOKU45 SMK45	20 20	4.54	<0.01	3 3	-2.13	0.17	20 20	4.33	<0.01
SOKU35 SMK45	20 20	3.56	<0.01	3 3	-1.87	0.20	20 20	-3.02	<0.01

Table 18

Results of regressions of deltas (Impact - SMK45) for microscopic sporophyte growth and mortality against the proportion of time a station was classifed in the plume. After data from the bottom at impact stations in SOKU45, SOKU35, SOKD45, and SOKD35 impact sites were used, and station was included as a dummy variable. Data were log(x + 0.08) transformed for mortality rate and untransformed for growth rates prior to calculation of deltas.

BIOLOGICAL VARIABLE	SLOPE VS. PROPORTION TIME IN PLUME	P VALUE FOR PROPORTION TIME IN PLUME	P VALUE FOR STATION EFFECT	N
Mortality rate	1.39	0.01	0.67	22
Growth rate	-0.50	0.02	0.64	26

Table 19

Regression of log transformed microscopic sporophyte mortality against log transformed seston flux. Included are all data collected before 1983. (At SMK all outplants during the After period were all on the bottom and are excluded from analysis.)

PARAMETER	PARAMETER ESTIMATE	P
Intercept	0.065	0.0001
Slope	0.015	0.02

$R^2 = 0.065$

Table 20

Sporophyte lengths at the end of the cobble transplant experiment done during 1986. The experiment ran form 16 May to 04 June 86. From Table 25, Schroeter et al. 1988.

A. Two-way, fixed-effect analysis of variance testing for differences in log-transformed lengths of sporophytes, stations, treatments (on the bottom or 20 cm above the bottom), and among replicate trays within each treatment and station. The mean square error for replicates (station*treatment) was used as an error term for station, treatment, and station*treatment effects.

SOURCE	DF	TYPE III SS	F	PR > F
Station	1	18.01	2.28	0.09
Treatment (height above bottom)	5	11.58	7.32	0.02
Station*Treatment	5	29.39	3.71	0.02
Replicates (Station*Treatment)	17	26.90	26.90	<0.01

B. Mean final sporophyte lengths, averaged over all cobbles as a given depth for each station. Duncan's multiple range tests were used to examine differences among means of log transformed final lengths at individual stations. Means with same letters are not significantly different at $p < 0.05$. Untransformed means are tabulated.

	------------ BOTTOM ----------		----- 20 CM ABOVE BOTTOM -----	
STATION	MEAN LENGTH (CM)	N	MEAN LENGTH (CM)	N
SMK45	A 41.4	22	A 41.2	24
SMK45CL	A 36.8	35	A 40.2	51
SOKD35	A 21.2	30	A 41.7	7
SOKU45	A 21.7	15	A 23.8	12
SOKU35	B 8.6	17	A 23.3	6
SOKD45	C 2.2	5	A 35.7	7

Table 21

Regression of log transformed sporophyte growth against log transformed irradiance and log transformed seston flux. Included are all data collected before 1983. (At SMK all outplants during the After period were on the bottom and are excluded from analysis.)

PARAMETER	PARAMETER ESTIMATE	P	PARTIAL R^2
Intercept	0.073	0.0001	--
Slopes			
Log (irradiance)	0.029	0.0001	0.12
Log (seston flux)	-0.017	0.0004	0.09

Total R^2 = 0.50

P for model = 0.0001

Table 22

BACIP tests on sporophyte production from gametophyte outplants (% female gametophytes producing sporophytes). Transformations were chosen to induce additivity. Power is 100 x the probability of detecting a 50% change at the impact site testing at the 0.05 level.

COMPARISON (CONTROL VS IMPACT)	HEIGHT OFF BOTTOM	TRANS-FORMATION	MEAN VALUES BEFORE CONTROL	MEAN VALUES BEFORE IMPACT	MEAN VALUES AFTER CONTROL	MEAN VALUES AFTER IMPACT	P	POWER (%)	% CHANGE
SMK45 vs SOKD45	0 m	log(x+0.001894)	0.066	0.007	0.004	0.003	0.066	5.9	517.3
			(n = 10)		(n = 12)				
SMK45 vs SOKU45	2 m	log(x)	0.070	0.028	0.005	0.002	0.972	9.7	4.7
			(n = 11)		(n = 12)				
SMK45 vs SOKD45	2 m	log(x)	0.070	0.045	0.001	0.003	0.349	8.2	279.1
			(n = 11)		(n = 15)				
SOKD45 vs SOKU45	2 m	log(x+0.001894)	0.076	0.023	0.006	0.002	0.323	16.6	71.8
			(n = 24)		(n = 17)				

Table 23

BACIP tests on microscopic sporophyte growth rates (proportion of length per day) during microscopic sporophyte outplants. Transformations were chosen to induce additivity. Power is 100 x the probability of detecting a 50% change at the impact site testing at the 0.05 level. Results are for 0 m depth only since sporophyte outplants were not done at other depths during the After period.

COMPARISON (CONTROL VS IMPACT)	TRANS-FORMATION	MEAN VALUES BEFORE CONTROL	IMPACT	MEAN VALUES AFTER CONTROL	IMPACT	P	POWER (%)	% CHANGE
SMK45 VS SOKU45	none	0.071	0.020	0.112	0.058	0.916	5.9	-5.9
		(n = 7)		(n = 8)				
SMK45 vs SOKD45	none	0.082	0.048	0.112	0.110	0.379	9.7	41.0
		(n = 6)		(n = 8)				
SOKD45 vs SOKU45	none	0.049	0.008	0.1011	0.048	0.58	5.3	-20.1
		(n = 14)		(n = 10)				

Table 24

BACIP tests on sporophyte mortality rate per day during microscopic sporophyte outplants. Transformations were chosen to induce additivity. Power is 100 x the probability of detecting a 50% change at the impact site testing at the 0.05 level. Results are for the 0 m depth only since sporophyte outplants were not done at other depths during the After period.

COMPARISON (CONTROL VS IMPACT)	TRANS-FORMATION	MEAN VALUES BEFORE CONTROL	IMPACT	AFTER CONTROL	IMPACT	P	POWER (%)	% CHANGE
SMK45 VS SOKU45	log(x)	0.036	0.131	0.117	0.114	0.002	46.1	-72.9
		(n = 7)		(n = 10)				
SMK45 vs SOKD45	log(x+0.0806)	0.034	0.069	0.131	0.091	0.134	12.5	-37.9
		(n = 6)		(n = 11)				
SOKD45 vs SOKU45	log(x)	0.052	0.085	0.135	0.114	0.069	52.5	-48.9
		(n = 13)		(n = 10)				

Table 25

Mean density (number/m^2) of Lytechinus at benthic invertebrates sampling stations nearest the microscopic sporophyte (and gametophyte) outplant stations in offshore SOK.

PERIOD	SOKU45 MEAN ± SE	SOKD45 MEAN ± SE
Before	5.9 ± 1.6	2.4 ± 0.6
After	3.3 ± 1.1	9.3 ± 1.7

Table 26

Mortality (%), mean growth rate, irradiance (E/m^2/d), temperature (°C), and seston flux (mmd^{-1}) for the 1986 (18 August 1986 - 11 January 1987) blade stage experiment. * ($p \leq 0.05$) and t ($p \leq 0.1$) indicate mortality or growth rates at an impact (SOK) station that differed significantly or nearly significantly from the value at SMK. A chi-square test was used to test pairwise for equality of mortality rates to each of the impact stations vs. SMK. Growth rate at each of the impact stations was compared with SMK using Duncan's multiple range test following a preliminary one-way ANOVA that indicated significant ($p < 0.01$) among station variation in growth rates. Physical-chemical and mortality data based on Tables 32, 34, 36 and 37, Schroeter et al. (1988).

STATION	---- MORTALITY ------ % THAT DIED	INITIAL N	---- GROWTH --- GROWTH RATE	N	IRRADI-ANCE	TEMPER-ATURE	SESTON FLUX
SMK	58	99	0.0067	42	1.17	16.3	0.6
SOKU45	67	51	0.0090	6	0.93	16.3	12.8
SOKU35	70	99	0.0064	30	1.22	16.9	10.1
SOKD35	82*	97	0.0062	17	1.39	16.7	5.0
LSOKN35 (north bed)	44*	98	0.0095	55	1.08	16.0	0.5

Table 27

Analyses of variance and Duncan's multiple range tests of differences in growth rates among stations during juvenile transplant experiments at inshore (~10 m depth) stations in 1986. Means with the same letter beside them are not significantly different. From Table 39, Schroeter et al. 1988.

---------------------- 24 JUNE 86 TO 5 AUGUST 86 ----------------------

SOURCE	DF	SS	F	PR > F
Station	2	0.008	34.46	<0.01
Error	51	0.006		
Total	53	0.014		

STATION	GROWTH RATE (d^{-1})	N
SMK35	A 0.048	21
SOKD35	B 0.035	20
SOKU35	C 0.017	13

------------------ 7 AUGUST 86 TO 18 SEPTEMBER 86 ------------------

SOURCE	DF	SS	F	PR > F
Station	2	0.006	5.50	<0.01
Error	47	0.025		
Total	19	0.031		

STATION	GROWTH RATE (d^{-1})	N
SMK35	A 0.022	14
SOKD35	A 0.022	21
SOKU35	B 0.015	15

Table 28

Analyses of variance and Duncan's multiple range tests of differences in growth rates among stations during juvenile transplant experiments at offshore (~13 m depth) stations in 1986. Means with the same letter beside them are not significantly different. From Table 40, Schroeter et al. 1988.

---------------------- 24 JUNE 86 TO 5 AUGUST 86 ----------------------

SOURCE	DF	SS	F	PR > F
Station	2	0.0014	5.94	<0.01
Error	49	0.0060		
Total	51	0.0074		

STATION		GROWTH RATE (d^{-1})	N
SMK45	A	0.031	16
SOKU45	BA	0.024	18
SOKD45	B	0.018	18

------------------ 7 AUGUST 86 TO 18 SEPTEMBER 86 ------------------

SOURCE	DF	SS	F	PR > F
Station	2	0.0000	0.30	0.74
Error	48	0.0038		
Total	50	0.0039		

STATION		GROWTH RATE (d^{-1})	N
SOKU45	A	0.019	19
SOKD45	A	0.019	14
SMK45	A	0.017	18

Table 29

Results of paired t-test of differences in daily irradiance (E/m^2/day) and daily temperature (°C), 2 m off bottom at stations in SOK vs SMK for periods from 24 June to 05 August and from 07 August to 18 September 1986. All tests corrected for serial correlations (see Methods). From Tables 41 and 42, Schroeter et al. 1988.

	24 JUNE TO 05 AUGUST							
	IRRADIANCE				TEMPERATURE			
STATIONS	N	MEAN	T	PR > T	N	MEAN	T	PR > T
SOKD35	10	2.25	-1.33	0.22	11	13.6	-0.19	0.86
SMK35	10	1.10			11	13.6		
SOKU35	10	1.15	-0.04	0.97	4	13.9	-1.56	0.26
SMK35	10	1.10			4	13.7		
SOKD45	38	3.15	0.43	0.67	39	13.8	-1.31	0.20
SMK45	38	3.27			39	13.6		
SOKU45	38	2.34	2.01	<0.05	39	13.6	0.04	0.97
SMK45	38	3.27			39	13.6		

	07 AUGUST TO 18 SEPTEMBER							
	IRRADIANCE				TEMPERATURE			
STATIONS	N	MEAN	T	PR > T	N	MEAN	T	PR > T
SOKD35	37	2.87	-4.33	<0.01	13	14.4	0.51	0.62
SMK35	37	1.40			13	14.5		
SOKU35	37	2.24	-2.92	<0.01	13	14.5	-0.02	0.99
SMK35	37	1.40			13	14.5		
SOKD45	43	2.36	-2.81	0.78	43	15.3	1.71	0.09
SMK45	43	2.15			43	15.6		
SOKU45	22	1.30	-1.39	0.18	23	13.9	4.32	<0.01
SMK45	22	1.94			23	14.2		

Table 30

Mean percent cover by fouling organisms on blades of transplanted juveniles during the two 1986 transplants. From Table 43, Schroeter et al. 1988.

	24 JUNE TO 05 AUGUST 86		07 AUGUST TO 18 SEPTEMBER 86	
STATION	MEAN	N	MEAN	N
OFFSHORE SITES				
SOKU45	2	18	6	19
SOKD45	21	18	45	13
SMK45	26	16	33	18
INSHORE SITES				
SOKU35	24	13	51	15
SOKD35	18	20	10	20
SMK35	<1	21	0	14

Table 31

Regression of log transformed juvenile growth rate against log transformed temperature and log transformed irradiance. Included are all data collected before 1983 and data from SMK in the After period. (All juvenile transplants were on racks raised off the bottom.)

PARAMETER	PARAMETER ESTIMATE	P	PARTIAL R^2
Intercept	0.26	0.0001	--
Slopes			
Log (temperature)	-0.092	0.0001	0.49
Log (irradiance)	0.0087	0.0002	0.27

Total R^2 = 0.56
P for model = 0.0001

Table 32

BACIP tests on juvenile growth rates from juvenile transplants. Transformations were chosen to induce additivity. Power is 100 x the probability of detecting a 50% change at the impact site testing at the 0.05 level. All transplants were on racks approximately 1 m off the bottom.

COMPARISON (CONTROL VS IMPACT)	TRANS-FORMATION	MEAN VALUES				P	POWER (%)	% CHANGE
		BEFORE		AFTER				
		CONTROL	IMPACT	CONTROL	IMPACT			
SMK45 VS SOKU45	none	0.018	0.013	0.015	0.014	0.083	74.6	43.5
		(n = 4)		(n = 8)				
SMK45 vs SOKD45	log(x+0.015)	0.017	0.016	0.013	0.014	0.566	86.8	5.1
		(n = 4)		(n = 8)				
SOKD45 vs SOKU45	none	0.022	0.016	0.0146	0.0138	0.046	93.4	51.4
		(n = 8)		(n = 8)				

Table 33

Results of 1986 adult transplant experiment. Mean numbers of fronds per plant, mean net change in fronds per plant, and results of a nested ANOVA testing for difference in net change among kelp forests and replicate stations within kelp forests. Comparison is between inshore SMK and the area of upcoast inshore SOK near "Transect 13" (LSOKU35TR13) where high mortality was observed in 1984. From Table 11, Dixon et al. 1988.

KELP FOREST	REPLICATE SAMPLING STATION	MEAN # FRONDS 05 SEP 86	MEAN # FRONDS 21 JAN 87	MEAN NET CHANGE PER PLANT
SMK35	1	19.5	20.8	+1.4
	2	19.6	22.3	+2.7
	3	23.9	29.4	+5.4
	Overall mean	21.0	24.1	+3.2
SOKU35 (LSOKU35TR13)	4	18.2	9.7	-8.5
	5	18.2	22.6	+4.4
	6	18.3	15.1	-3.2
	Overall mean	18.2	15.8	-2.5

ANOVA

SOURCE	DF	S	F	P
Kelp Forest	1	857.1	11.09	<0.01
Replicate Station (Kelp Forest)	2	157.6	1.02	0.36
Error	104	8039.1	--	--
Total	107	9053.9		

8. FIGURES

Figure 1: A diagrammatic representation of the Macrocystis pyrifera life cycle. The names of each life-stage and approximate size ranges are given. On adult and subadult plants, the various structures of the plant are labeled as follows: (a) holdfast composed of haptera, (b) primary dichotomy, (c) sporophyll, (d) apical meristem, or "scimitar blade", (e) frond, composed of : (f) stipe, and (g) blade. The blade is made up of (h) lamina, and (i) pneumatocyst.

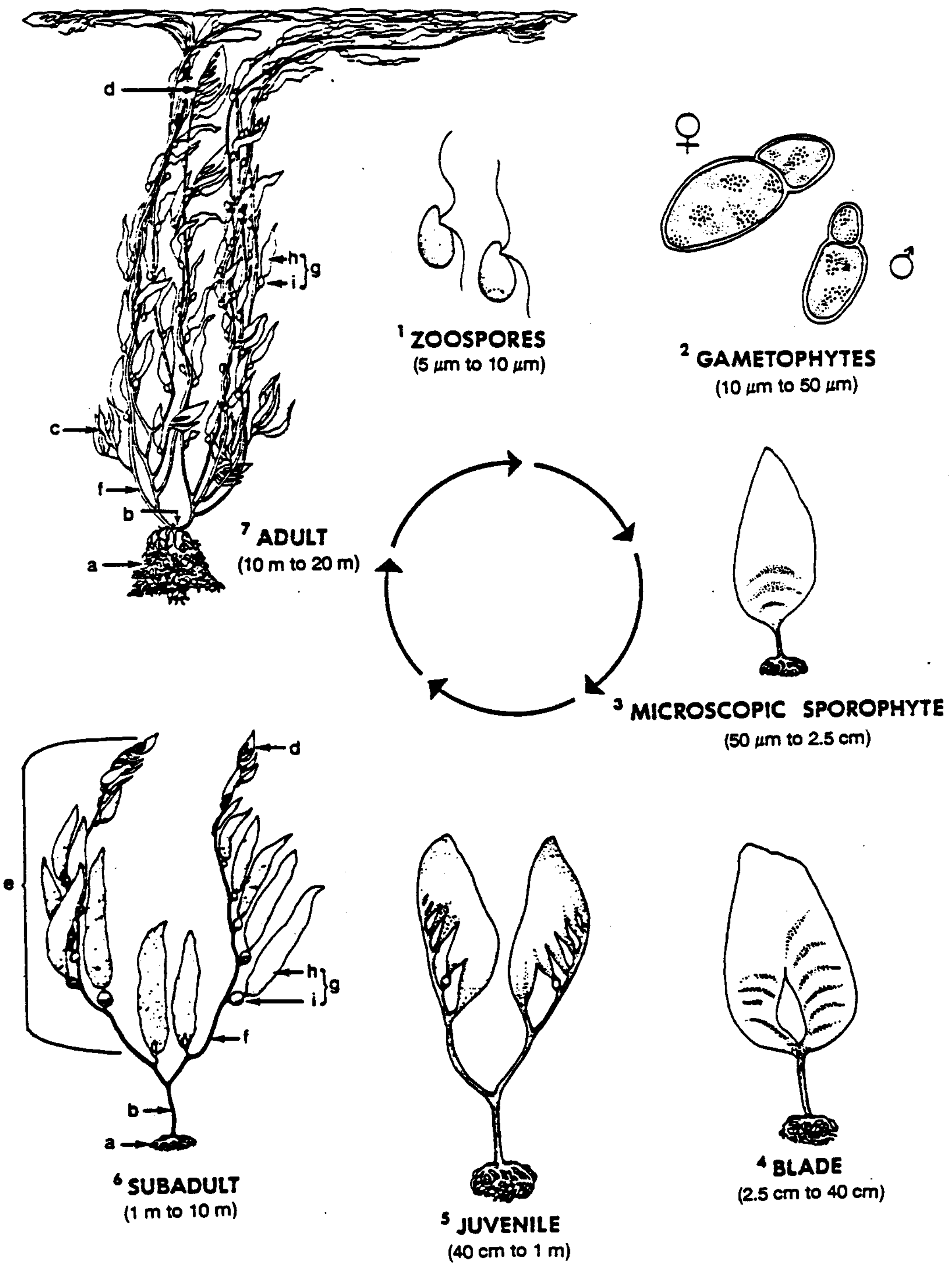
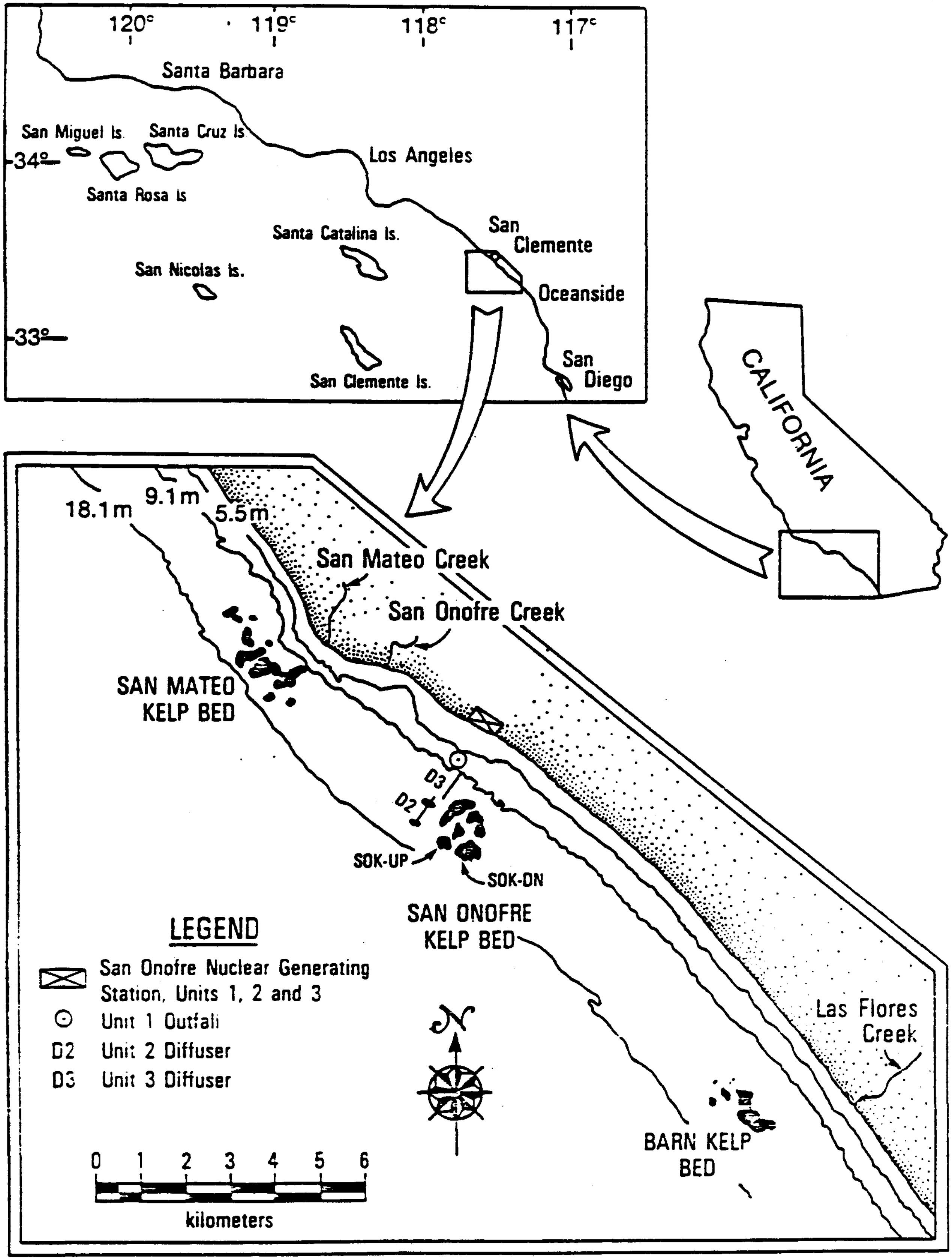
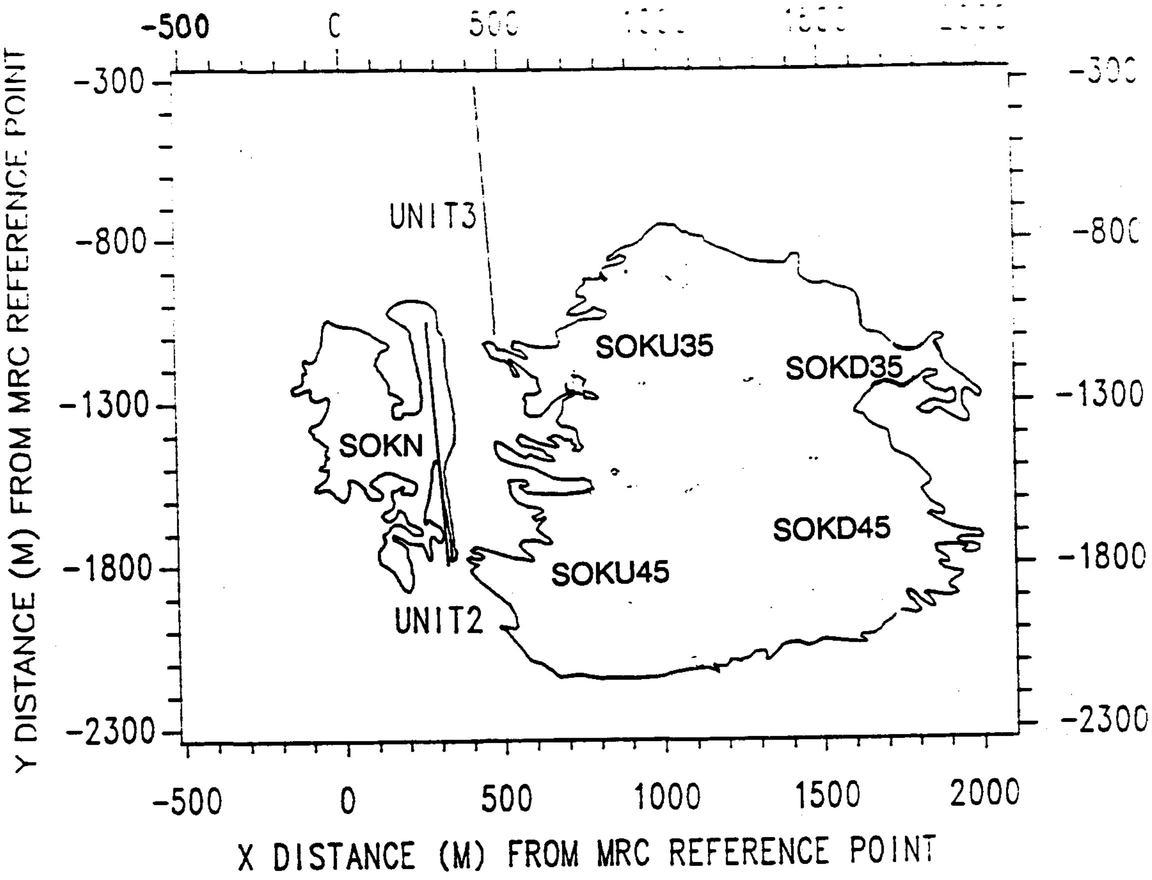

d
♀
h
i
g
¹ ZOOSPORES
(5 µm to 10 µm)
² GAMETOPHYTES
(10 µm to 50 µm)
♂
c
f
b
⁷ ADULT
(10 m to 20 m)
a
³ MICROSCOPIC SPOROPHYTE
(50 µm to 2.5 cm)
d
e
h
i
g
f
b
a
⁶ SUBADULT
(1 m to 10 m)
⁵ JUVENILE
(40 cm to 1 m)
⁴ BLADE
(2.5 cm to 40 cm)

Figure 2: Kelp forests near the San Onofre Nuclear Generating Station.



120°
119°
118°
117°
Santa Barbara
San Miguel Is.
Santa Cruz Is.
34°
Santa Rosa Is
Los Angeles
Santa Catalina Is.
San Clemente
San Nicolas Is.
Oceanside
33°
San Clemente Is.
San Diego
CALIFORNIA
18.1m
9.1m
5.5m
San Mateo Creek
San Onofre Creek
SAN MATEO KELP BED
D3
D2
SOK-UP
SOK-DN
SAN ONOFRE KELP BED
LEGEND
San Onofre Nuclear Generating Station, Units 1, 2 and 3
Unit 1 Outfall
D2 Unit 2 Diffuser
D3 Unit 3 Diffuser
N
0 1 2 3 4 5 6
kilometers
BARN KELP BED
Las Flores Creek

Figure 3: San Onofre kelp forest (SOK). The area of hard substrate is outlined in the upper figure, and the depth contours (m) are shown in the lower figure. SOKU35, SOKD35, SOKU45 and SOKD45 refer to four quadrats of the main SOK kelp bed. SOKN refers to an area of kelp immediately upcoast (northwest) of the diffusers.


-500
0
500
1000
1500
2000
-300
-800
-1300
-1800
-2300
UNIT3
SOKU35
SOKD35
SOKN
SOKD45
SOKU45
UNIT2
Y DISTANCE (M) FROM MRC REFERENCE POINT
X DISTANCE (M) FROM MRC REFERENCE POINT

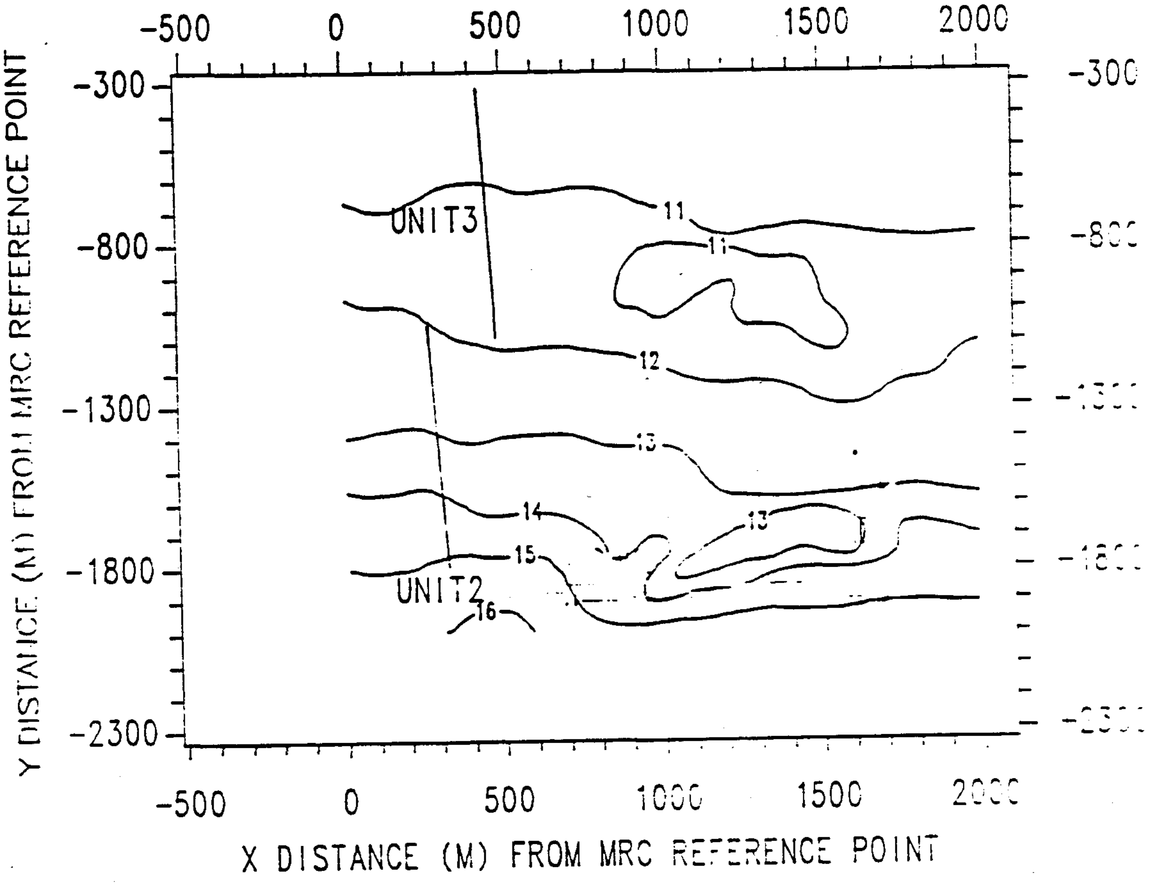
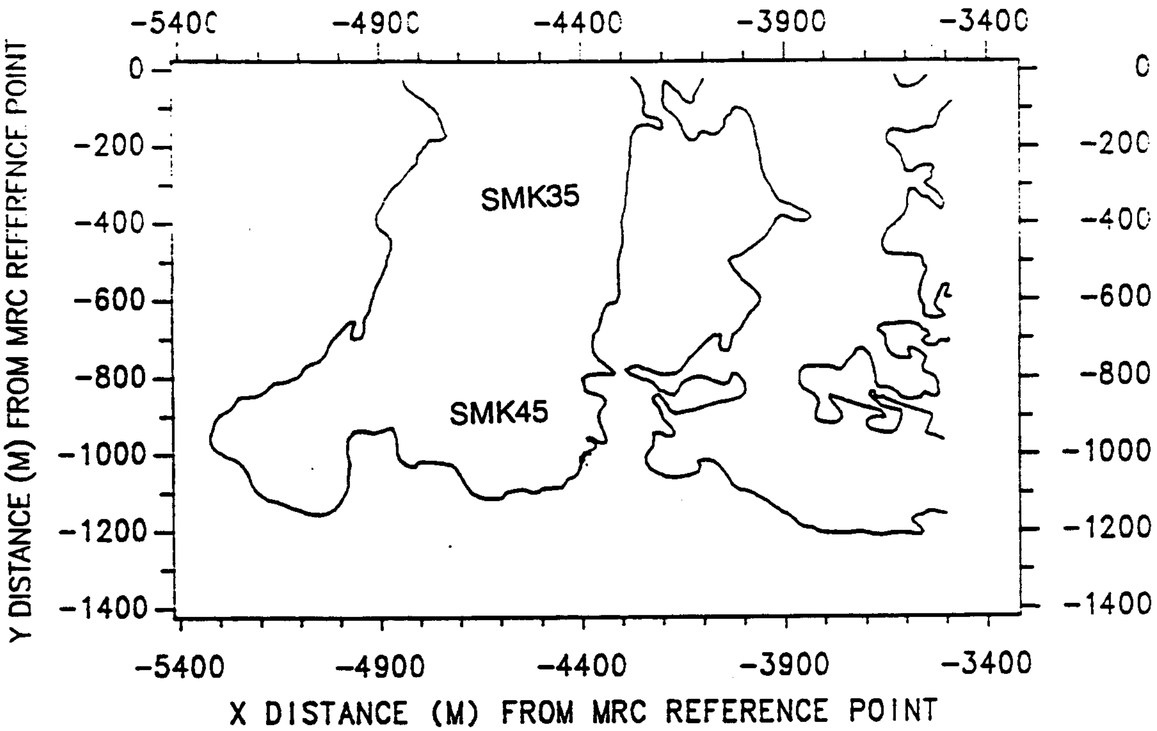

-500
0
500
1000
1500
2000
-300
-800
-1300
-1800
-2300
UNIT3
11
11
12
13
14
13
15
UNIT2
16
Y DISTANCE (M) FROM MRC REFERENCE POINT
X DISTANCE (M) FROM MRC REFERENCE POINT

Figure 4: San Mateo (SMK) kelp forest. The area of hard substrate is outlined in the upper figure, and the depth contours (m) are shown in the lower figure. SMK45 and SMK35 refer to the inshore and offshore halves of the kelp forest.


SMK35
SMK45
Y DISTANCE (M) FROM MRC REFERENCE POINT
X DISTANCE (M) FROM MRC REFERENCE POINT
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-4900
-4400
-3900
-3400
0
-200
-400
-600
-800
-1000
-1200
-1400

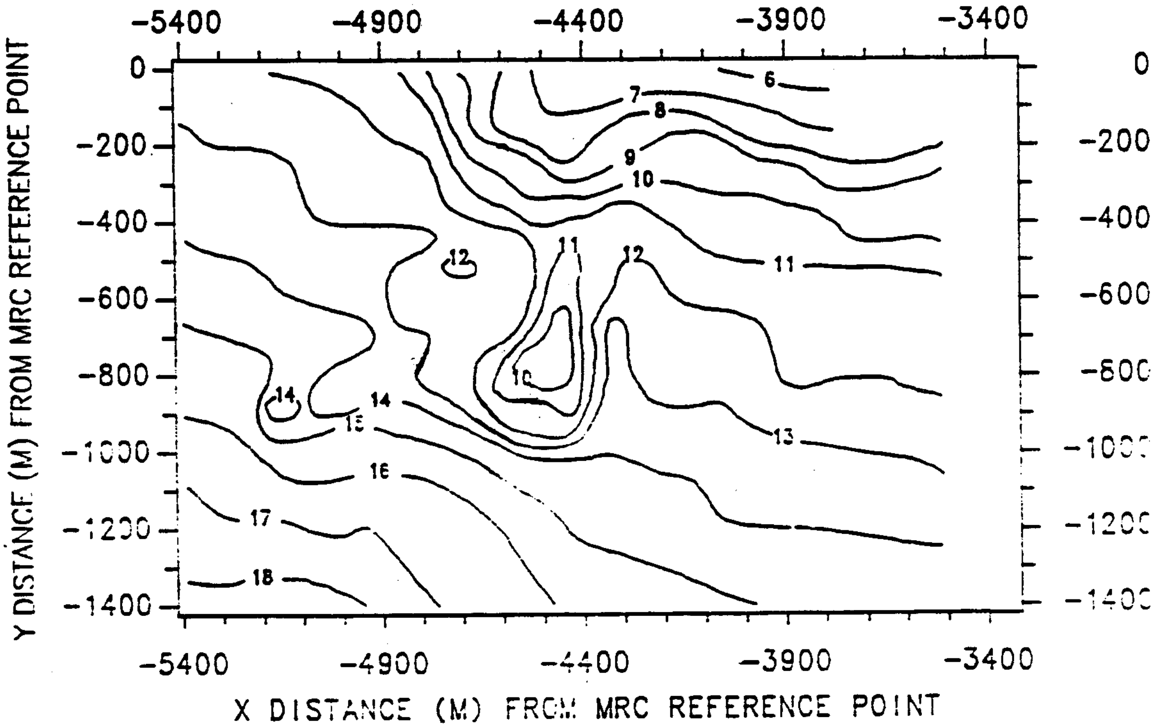
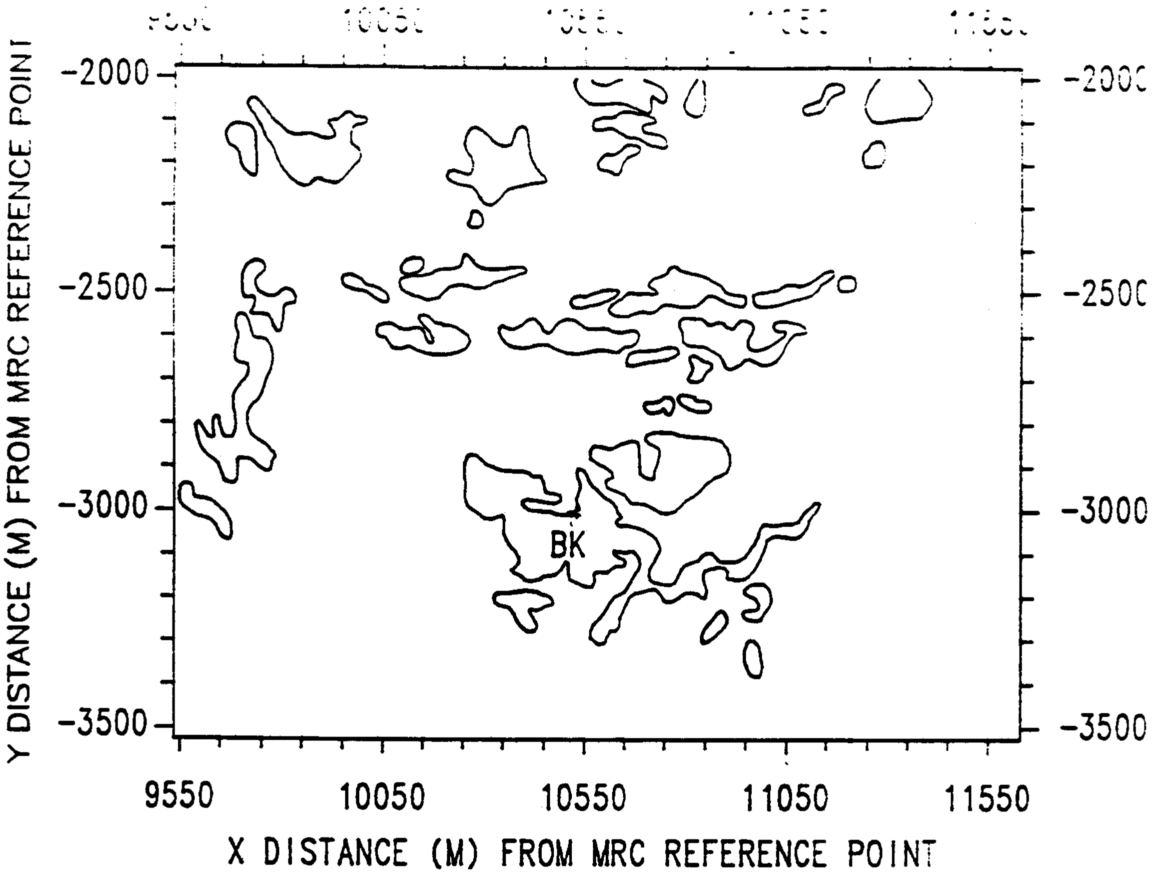
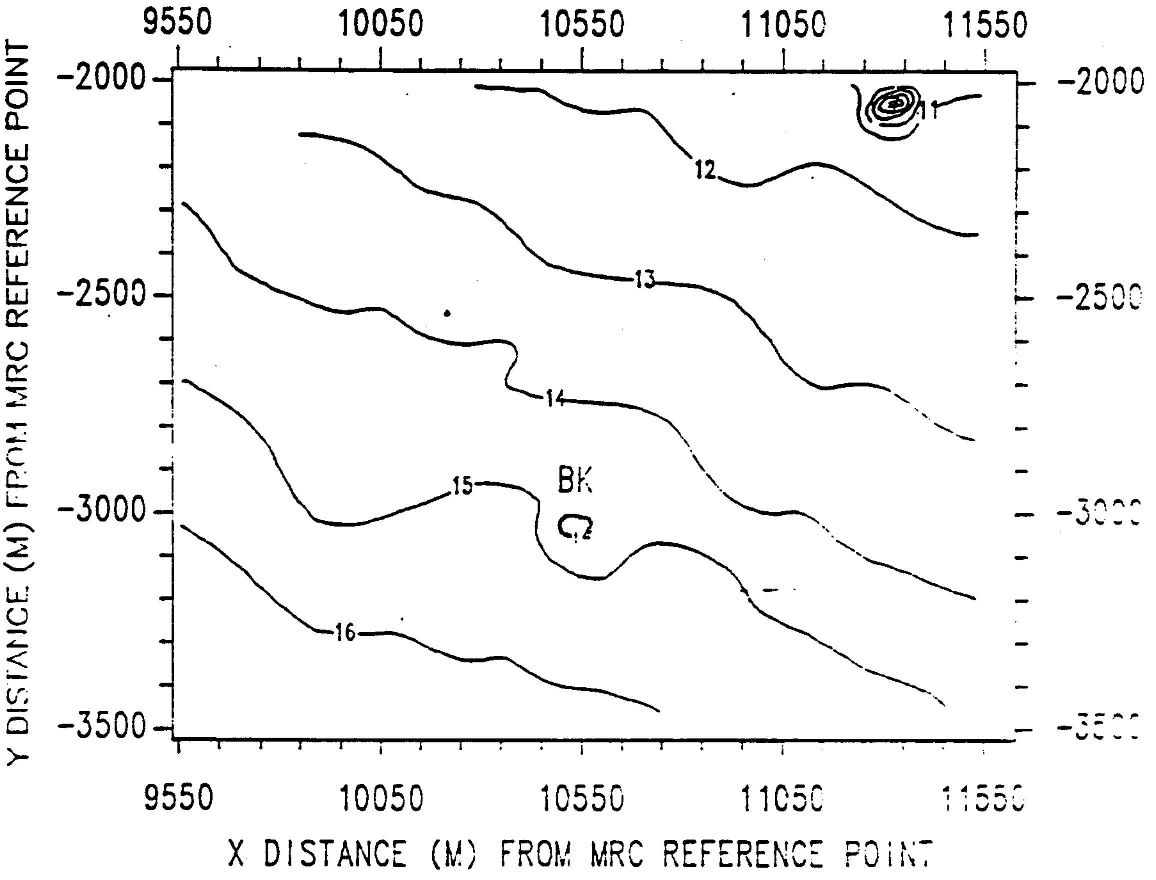

6
7
8
9
10
11
12
12
11
12
10
13
14
14
15
16
17
18
Y DISTANCE (M) FROM MRC REFERENCE POINT
X DISTANCE (M) FROM MRC REFERENCE POINT
-5400
-4900
-4400
-3900
-3400
0
-200
-400
-600
-800
-1000
-1200
-1400

Figure 5: Barn (BK) kelp forest. The area of hard substrate is outlined in the upper figure, and the depth contours (m) are shown in the lower figure.

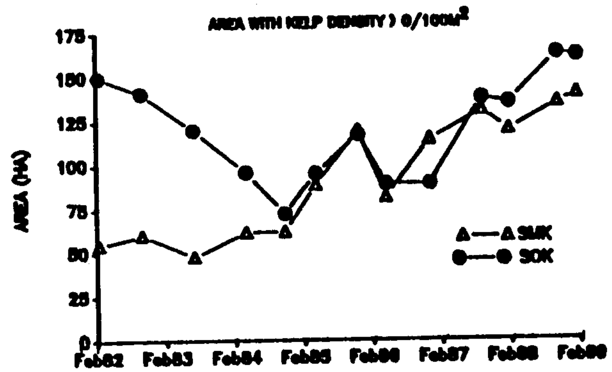


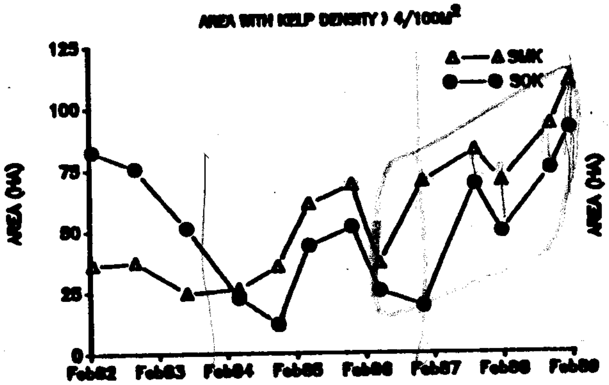
-2000
-2500
-3000
-3500
9550
10050
10550
11050
11550
BK
Y DISTANCE (M) FROM MRC REFERENCE POINT
X DISTANCE (M) FROM MRC REFERENCE POINT

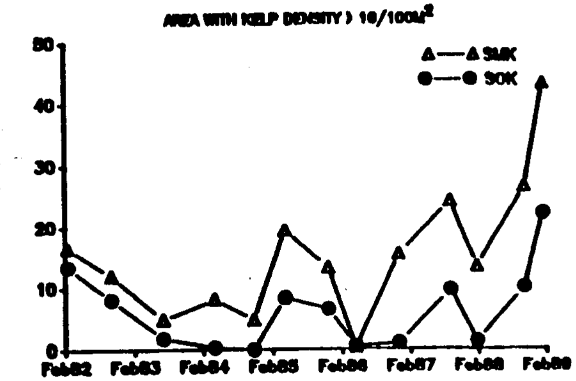


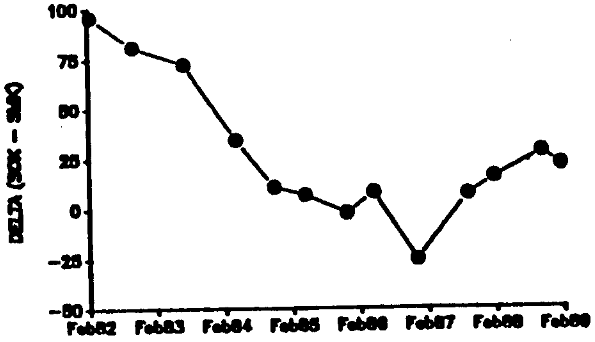
9550
10050
10550
11050
11550
-2000
-2500
-3000
-3500
11
12
13
14
15
16
BK
12
Y DISTANCE (M) FROM MRC REFERENCE POINT
X DISTANCE (M) FROM MRC REFERENCE POINT

Figure 6: Area of kelp at SOK and SMK (upper graphs) delineated by densities of plants (> 0 plants / $100m^2$, > 4 plants / $100m^2$, and > 16 plants / $100m^2$), based on down-looking sonar of hard substrate. Deltas (lower graphs) are differences in area of kelp between SOK and SMK.


AREA WITH KELP DENSITY > 0/100M²
AREA (HA)
175
150
125
100
75
50
25
0
Feb82
Feb83
Feb84
Feb85
Feb86
Feb87
Feb88
Feb89
Δ—Δ SMK
●—● SOK


AREA WITH KELP DENSITY > 4/100M²
AREA (HA)
125
100
75
50
25
0
Feb82
Feb83
Feb84
Feb85
Feb86
Feb87
Feb88
Feb89
Δ—Δ SMK
●—● SOK


AREA WITH KELP DENSITY > 10/100M²
AREA (HA)
50
40
30
20
10
0
Feb82
Feb83
Feb84
Feb85
Feb86
Feb87
Feb88
Feb89
Δ—Δ SMK
●—● SOK


DELTA (SOK − SMK)
100
75
50
25
0
−25
−50
Feb82
Feb83
Feb84
Feb85
Feb86
Feb87
Feb88
Feb89


DELTA (SOK − SMK)
50
25
0
−25
−50
−75
Feb82
Feb83
Feb84
Feb85
Feb86
Feb87
Feb88
Feb89

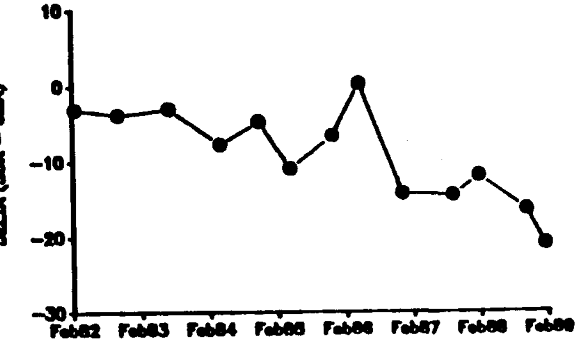
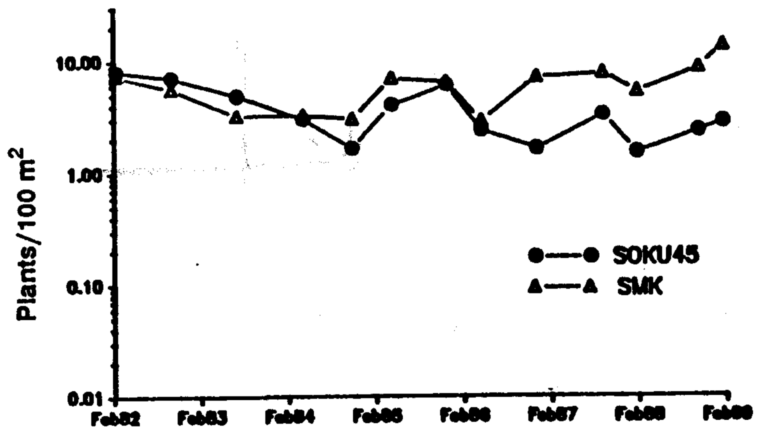
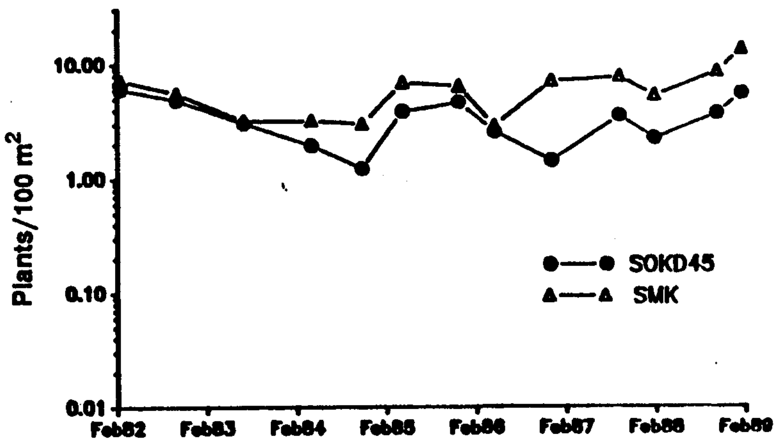
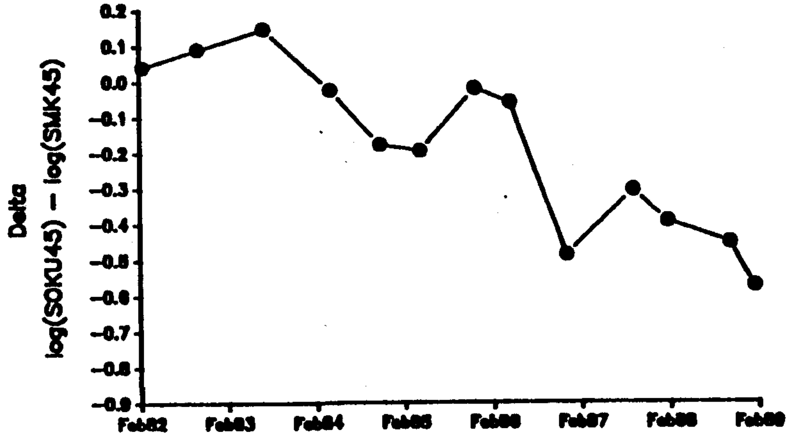
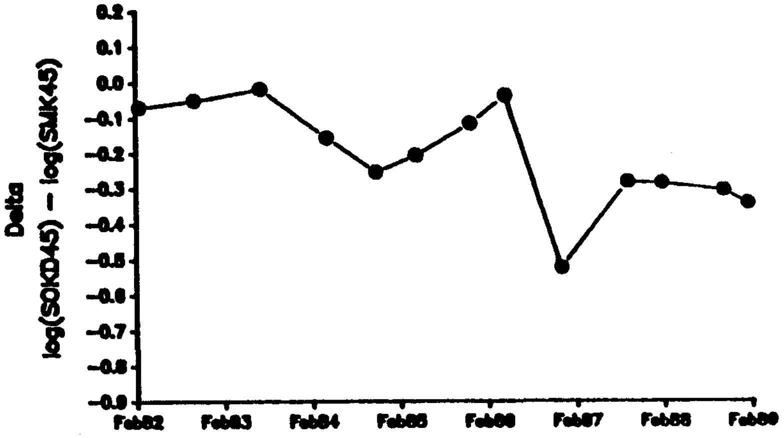

DELTA (SOK − SMK)
10
0
−10
−20
−30
Feb82
Feb83
Feb84
Feb85
Feb86
Feb87
Feb88
Feb89

Figure 7: Densities of kelp based on down-looking sonar (upper graphs): at SMK and the two quadrants within SOK at the 45' depth; SMK and the two quadrants at 35' depth in SOK; and SMK and SOKN. Deltas (lower graphs) are differences in the log-transformed values for the respective comparisons.


Plants/100 m²
10.00
1.00
0.10
0.01
Feb82
Feb83
Feb84
Feb85
Feb86
Feb87
Feb88
Feb89
●—● SOKU45
▲—▲ SMK


Plants/100 m²
10.00
1.00
0.10
0.01
Feb82
Feb83
Feb84
Feb85
Feb86
Feb87
Feb88
Feb89
●—● SOKD45
▲—▲ SMK

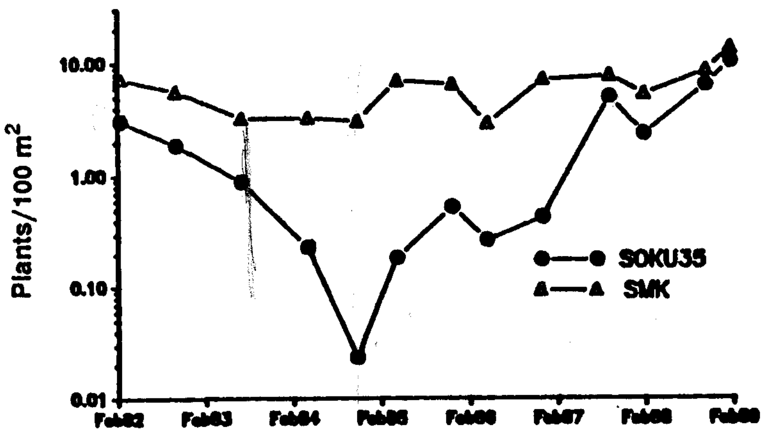

Delta
log(SOKU45) – log(SMK45)
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
Feb82
Feb83
Feb84
Feb85
Feb86
Feb87
Feb88
Feb89

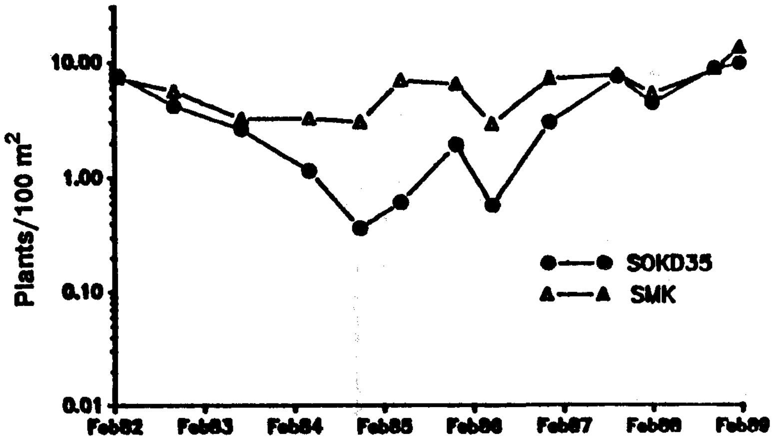

Delta
log(SOKD45) – log(SMK45)
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
Feb82
Feb83
Feb84
Feb85
Feb86
Feb87
Feb88
Feb89

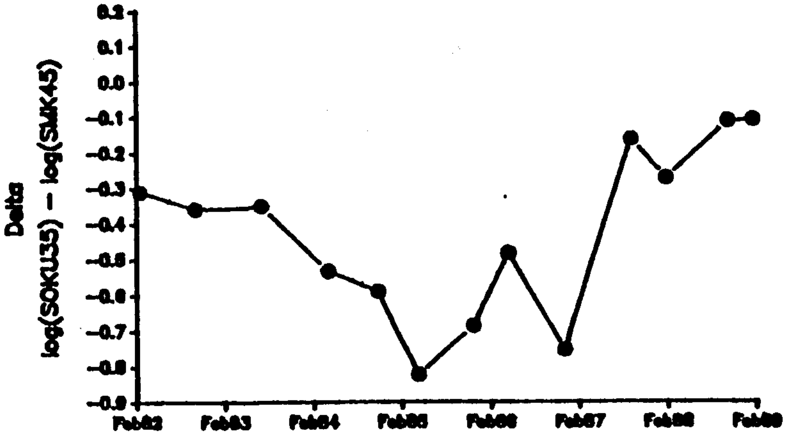
2 issues

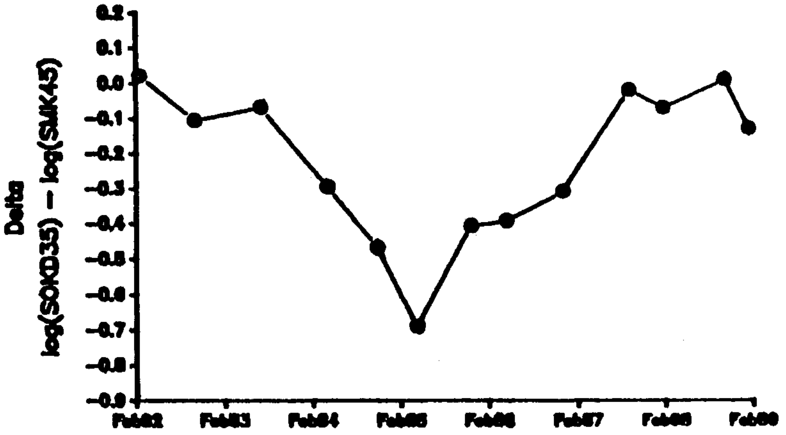
1) [illegible]

② [illegible] for loss









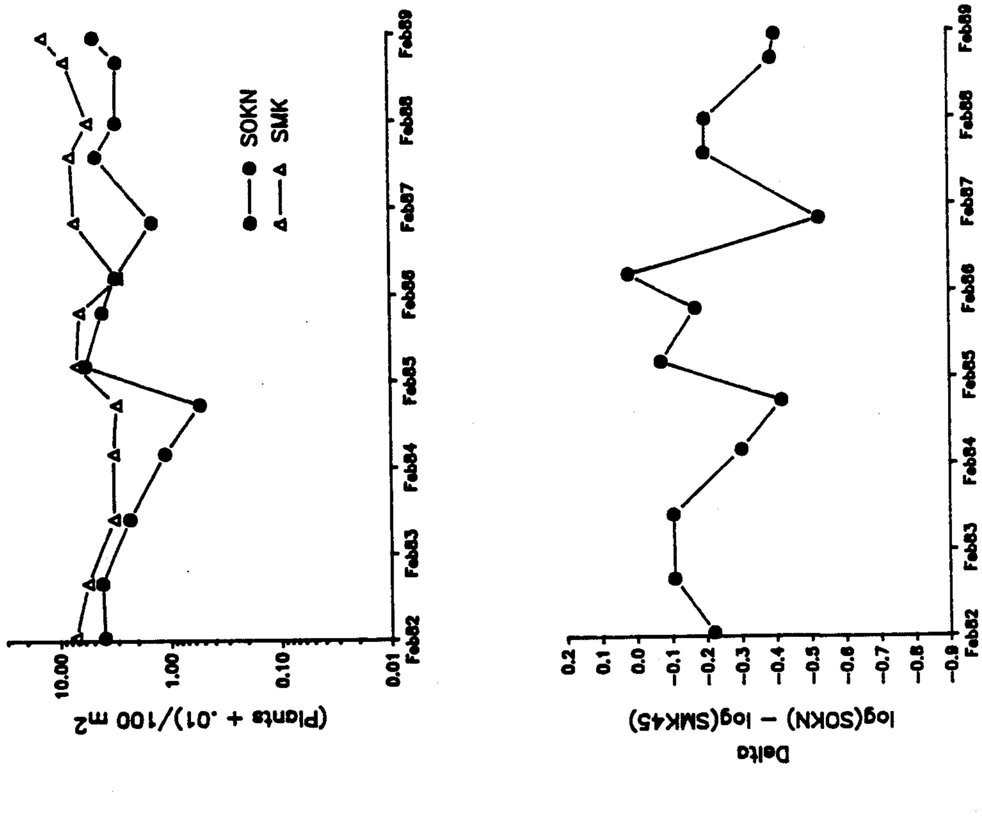
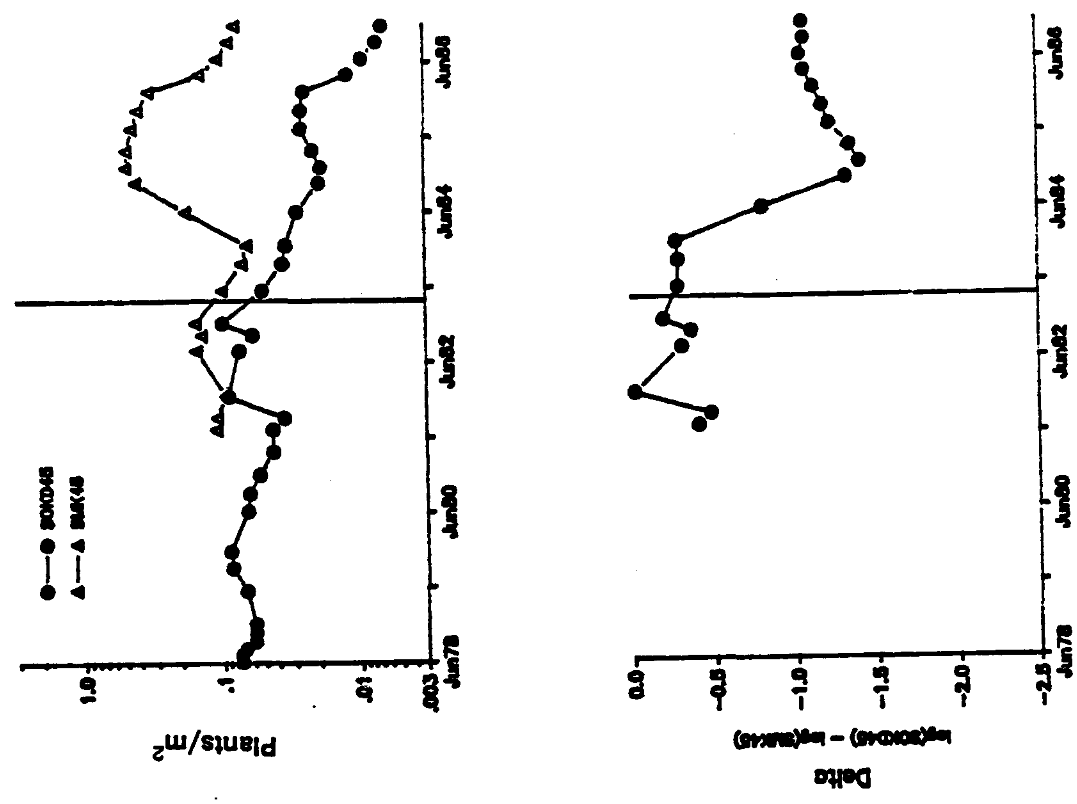
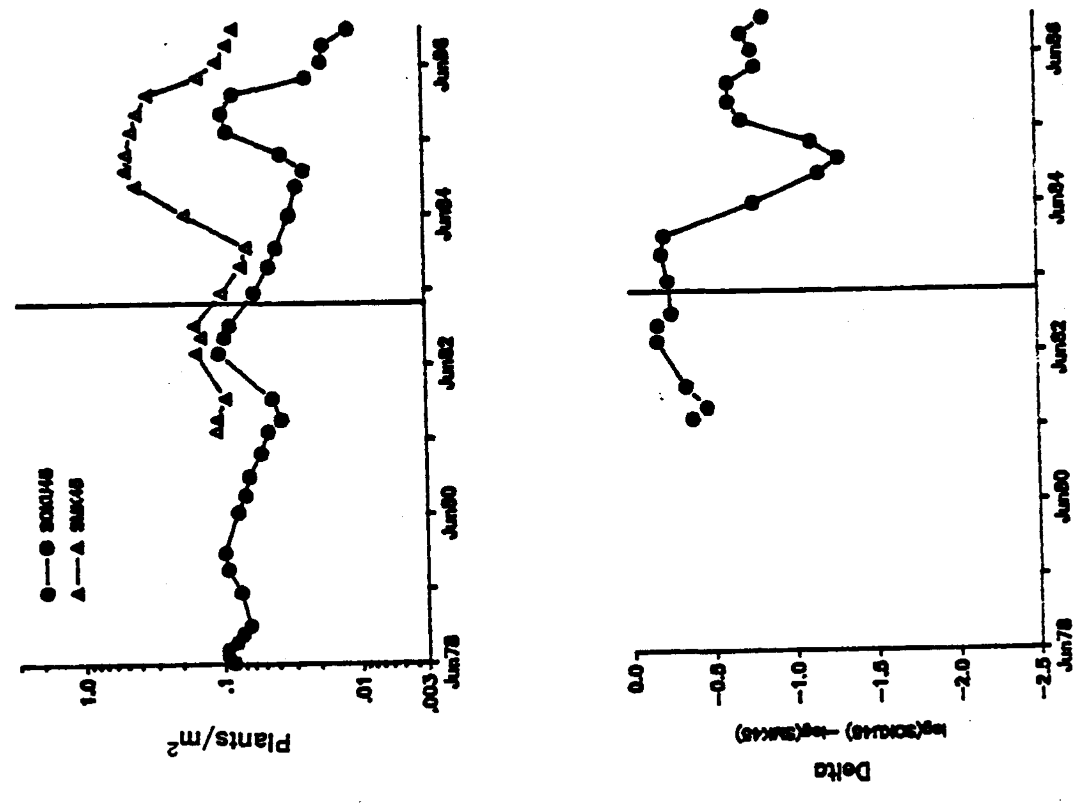
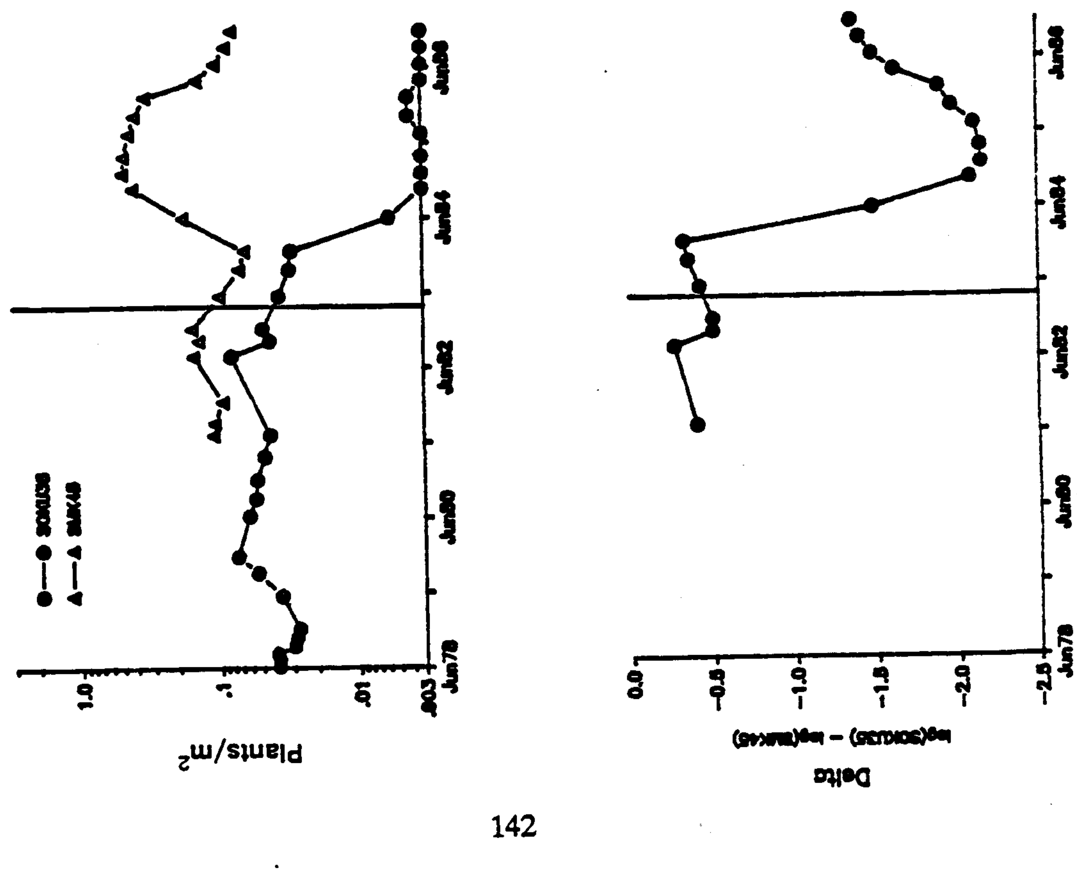

(Plants + .01)/100 m2
10.00
1.00
0.10
0.01
Feb82
Feb83
Feb84
Feb85
Feb86
Feb87
Feb88
Feb89
●—● SOKN
Δ—Δ SMK
Delta
log(SOKN) − log(SMK45)
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
−0.9
Feb82
Feb83
Feb84
Feb85
Feb86
Feb87
Feb88
Feb89

Figure 8: Mean densities (plants / m^2) of adult kelp plants from transects within the SOK and SMK kelp beds (upper graphs). Deltas (lower graphs) are differences in the log-transformed values for the respective station comparisons. Vertical line separates Before and After periods.


●—● SOKD48
△—△ SMK48
Plants/m²
1.0
.1
.01
.003
Jun78
Jun80
Jun82
Jun84
Jun86
Delta
log(SOKD48) – log(SMK48)
0.0
−0.5
−1.0
−1.5
−2.0
−2.5


●—● SOKU48
△—△ SMK48
Plants/m²
1.0
.1
.01
.003
Jun78
Jun80
Jun82
Jun84
Jun86
Delta
log(SOKU48) – log(SMK48)
0.0
−0.5
−1.0
−1.5
−2.0
−2.5


Plants/m^2
1.0
.1
.01
.003
Jun78
Jun80
Jun82
Jun84
Jun86
SOKO35
SMK45
Delta
log(SOKO35) − log(SMK45)
0.0
−0.5
−1.0
−1.5
−2.0
−2.5

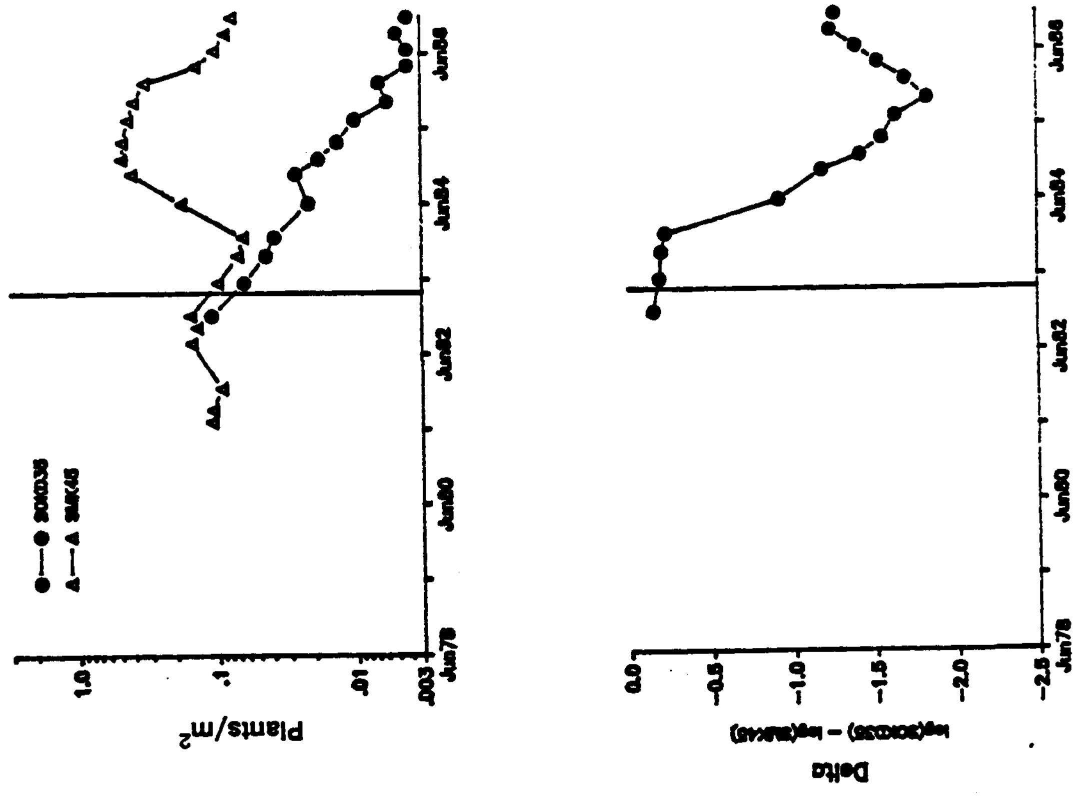

Plants/m^2
1.0
.1
.01
.003
Jun78
Jun80
Jun82
Jun84
Jun86
SOKO35
SMK45
Delta
log(SOKO35) − log(SMK45)
0.0
−0.5
−1.0
−1.5
−2.0
−2.5

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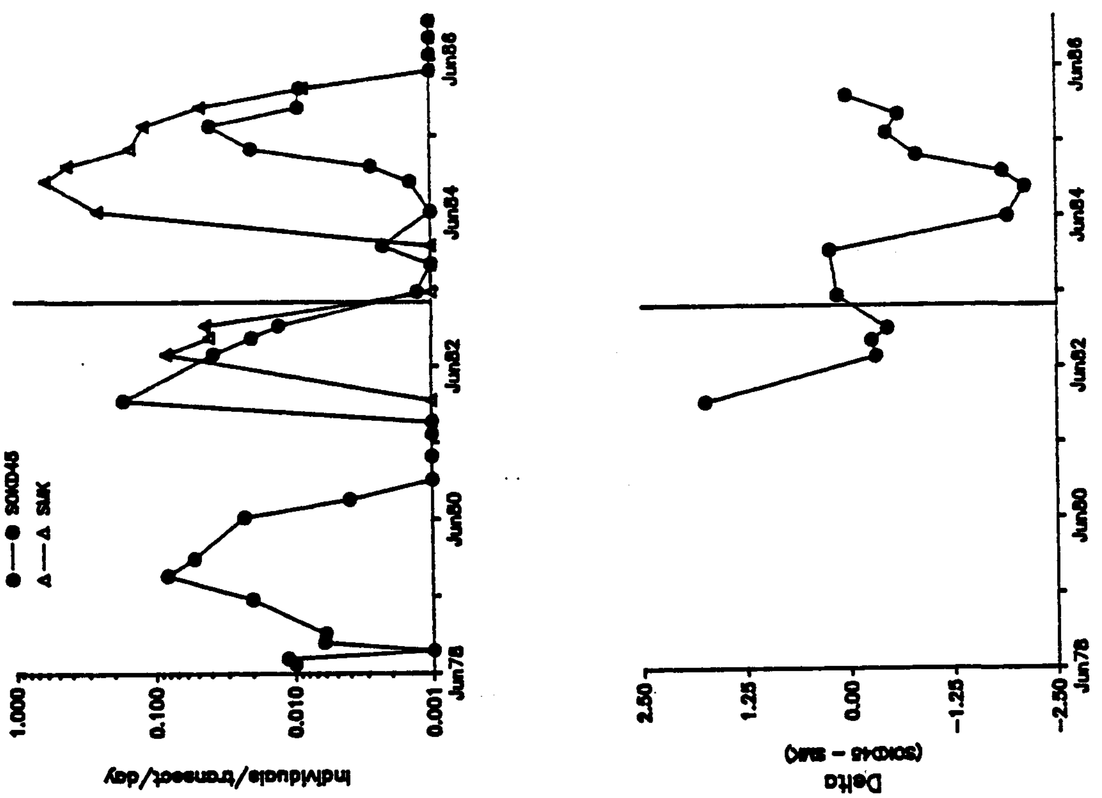
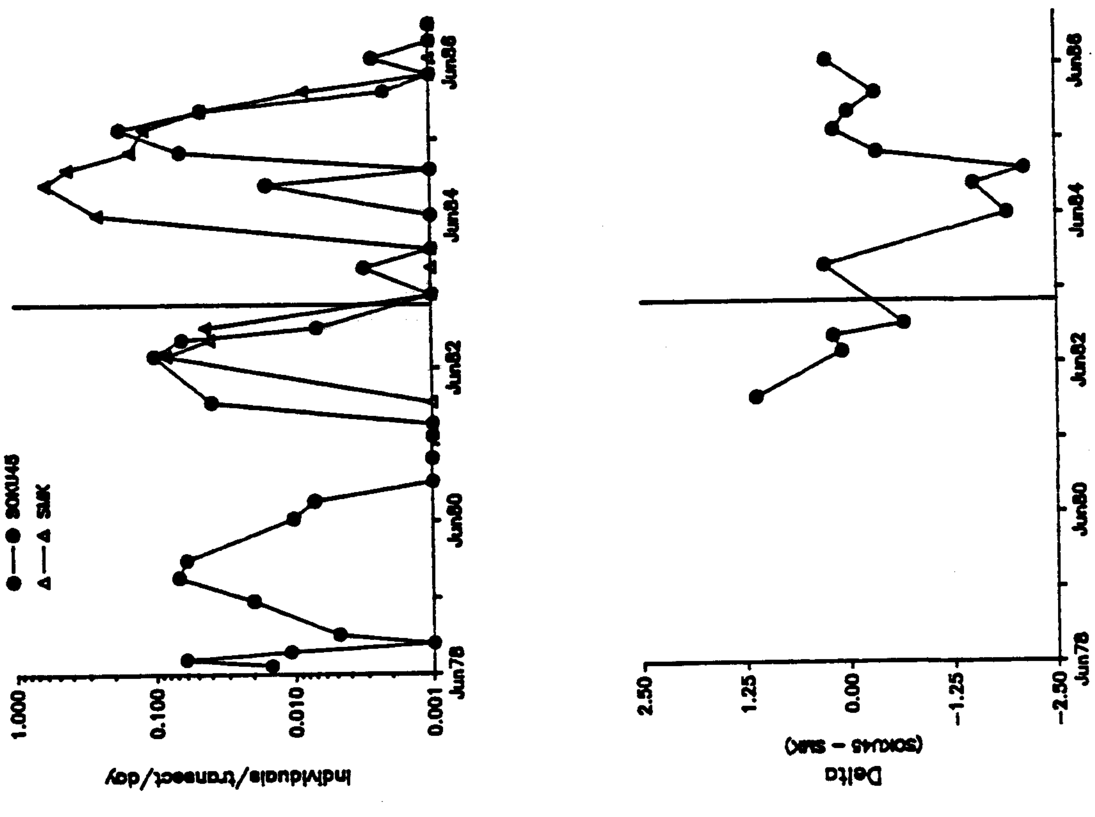
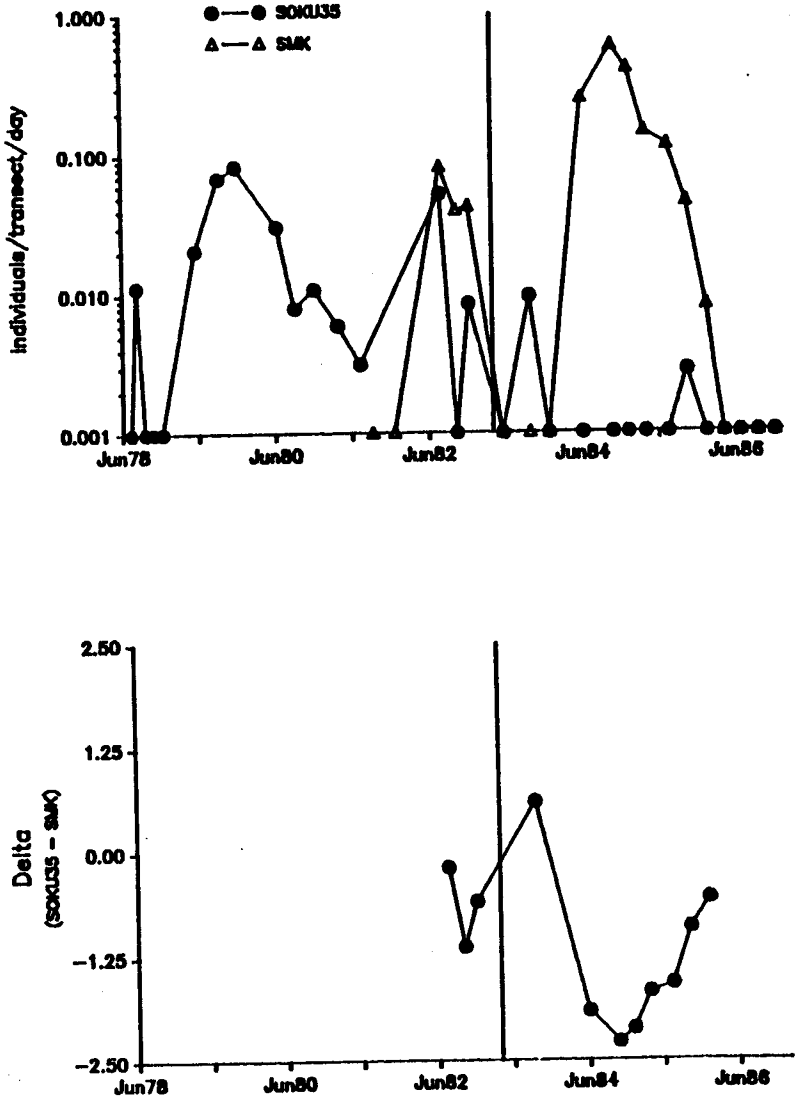
Figure 9: Mean recruitment rates (individuals / transect / day) of adult kelp plants into transects within the SOK and SMK kelp beds (upper graphs). Deltas (lower graphs) are differences in the values for the respective station comparisons. Vertical line separates Before and After periods.



●—● SOKD45
Δ—Δ SMK
Individuals/transect/day
1.000
0.100
0.010
0.001
Jun78
Jun80
Jun82
Jun84
Jun86
Delta
(SOKD45 − SMK)
2.50
1.25
0.00
−1.25
−2.50



●—● SOKU45
Δ—Δ SMK
Individuals/transect/day
1.000
0.100
0.010
0.001
Jun78
Jun80
Jun82
Jun84
Jun86
Delta
(SOKU45 − SMK)
2.50
1.25
0.00
−1.25
−2.50


●—● SOKU35
Δ—Δ SMK
Individuals/transect/day
1.000
0.100
0.010
0.001
Jun78
Jun80
Jun82
Jun84
Jun86
Delta
(SOKU35 - SMK)
2.50
1.25
0.00
-1.25
-2.50

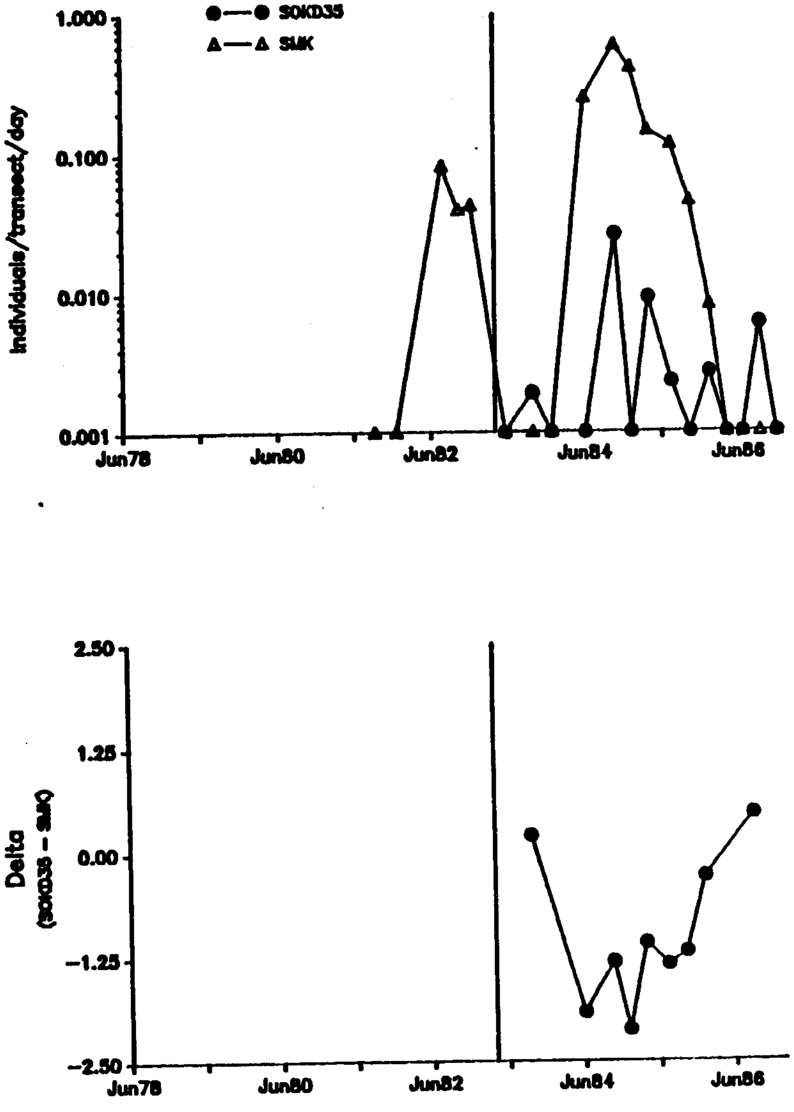

●—● SOKD35
Δ—Δ SMK
Individuals/transect/day
1.000
0.100
0.010
0.001
Jun78
Jun80
Jun82
Jun84
Jun86
Delta
(SOKD35 - SMK)
2.50
1.25
0.00
-1.25
-2.50

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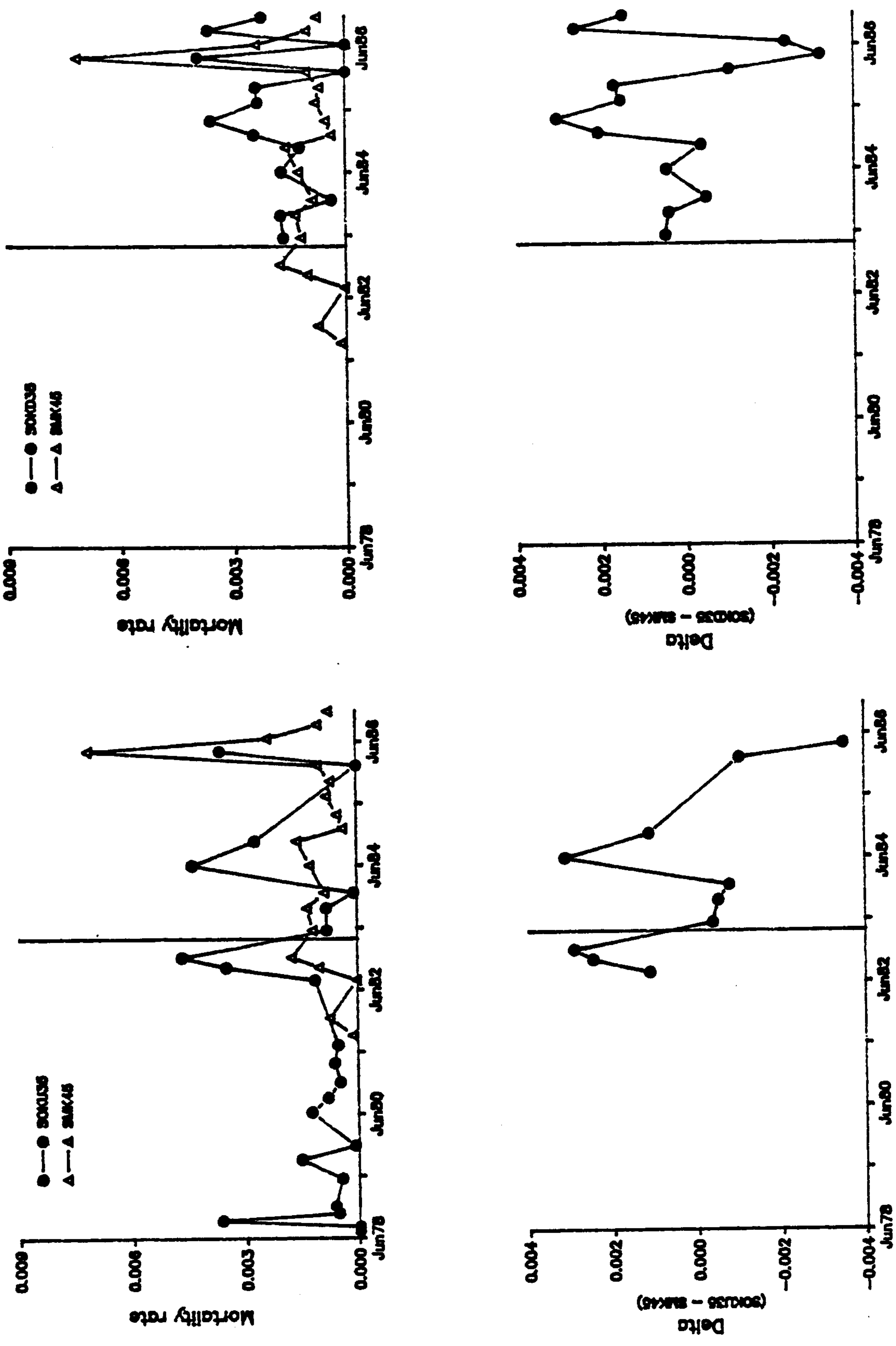
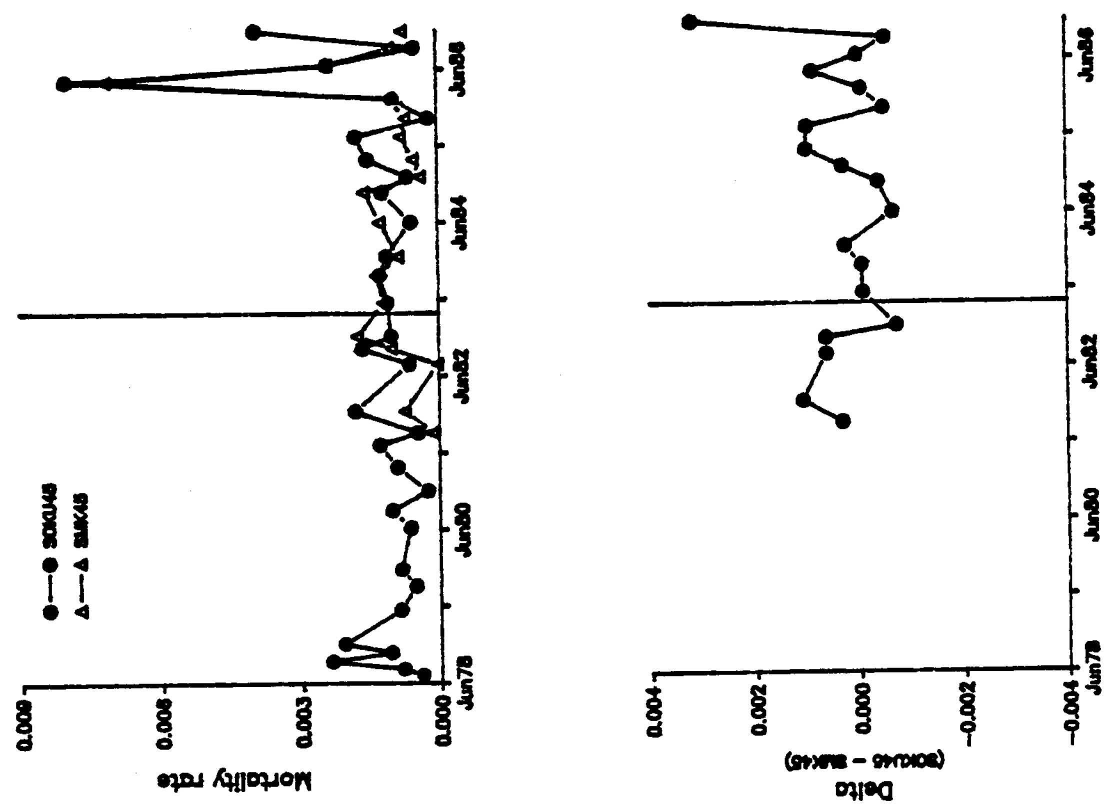
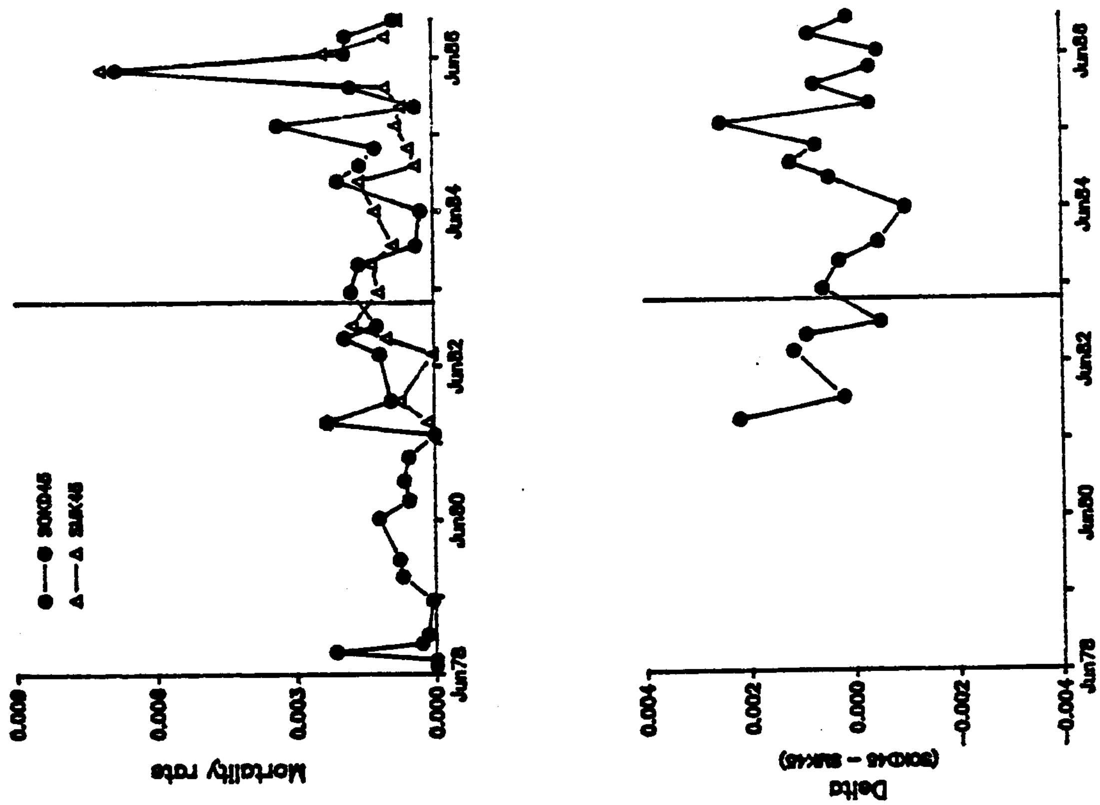
Figure 10: Mean mortality rates of adult kelp plants in transects within the SOK and SMK kelp beds (upper graphs). Deltas (lower graphs) are differences in the values for the respective station comparisons. Vertical line separates Before and After periods.


Mortality rate
0.009
0.006
0.003
0.000
Jun78
Jun80
Jun82
Jun84
Jun86
SOKD35
SMK45
Delta
(sokd35 − smk45)
0.004
0.002
0.000
−0.002
−0.004



Mortality rate
0.009
0.006
0.003
0.000
Jun78
Jun80
Jun82
Jun84
Jun86
● SOKU45
Δ SMK45
Delta
(SOKU45 - SMK45)
0.004
0.002
0.000
-0.002
-0.004



Mortality rate
0.009
0.006
0.003
0.000
Jun78
Jun80
Jun82
Jun84
Jun86
● SOKD45
Δ SMK45
Delta
(SOKD45 - SMK45)
0.004
0.002
0.000
-0.002
-0.004

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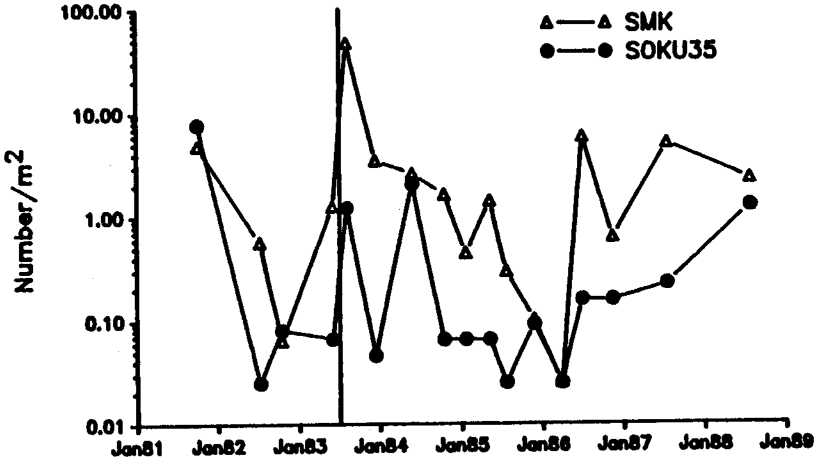
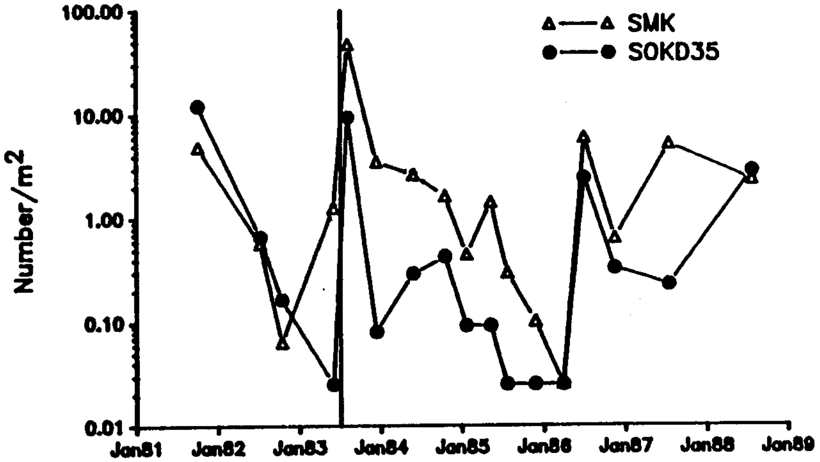
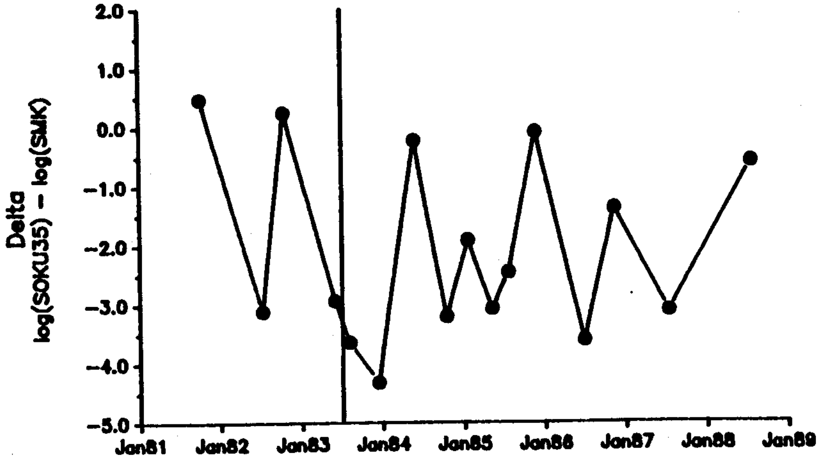
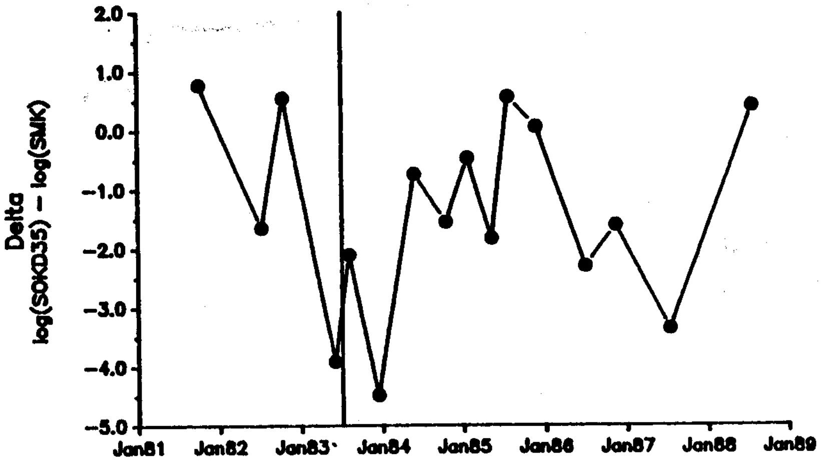
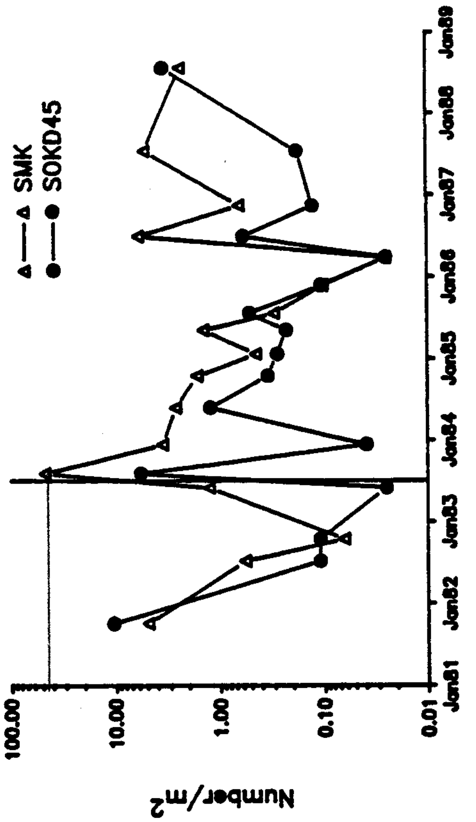
Figure 11: Densities of young-of-the-year kelp plants from kelp forest-wide recruitment stations within the SOK and SMK kelp beds (upper graphs). Deltas (lower graphs) are differences in the log-transformed values for the respective station comparisons. Vertical line separates Before and After periods.

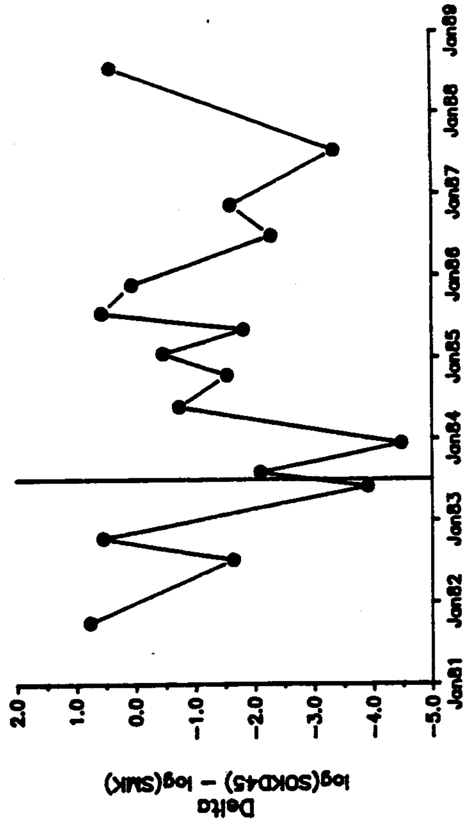

Number/m2
100.00
10.00
1.00
0.10
0.01
Jan81
Jan82
Jan83
Jan84
Jan85
Jan86
Jan87
Jan88
Jan89
SMK
SOKU35

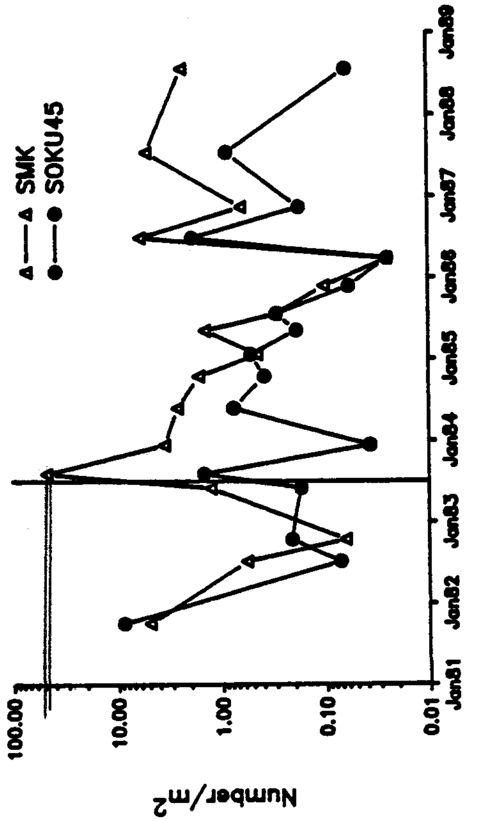

Number/m2
100.00
10.00
1.00
0.10
0.01
Jan81
Jan82
Jan83
Jan84
Jan85
Jan86
Jan87
Jan88
Jan89
SMK
SOKD35


Delta
log(SOKU35) – log(SMK)
2.0
1.0
0.0
–1.0
–2.0
–3.0
–4.0
–5.0
Jan81
Jan82
Jan83
Jan84
Jan85
Jan86
Jan87
Jan88
Jan89


Delta
log(SOKD35) – log(SMK)
2.0
1.0
0.0
–1.0
–2.0
–3.0
–4.0
–5.0
Jan81
Jan82
Jan83
Jan84
Jan85
Jan86
Jan87
Jan88
Jan89


Δ——Δ SMK
●——● SOKD45
Number/m^2
100.00
10.00
1.00
0.10
0.01
Jan81
Jan82
Jan83
Jan84
Jan85
Jan86
Jan87
Jan88
Jan89


Delta
log(SOKD45) – log(SMK)
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
−5.0
Jan81
Jan82
Jan83
Jan84
Jan85
Jan86
Jan87
Jan88
Jan89


Δ——Δ SMK
●——● SOKU45
Number/m^2
100.00
10.00
1.00
0.10
0.01
Jan81
Jan82
Jan83
Jan84
Jan85
Jan86
Jan87
Jan88
Jan89

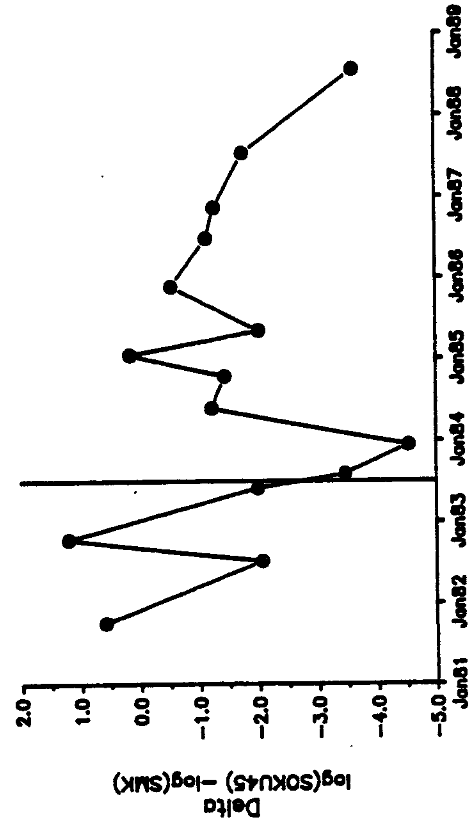

Delta
log(SOKU45) –log(SMK)
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
−5.0
Jan81
Jan82
Jan83
Jan84
Jan85
Jan86
Jan87
Jan88
Jan89

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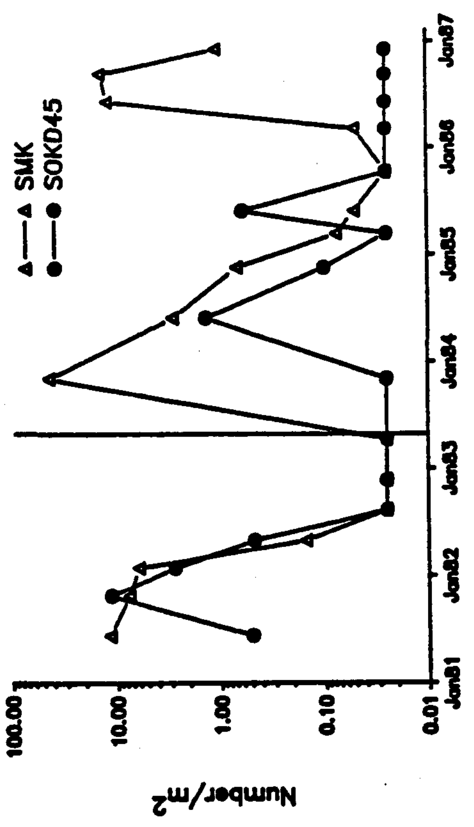
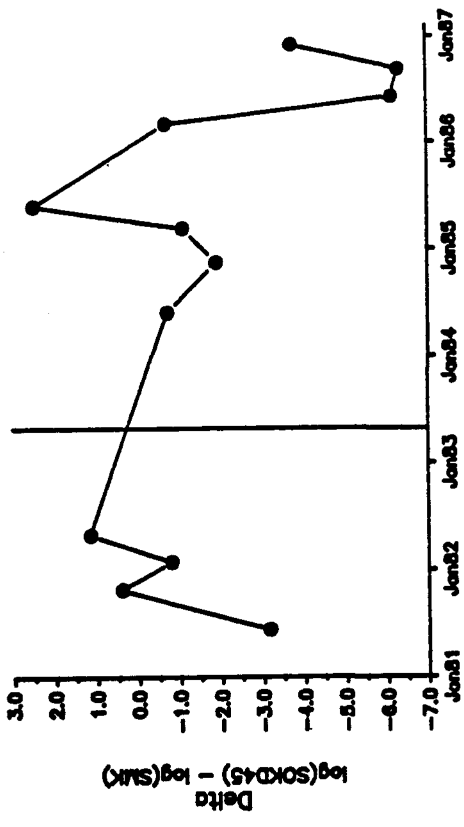
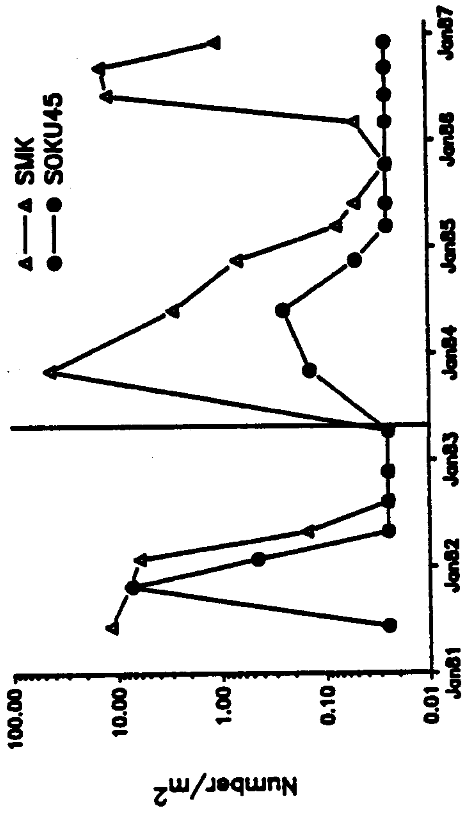
Figure 12: Density of young-of-the-year kelp plants from stations used to sample kelp forest invertebrates within the SOK and SMK kelp beds (upper graphs). Deltas (lower graphs) are differences in the log-transformed values for the respective station comparisons. Vertical line separates Before and After periods.


SMK
SOKD45
Number/m^2
100.00
10.00
1.00
0.10
0.01
Jan81
Jan82
Jan83
Jan84
Jan85
Jan86
Jan87


Delta
log(SOKD45) – log(SMK)
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
−5.0
−6.0
−7.0
Jan81
Jan82
Jan83
Jan84
Jan85
Jan86
Jan87


SMK
SOKU45
Number/m^2
100.00
10.00
1.00
0.10
0.01
Jan81
Jan82
Jan83
Jan84
Jan85
Jan86
Jan87

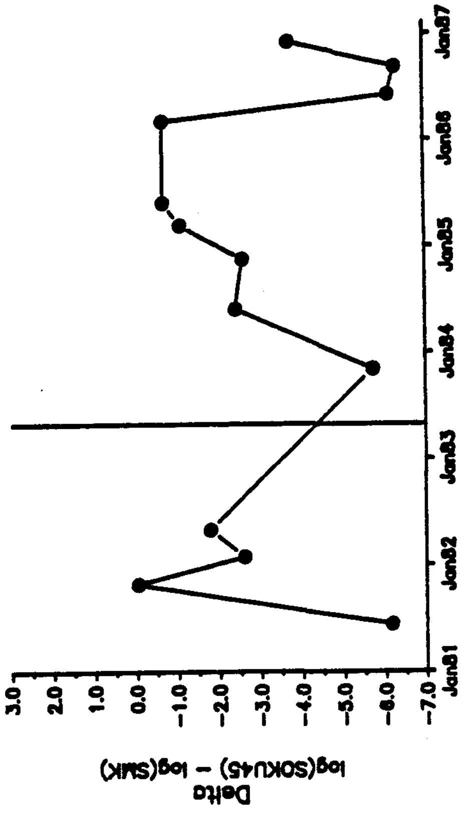

Delta
log(SOKU45) – log(SMK)
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
−5.0
−6.0
−7.0
Jan81
Jan82
Jan83
Jan84
Jan85
Jan86
Jan87

Figure 13: Mean densities of (A) female gametophytes (as estimated from sporophytes produced after culturing) and (B) newly recruited microscopic sporophytes in 1986. Values are means from stations at SOKU35, SOKU45, SOKD45, and SMK45.

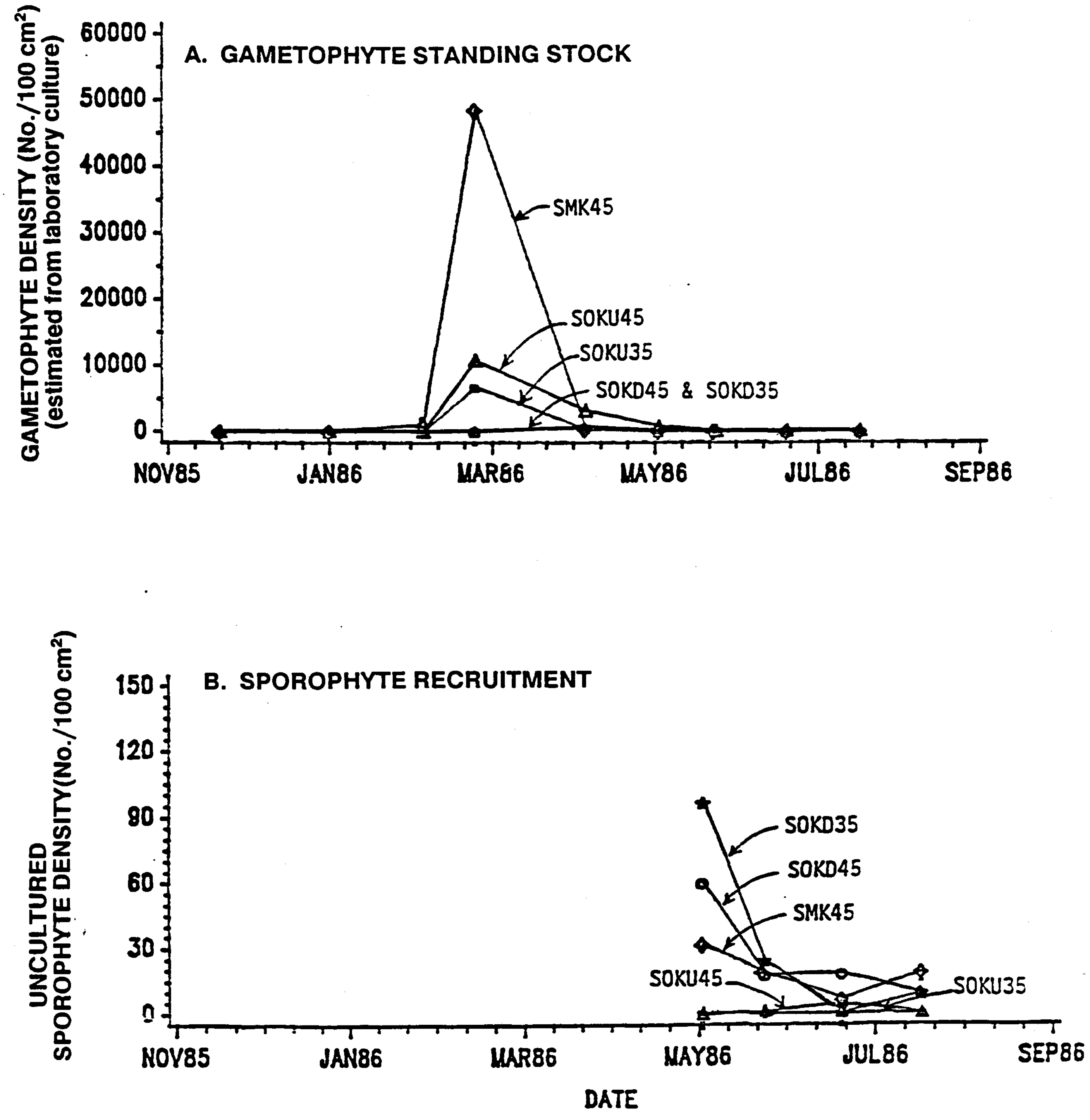
A. GAMETOPHYTE STANDING STOCK
GAMETOPHYTE DENSITY (No./100 cm²) (estimated from laboratory culture)
60000
50000
40000
30000
20000
10000
0
NOV85
JAN86
MAR86
MAY86
JUL86
SEP86
SMK45
SOKU45
SOKU35
SOKD45 & SOKD35
B. SPOROPHYTE RECRUITMENT
UNCULTURED SPOROPHYTE DENSITY(No./100 cm²)
150
120
90
60
30
0
NOV85
JAN86
MAR86
MAY86
JUL86
SEP86
DATE
SOKD35
SOKD45
SMK45
SOKU45
SOKU35

Figure 14: Survivorship of <u>Macrocystis</u> blades transplanted to stations in SMK, SOK, and SOKN from 18 August 1986 to 11 January 1987. From Schroeter <u>et al.</u> 1988.

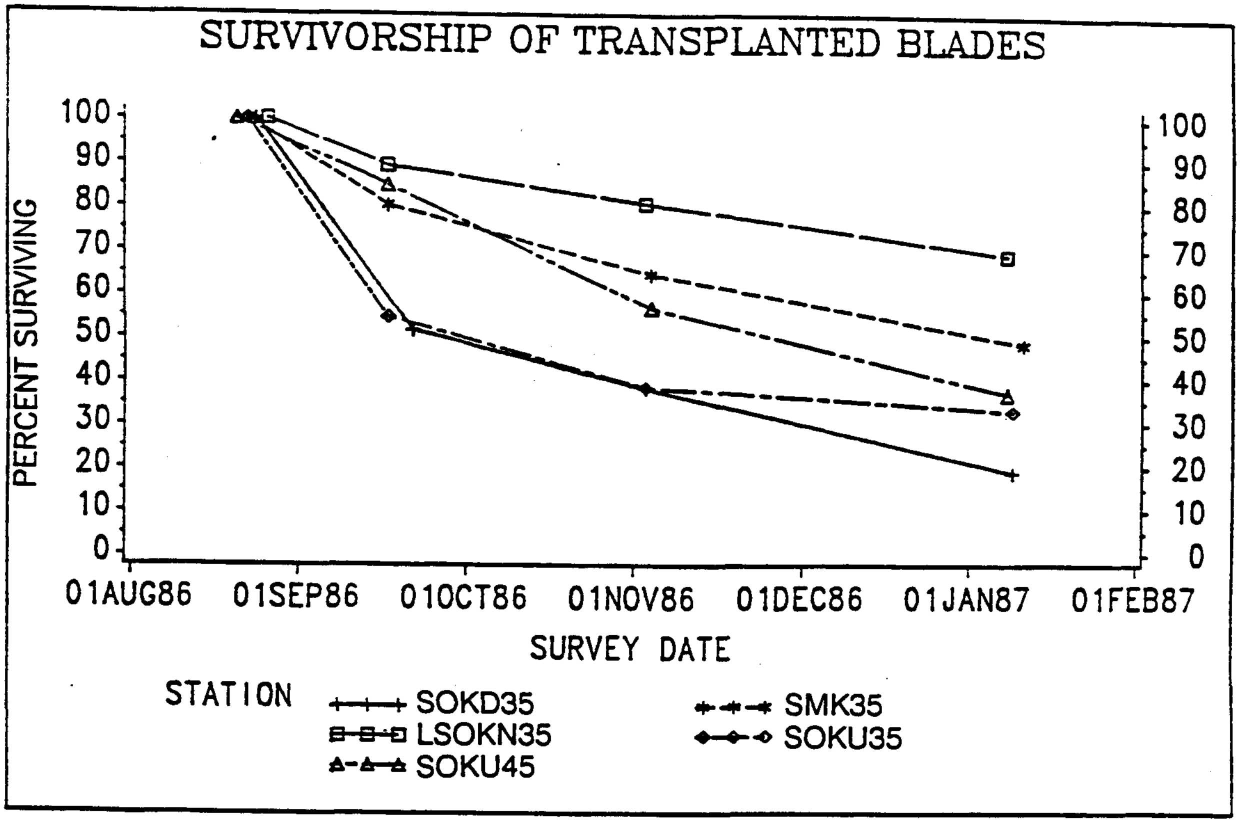

SURVIVORSHIP OF TRANSPLANTED BLADES
PERCENT SURVIVING
100
90
80
70
60
50
40
30
20
10
0
01AUG86
01SEP86
01OCT86
01NOV86
01DEC86
01JAN87
01FEB87
SURVEY DATE
STATION
SOKD35
LSOKN35
SOKU45
SMK35
SOKU35

Figure 15: Size distribution of subadult and adult giant kelp plants near Transects 14 and 16 in the San Mateo, and Transect 1 in the San Onofre kelp forests.

SIZE DISTRIBUTION OF MACROCYSTIS
ON 12/04/87

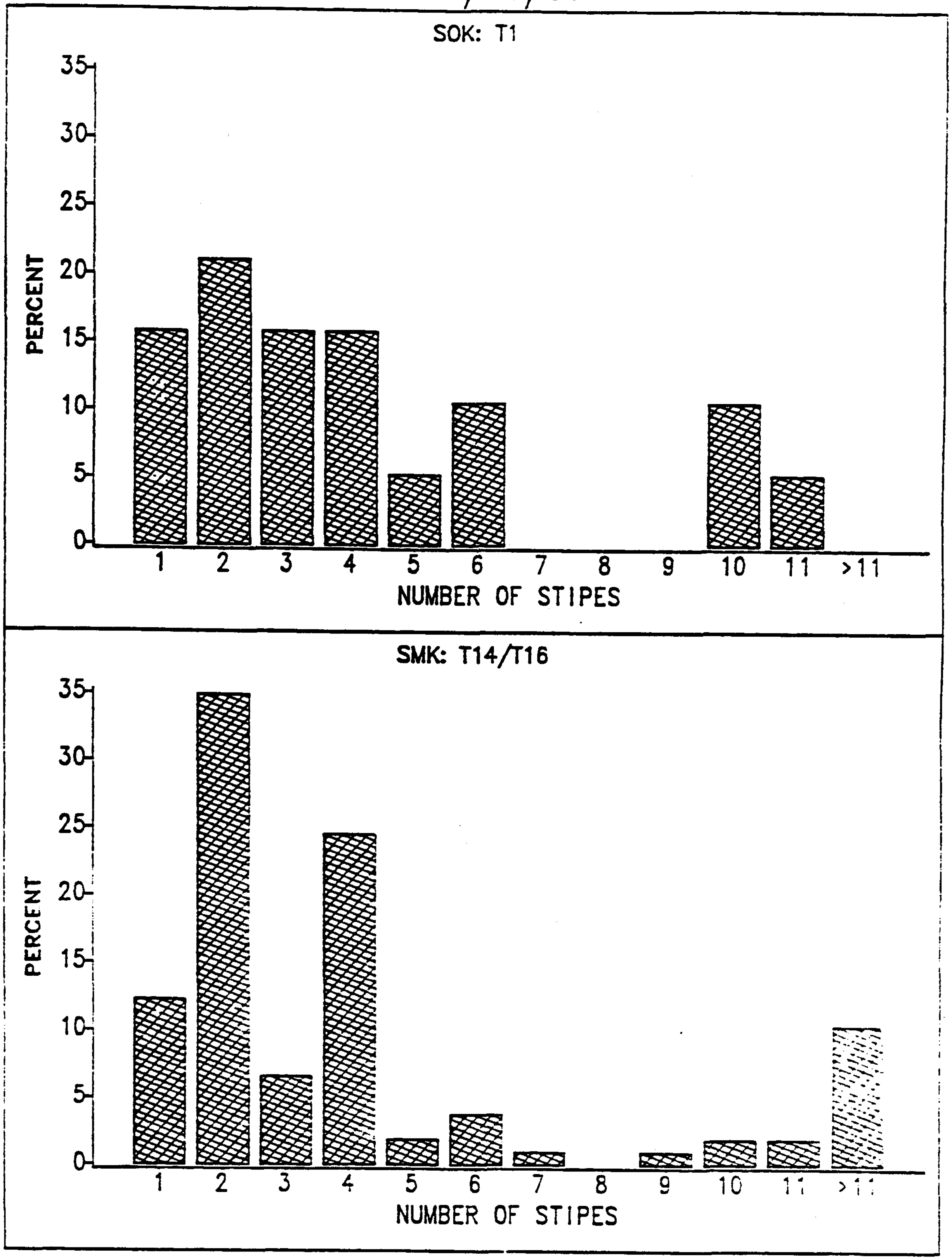
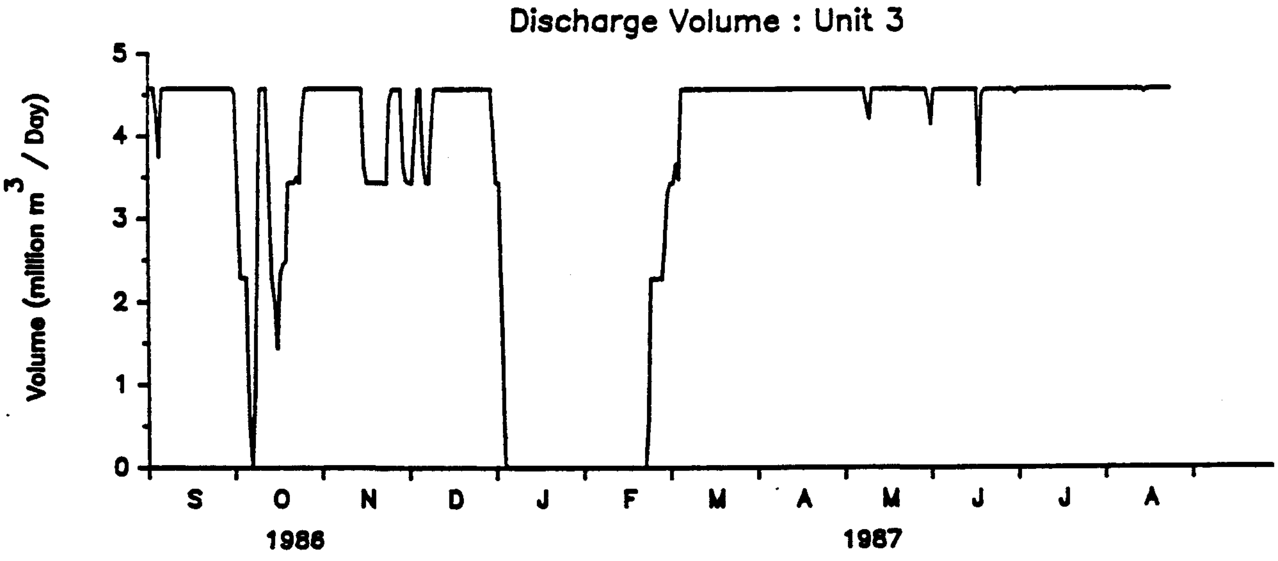
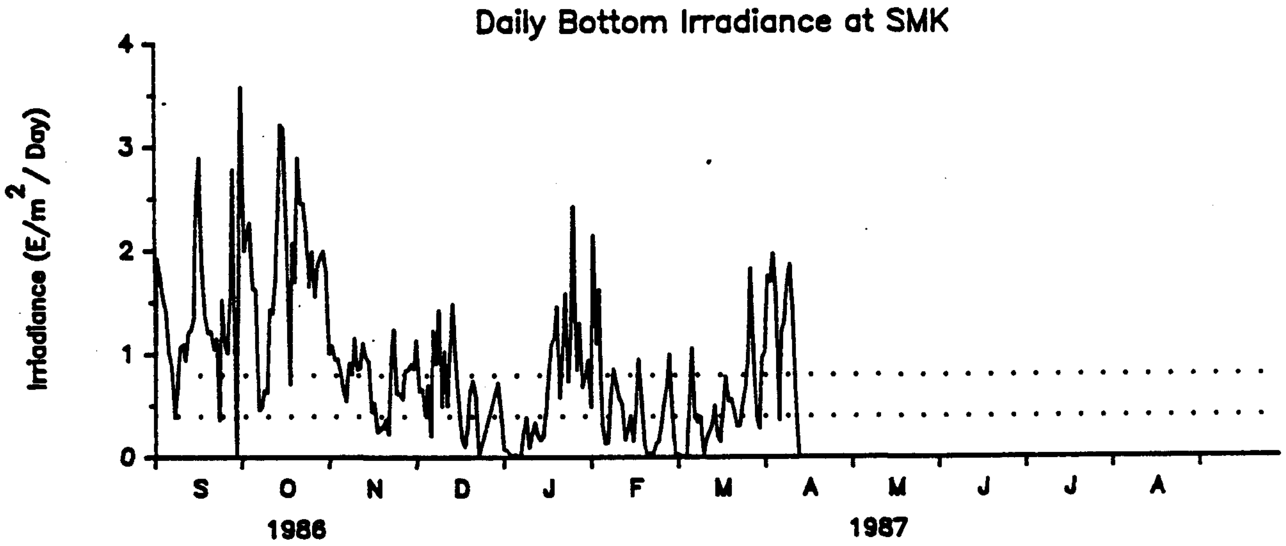


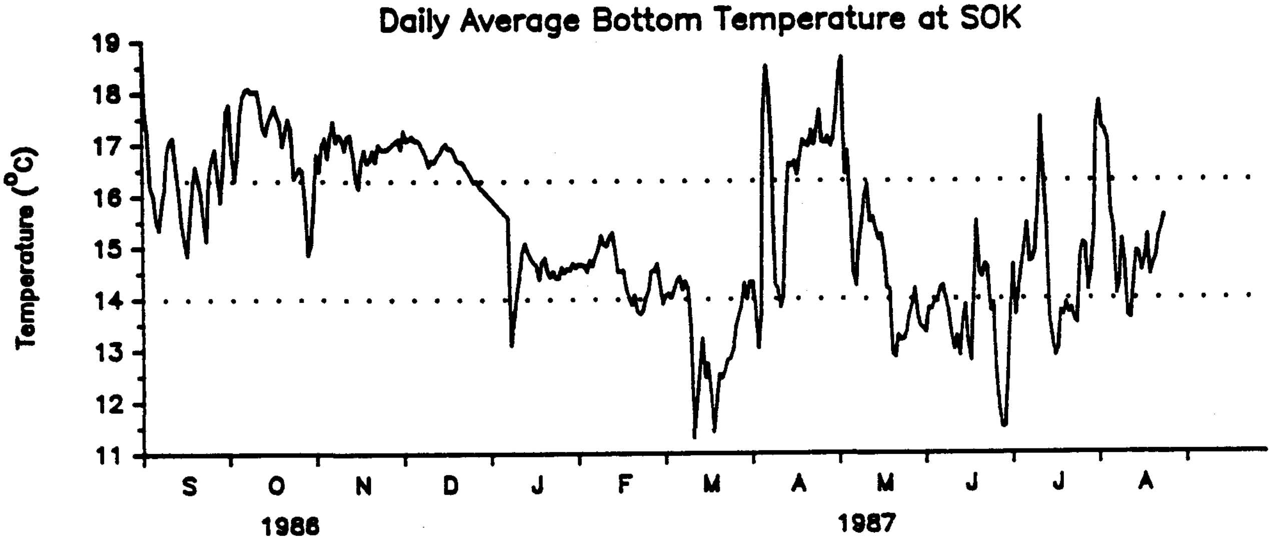
Figure 16: Discharge volume of Unit 3, bottom irradiance in the San Mateo kelp forest, and bottom temperature in the San Onofre kelp forest in 1986-87. There were no irradiance meters at San Onofre during this period.

Probability of recruitment is low when irradiance values are below lower dotted horizontal line, moderate when they are between horizontal lines, and high when they are above upper dotted horizontal line in Panel 2.

Probability of recruitment is low when temperature values are above upper dotted horizontal line, moderate when they are between horizontal lines, and high when they are below lower dotted line on Panel 3.


Discharge Volume : Unit 3


Daily Bottom Irradiance at SMK


Daily Average Bottom Temperature at SOK

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APPENDICES

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Appendix A. Effects of SONGS on the physical environment

The effects of SONGS Units 2 and 3 on the physical environment are considered in detail in Final Technical Report L. Here we briefly summarize those results and present some additional results especially pertinent to giant kelp populations in SOK. We concentrate on physical factors that might influence giant kelp; in particular irradiance, seston flux and concentration, and the sediments with unusual bulk characteristics that appeared unexpectedly in SOK during 1985.

Of special interest is the effect of SONGS on irradiance on the bottom. The turbid plume from Units 2 and 3 was predicted to cause substantial reductions in irradiance, thereby having negative effects on giant kelp in SOK. When the current is moving to the southeast, toward the main SOK kelp forest, the plume from SONGS Units 2 and 3 causes an average reduction in irradiance of about 0.46 $E/m^2/d$ (26%) throughout SOK (Final Technical Report L). The reduction in irradiance was approximately as large in downcoast SOK as in upcoast SOK, perhaps larger (Final Technical Report L). When currents move to the northwest there is no statistically significant effect in SOK, which lies to the southeast of the diffusers, but there is a nonsignificant increase in average irradiance within SOK, on the order of 0.26 $E/m^2/d$. (The downstream effect is based on data from meters on the bottom when the currents went downcoast 5 out of 9 daylight hours. The upstream effect is the average of results when the current went upcoast 5 out of 9 daylight hours (approximately 0) and when it went upcoast 9 out of 9 daylight hours (about equal magnitude to the downstream effect).) An increase in irradiance within SOK when currents move to the northwest might result because clearer water from offshore is drawn in to makeup for water pushed offshore and upcoast by SONGS' discharge.

The current moves to the southeast (downcoast) about 60% of the time, so the overall average decrease (ignoring a possible positive effect on the upstream side) is about 0.27 $E/m^2/d$, or 16% of the average irradiance in SOK. If we take into account the possible positive effect on the 40% of the days the current goes to the northwest, the decline becomes about 0.2 $E/m^2/d$, or about 12% of the average irradiance in SOK.

Seston flux was predicted to increase after Units 2 and 3 began operations, and this was predicted to have negative effects on small stages of giant kelp. Seston flux was measured by the accumulation of seston in tubes, and this measures the vertical flux or settling rate. Measured in this way, the predicted increase in seston flux has occurred in upcoast SOK. We have relatively little Before data from SMK, and a much longer time series from the upcoast (SOKU45) and downcoast (SOKD45) stations in SOK. The BACIP result for the comparison of SOKU45 with SMK was not quite significant but suggests an increase in seston flux in upcoast SOK (Table A1). The statistically more powerful BACIP comparison between upcoast and downcoast SOK demonstrated a significant increase (45%) in seston flux in upcoast SOK (Table A2).

For a given level of surface irradiance, the irradiance reaching the bottom should be a function of suspended material in the water. Reitzel (1980) showed that extinction is tightly correlated with both cross-sectional area of seston in the water column ($r^2=0.81$) and seston weight ($r^2=0.77$). We use both irradiance and seston flux (the amount of sediment accumulating in a tube per day) to explain variation in the success of giant kelp. If irradiance and seston flux were very tightly correlated it would be difficult to disentangle the effects of these two factors. However, despite the tight relationship demonstrated by Reitzel, irradiance at the bottom is only weakly correlated with seston flux at the bottom, as estimated with seston tubes ($r^2=0.15$). This analysis used data on irradiance and seston flux collected as part of the microscopic sporophyte outplants. Although the r^2 is not as large as we might expect based on the earlier work, it is statistically significant (Table A3), and strong enough that it should be kept in mind as the biological results are interpreted. There was also a weak but significant negative correlation of irradiance and seston flux for the gametophyte outplants (Table A3). These results are presented for completeness, but we note that they are not independent of the previous results because some of the seston and irradiance data collected as part of the gametophyte outplants overlap with data collected with the microscopic sporophyte outplants.

There are at least three reasons why irradiance and seston flux are only weakly correlated: (1) some of the seston collected in the tubes comes from movement of sediments along the bottom, and this material is coarse and causes relatively little extinction, (2) measurements of vertical flux of seston near the bottom may not reflect total seston concentration throughout the water column, and (3) irradiance on the bottom responds to variations in surface irradiance as well as to seston concentration.

The tight correlation between seston concentration and extinction by Reitzel (1980) suggests that extinction near the bottom could be used as an indirect measure of seston concentration there. The horizontal movement of such seston might have deleterious effects on small kelp, but this flux would not be detected by the seston tubes. We have therefore tested whether SONGS causes an increase in extinction between 2 m off the bottom and the bottom in SOK. To do this we calculated the difference between the extinction observed in SOK and extinction observed at the stations northwest of the diffusers for each day from 1984 through the end of 1986. We then compared extinction on days when the current was going over SOK (on nine of nine daylight hours), and days when it was going toward the northwest, away from SOK. The stations northwest of SONGS were P-N and PI-N (see Final Technical Report L), and the stations used in SOK were at SOKU45, SOKD45, and SOKD35. For both the upcoast and SOK stations, irradiance was first averaged over the stations at each depth for each hour, extinction was estimated for each hour, and then averaged for the nine daylight hours.

We model the effect of current direction on the difference between the southeast and northwest stations in extinction (D) as:

$$D = X + I\,B + e,$$

where X is the expected difference in extinction when the current is going upcoast, and I is a dummy variable set to 0 if the current goes upcoast, and to 1 if the current goes downcoast. Since both the upcoast and SOK stations can be impacted by SONGS, and we assume these effects are symmetrical, we take B as equaling twice the effect on extinction in SOK when the current drives the plume towards SOK. (For discussion of a similar model, see the presentation of the plume model in Final Technical Report L). e is the error term, and is assumed to follow an AR(3) process. The parameter B is tested to determine whether it differs from zero using a t-test, after adjusting for serial correlations (see Methods).

SONGS causes extinction near the bottom in SOK to increase significantly. The parameter B in Table A4 is 0.09, so when a station is downstream extinction is increased on the order of 0.045 m^{-1}.

We tested for differences in extinction near the bottom within SOK. To do this we repeated the above analysis now using as our data the differences in extinction between two stations within SOK. First we compared SOKD45 and SOKU45, which are both at the same depth, but different distances from the diffusers. Then we compared SOKD45 and SOKD35 which are the same distance from the diffusers, but at different depths. In these pairings, we would expect a more heavily impacted station to show a relative increase in extinction when the current moved toward the southeast, and over these stations. The results in Table A4 provide no evidence for differential effects within SOK on extinction. B in both tests was small and not significantly different from 0.

An unexpected change in the environment that could well be influencing giant kelp populations is the appearance of fine sediments with unusual bulk properties (Final Technical Report B). These sediments appeared in October 1985 in upcoast SOK, and have increased in area since that time. As of July 1988 they covered about 30 hectares (15 percent of the cobble area underlying SOK). They have been shown to reduce cover of understory algae and cause reductions in the density of benthic invertebrates (Final Technical Reports B and F). The timing of their appearance, and their concentration in the areas of SOK nearest the diffusers suggest that SONGS may responsible. Mechanisms responsible for the production of these sediments are still under investigation as this report is being prepared, and will be discussed in Final Technical Report B.

Table A1

BACIP tests on vertical setson flux (bottom data collected during gametophyte outplants), comparing the near (SOKU45) and far (SOKD45) impact sites with SMK. P-values are underestimated because station differences were temporally controlled. Time series models were not fit because of the limited Before data. Daily seston flux values were log (x + 0.53) transformed.

COMPARISON (CONTROL VS IMPACT)	MEAN VALUES				P	POWER (%)	% CHANGE
	BEFORE		AFTER				
	CONTROL	IMPACT	CONTROL	IMPACT			
SMK45 vs SOKU45	2.37	6.69	2.93	11.16	0.077	93.1	35.5
	(n = 14)		(n = 21)				
SMK45 vs SOKD45	2.37	7.86	2.93	7.47	0.21	96.1	-20.3
	(n = 14)		(n = 21)				

Table A2

BACIP tests on seston flux (bottom data collected during gametophyte outplants) using an AR(1) time series model to correct for serial correlations (Preliminary analysis with an AR(3) model produced similar results and indicated that higher order correlations were not present). Only the SOKU45 (Impact) versus SOKD45 (Control) comparison is tested using a time series model, because too few data were available to use this method with comparisons with SMK. Daily seston flux was log (x + 0.53) transformed to induce additivity. Power to detect a 50% change at the impact sites was estimated assuming uncorrelated errors and this is somewhat inflated.

MEAN VALUES				P	POWER (%)	% CHANGE
BEFORE		AFTER				
CONTROL (SOKD)	IMPACT (SOKU)	CONTROL (SOKD)	IMPACT (SOKU)			
7.62	7.65	7.47	11.16	0.001	~100%	45.8
(n = 31)		(n = 21)				

Table A3

Regressions of seston flux versus irradiance. Data come from the bottom and were log transformed. Separate regressions were done on data collected as part of the microscopic sporophyte and gametophyte data sets; note that irradiance and seston flux data overlap between these sets.

DATA SET	INTERCEPT	SLOPE	R^2	P
Microscopic sporophyte outplants	1.76	-0.45	0.16	<0.0001
Gametophyte outplants	1.82	-0.35	0.12	<0.0001

Table A4

Effect of current direction on the difference in extinction of irradiance near the bottom (2 m to 0 m) for specified pairs of stations. Analyses used an AR(3) model to account for serially correlated errors.

STATION PAIR	EFFECT OF CURRENT DIRECTION (B)	P	d.f.
Upcoast of diffusers vs. SOK	0.09	0.003	302
SOKD45 vs. SOKU45	-0.03	0.39	323
SOKD35 vs. SOKD45	-0.01	0.62	376

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Appendix B

Table of Station Locations for Field Studies of Giant Kelp

A. Transects Used to Estimate Abundance of Adult, Subadult, and Juvenile Kelp

STATION NAME IN DATABASE	MRC COORDINATE (M) X	Y	DEPTH (M)	GENERAL AREA
TRANS1	817	-865	11.5	SOKU35
TRANS2	732	-1120	11.5	SOKU35
TRANS3	763	-1443	13.5	SOKU45
TRANS4	735	-1717	14.0	SOKU45
TRANS5	844	-1855	14.5	SOKU45
TRANS6	1005	-1947	14.5	SOKU45
TRANS7	1589	-1784	13.7	SOKD45
TRANS8	1751	-1783	14.5	SOKD45
TRANS9	840	-1774	13.7	SOKU45
TRANS10	880	-1813	13.7	SOKU45
TRANS11	1595	-1686	13.7	SOKD45
TRANS12	1675	-1709	13.7	SOKD45
TRANS13	729	-2062	16.7	SOKU45
TRANS14	-4620	-1000	14.5	SMK
TRANS15	-4590	-950	12.5	SMK
TRANS16	-4400	-974	12.5	SMK
TRANS17	-4405	-752	11.0	SMK
TRANS18	1077	-901	11.0	SOKU35
TRANS19	1022	-884	11.0	SOKU35
TRANS20	1496	-1227	11.5	SOKD35
TRANS21	1718	-1206	12.0	SOKD35
TRANS22	1745	-1182	12.0	SOKD35
TRANS23	1818	-1135	11.5	SOKD35
TRANS24	1486	-1541	13.0	SOKD45
TRANS25	0	-1407	13.5	SOKN
TRANS26	54	-1375	13.0	SOKN

B. Stations Used to Estimate the Recruitment of Kelp YOY and the Abundance of Sea Urchins

STATION NAME IN DATABASE	MRC COORDINATE (M) X	Y	DEPTH (M)	GENERAL AREA
USC111	802	-898	11.0	SOKU35
USC112	907	-894	11.0	SOKU35
USC113	1100	-892	11.0	SOKU35
USC121	723	-1248	11.0	SOKU35
USC122	952	-1227	11.0	SOKU35
USC123	1099	-1237	11.0	SOKU35
USC124	1330	-1245	11.0	SOKD35
USC125	1502	-1224	11.0	SOKD35
USC126	1704	-1215	11.0	SOKD35
USC131	783	-1571	11.0	SOKU45
USC132	909	-1555	11.0	SOKU45
USC133	1105	-1569	11.0	SOKU45
USC134	1306	-1495	11.0	SOKD45
USC135	1509	-1495	11.0	SOKD45
USC136	1698	-1560	11.0	SOKD45
USC141	707	-1894	14.0	SOKU45
USC142	896	-1905	14.0	SOKU45
USC143	1101	-1905	14.0	SOKU45
USC144	1297	-1898	14.0	SOKD45
USC145	1508	-1896	14.0	SOKD45
USC146	1704	-1899	14.0	SOKD45
USC151	702	-2094	14.0	SOKU45
USC152	899	-2089	14.0	SOKU45
USC153	1106	-2093	14.0	SOKU45
TRANS27C	1693	-1492	14.0	SOKD45
TRANS28C	881	-1599	14.0	SOKU45
TRANS30C	1487	-1200	14.0	SOKD35
TRANS31C	828	-874	14.0	SOKU35
TRANS32C	1891	-1691	14.0	SOKD45
TRANS33C	1002	-1823	14.0	SOKU45

B. Stations Used to Estimate the Recruitment of Kelp YOY and the Abundance of Sea Urchins (continued)

STATION NAME IN DATABASE	MRC COORDINATE (M) X	Y	DEPTH (M)	GENERAL AREA
TRANS35K	1647	-1487	14.0	SOKD45
TRANS36K	1030	-1814	14.0	SOKU45
USC1N001	-7	-1136	12.5	SOKN
USC1N002	15	-1244	12.5	SOKN
USC211	-4591	-203	9.5	SMK
USC212	-4413	-185	9.5	SMK
USC221	-4446	-553	11.5	SMK
USC231	-4800	-750	11.5	SMK
USC232	-4593	-734	11.5	SMK
USC233	-4404	-752	10.5	SMK
USC241	-4522	-845	10.5	SMK
USC251	-5100	-1000	15.5	SMK
USC252	-4774	-1000	15.5	SMK
USC253	-4596	-1037	16.5	SMK
USC254	-4392	-1000	13.5	SMK
TRANS29C	-4945	-742	14.5	SMK
TRANS34C	-5020	-866	13.5	SMK
TRANS37K	-4966	-775	13.5	SMK

C. Stations Used to Estimate the Recruitment of Kelp YOY and the Abundance of Large Kelp Forest Invertebrates

STATION NAME IN DATABASE	MRC COORDINATE (M) X	Y	DEPTH (M)	GENERAL AREA
USC01	-4504	-903	11.5	SMK
USC02	735	-1793	14.5	SOKU45
USC03	1689	-1704	14.5	SOKD45
USC04	10538	-3005	15.0	BK

D. Stations Used for Gametophyte and Sporophyte Outplants

STATION NAME IN DATABASE	MRC COORDINATE (M) X	MRC COORDINATE (M) Y	DEPTH (M)	GENERAL AREA
SOKU55	800	-2000	15.5	SOKU45
SOKU45	850	-1600	13.7	SOKU45
SOKD55	1600	-2000	15.5	SOKD45
SOKD45	1800	-1300	13.7	SOKD45
SOKU35	917	-882	10.7	SOKU35
SOKD35	1493	-1200	10.7	SOKD35
SMK45	-4943	-738	13.7	SMK
SMKCAN	-4609	-1010	13.7	SMK
SMK55	-5000	-1000	16.8	SMK
BK45	10889	-2876	13.7	BK
BK55	10800	-2800	16.8	BK

E. Stations Used for Cobble Transplants in 1986

STATION NAME IN DATABASE	MRC COORDINATE (M) X	MRC COORDINATE (M) Y	DEPTH (M)	GENERAL AREA
SOKU45	850	-1600	13.5	SOKU45
SOKU35	917	-882	11.5	SOKU35
SOKD45	1800	-1300	12.5	SOKD45
SOKD35	1493	-1200	11.5	SOKD35
TRANS17	-4405	-752	11.0	SMK
SMK45CL	-5027	-863	14.5	SMK
SMK45	-4943	-738	13.5	SMK

F. Stations Used to Monitor Gametophyte Standing Stock and Settlement(*)

STATION NAME IN DATABASE	MRC COORDINATE (M)		DEPTH (M)	GENERAL AREA
	X	Y		
SOKU45*	850	-1600	13.7	SOKU45
SOKU45CL	992	-1840	13.5	SOKU45
SOKU45CN	1030	-1841	13.5	SOKU45
TRANS4	735	-1717	14.0	SOKU45
TRANS9	840	-1774	13.7	SOKU45
SOKU35*	917	-882	10.7	SOKU35
SOKD45*	1800	-1300	13.7	SOKD45
SOKD45CL	1903	-1692	14.5	SOKD45
SOKD45CN	1647	-1487	12.5	SOKD45
SOKDCN2	1930	-1690	14.0	SOKD45
TRANS11	1595	-1686	13.7	SOKD45
TRANS24	1486	-1541	13.0	SOKD45
SOKD35*	1493	-1200	10.7	SOKD35
TRANS17	-4405	-752	11.0	SMK
SMK45*	-4943	-738	13.7	SMK
SMK45CL	-5027	-863	13.5	SMK
SMK45CN	-4966	-775	13.7	SMK
SMKCN2	-5060	-860	13.5	SMK
BKGS45	10600	-2900	16.8	BK

G. Stations for 1986 Blade Transplant Experiments

STATION NAME IN DATABASE	MRC COORDINATE (M)		DEPTH (M)	GENERAL AREA
	X	Y		
TPU35	917	-882	10.7	SOKU35
TRANS18	1077	-901	10.7	SOKU35
TPD35	1493	-1200	10.7	SOKD35
TPD45	1800	-1300	13.7	SOKD45
TPN35	0	-1175	12.5	SOKN
SMK35	-4408	-906	12.5	SMK
SMK40	-4591	-925	12.2	SMK
SMK40CAN	-4603	-852	12.2	SMK

H. Stations Used to Monitor the Growth of Transplanted Juvenile Kelp

STATION NAME IN DATABASE	MRC COORDINATE (M)		DEPTH (M)	GENERAL AREA
	X	Y		
SOKU45	850	-1600	13.5	SOKU45
SOKU-CAN	730	-1050	11.5	SOKU45
SOKD45	1800	-1300	12.5	SOKD45
SOKD-CAN	1800	-1500	12.5	SOKD45
SOKU35	917	-882	11.5	SOKU35
SOKD35	1493	-1200	11.5	SOKD35
SMK45	-4943	-738	13.5	SMK
SMK-CAN	-4609	-1010	14.5	SMK
SMK35	-4379	-480	11.5	SMK

I. Stations Used to Monitor Survivorship of Juvenile Kelp

STATION NAME IN DATABASE	MRC COORDINATE (M)		DEPTH (M)	GENERAL AREA
	X	Y		
JS1	936	-1850	15.2	SOKU45
JS2	983	-1827	15.2	SOKU45
JS3	1109	-1813	15.2	SOKU45
JS4	1722	-1501	13.7	SOKD45
JS5	1768	-1534	13.7	SOKD45
JS6	1795	-1568	13.7	SOKD45
JS7	1656	-1171	9.0	SOKD35
JS8	1707	-1150	9.0	SOKD35
JS9	1735	-1198	9.0	SOKD35
JS10	1101	-1604	13.7	SOKU45
JS11	1063	-1623	13.7	SOKU45
JS12	1117	-1664	13.7	SOKU45
JS13	1657	-1520	13.7	SOKD45
JS14	1748	-1610	13.7	SOKD45
JS15	1770	-1639	13.7	SOKD45
JS16	1606	-1210	9	SOKD45
SOKUJT	850	-1550	13.7	SOKU45

J. Stations Used to Monitor the Survival of Transplanted Adult Kelp

STATION NAME IN DATABASE	MRC COORDINATE (M) X	Y	DEPTH (M)	GENERAL AREA
SOKATP1	817	-865	11.0	SOKU35
SOKATP2	732	-1120	12.5	SOKU35
SOKATP3	1022	-844	11.0	SOKU35
SMKATP1	-4709	-248	10.5	SMK
SMKATP2	-4388	-358	10.5	SMK
SMKATP3	-3970	-648	12.0	SMK

K. Stations Used in Physical and Chemical Studies of the Unit 2 and 3 Plumes

STATION NAME IN DATABASE	MRC COORDINATE (M) X	Y	DEPTH (M)
PLR-N	-4948	-706	13.7
PMR-N	-2300	-2154	16.7
PI-N	-945	-1044	13.5
PL-45	-271	-1646	15.0
P-N	-66	-997	12.0
D-ON	328	-230	9.0
P-S	826	-843	10.7
PMR-S	2979	-2373	16.5
PLR-S	5624	-1789	14.0

L. Stations Used in Nutrient Addition Experiments

STATION NAME IN DATABASE	MRC COORDINATE (M) X	Y	DEPTH (M)	GENERAL AREA
SMK45	-4943	-738	13.5	SMK

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Appendix C: Documentation of software

Any new programs used to analyze data from MRC data bases (i.e. data bases documented in the MRC's Data Standards Document) and leading to the creation of the Figures and Tables in this report, are documented in this Appendix in the following set of flow charts. Permanent copies of all these programs have been saved, and will be kept on a read-only space of the mainframe computer we are using while we continue to analyze data, after which they will be written to tape.

Tables and Figures that are not documented in these flow charts were taken from Final Reports to the MRC, and they are documented in the flow charts of those reports.

Flow charts of the program logic for the tables and figures requiring new analyses.

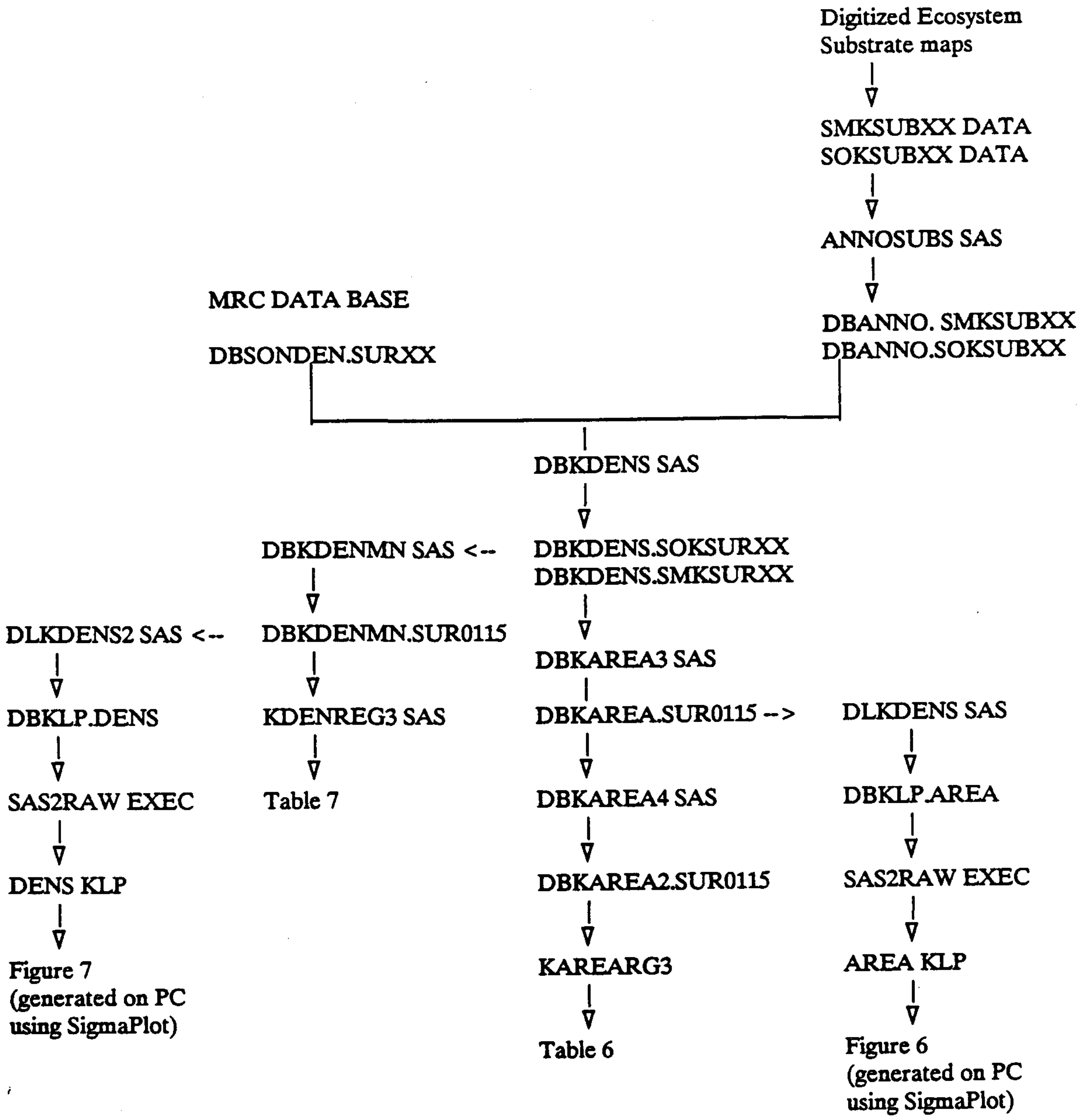
Analysis of SONGS' operating history.

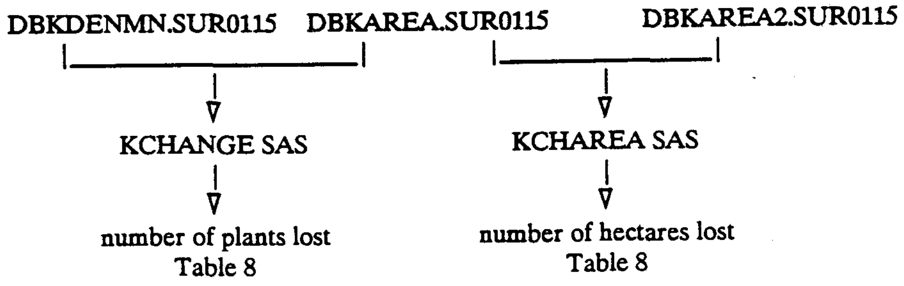
Table 5.

DBSONGS.YRXX
|
∇
OPHIST SAS
|
∇
Table 5

Analysis of down-looking SONAR data.

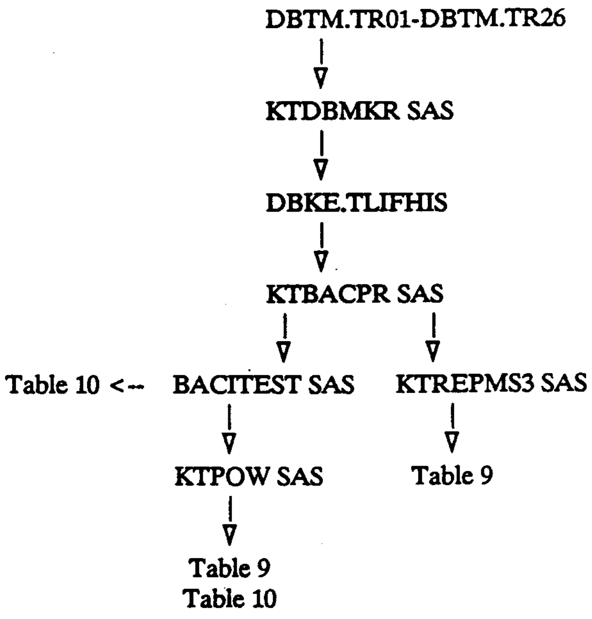
Table 6, Table 7, Table 8, Figure 6, Figure 7.





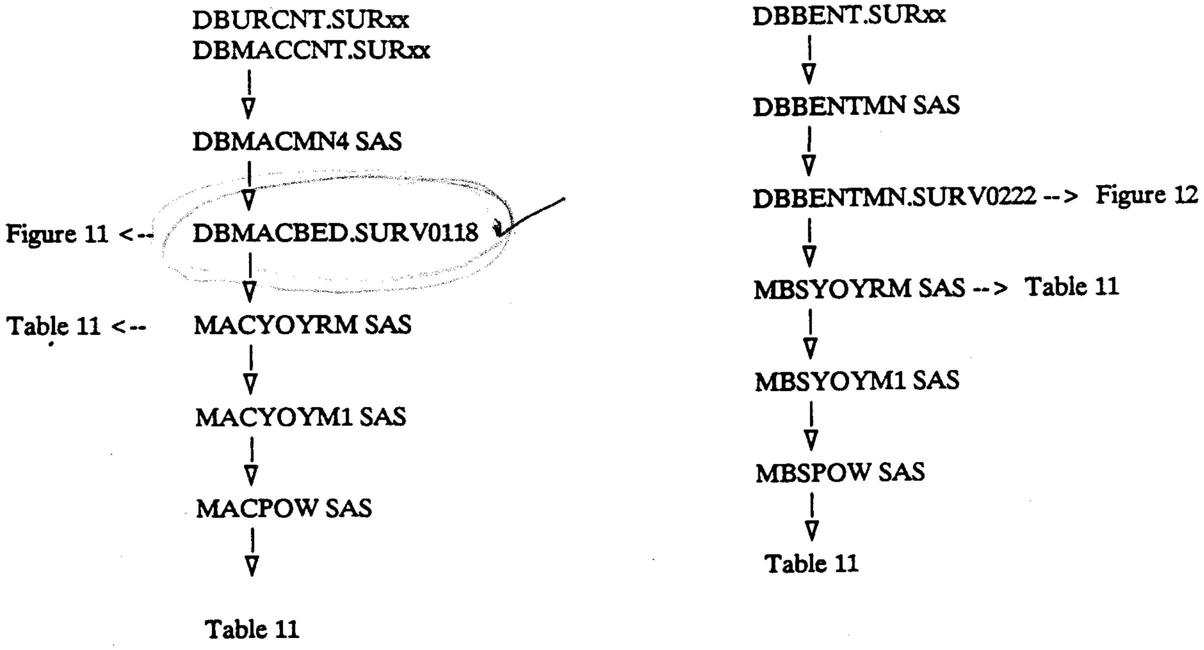
Programs and data bases used in analyses of adult kelp transect density, recruitment, and mortality.

Table 9, Table 10.



Programs and data bases used in analyses of kelp young-of-year recruitment.

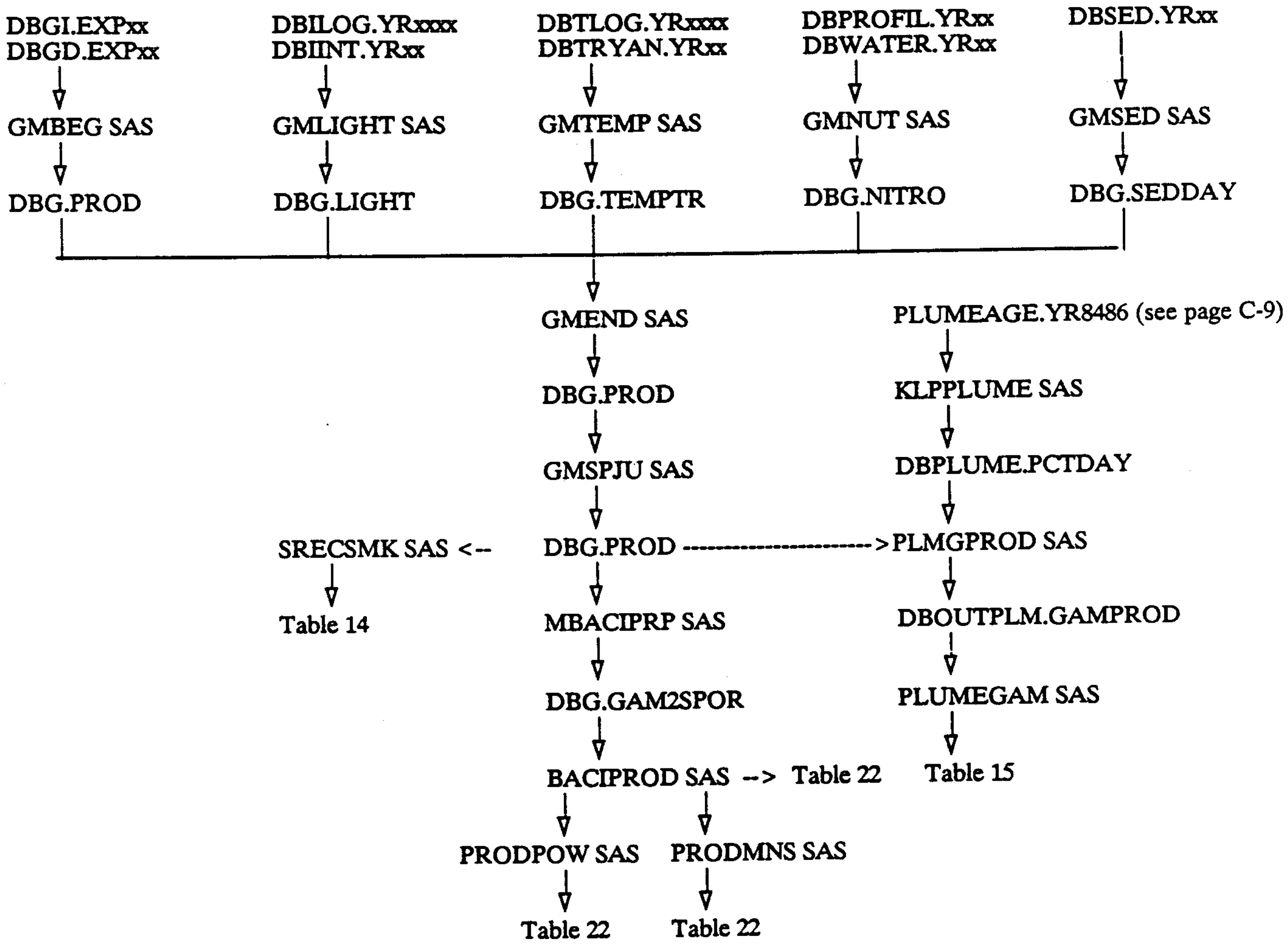
Table 11, Figure 11, Figure 12.



Programs and data bases used in productivity of sporophytes.

Table 14, Table 15, Table 22.

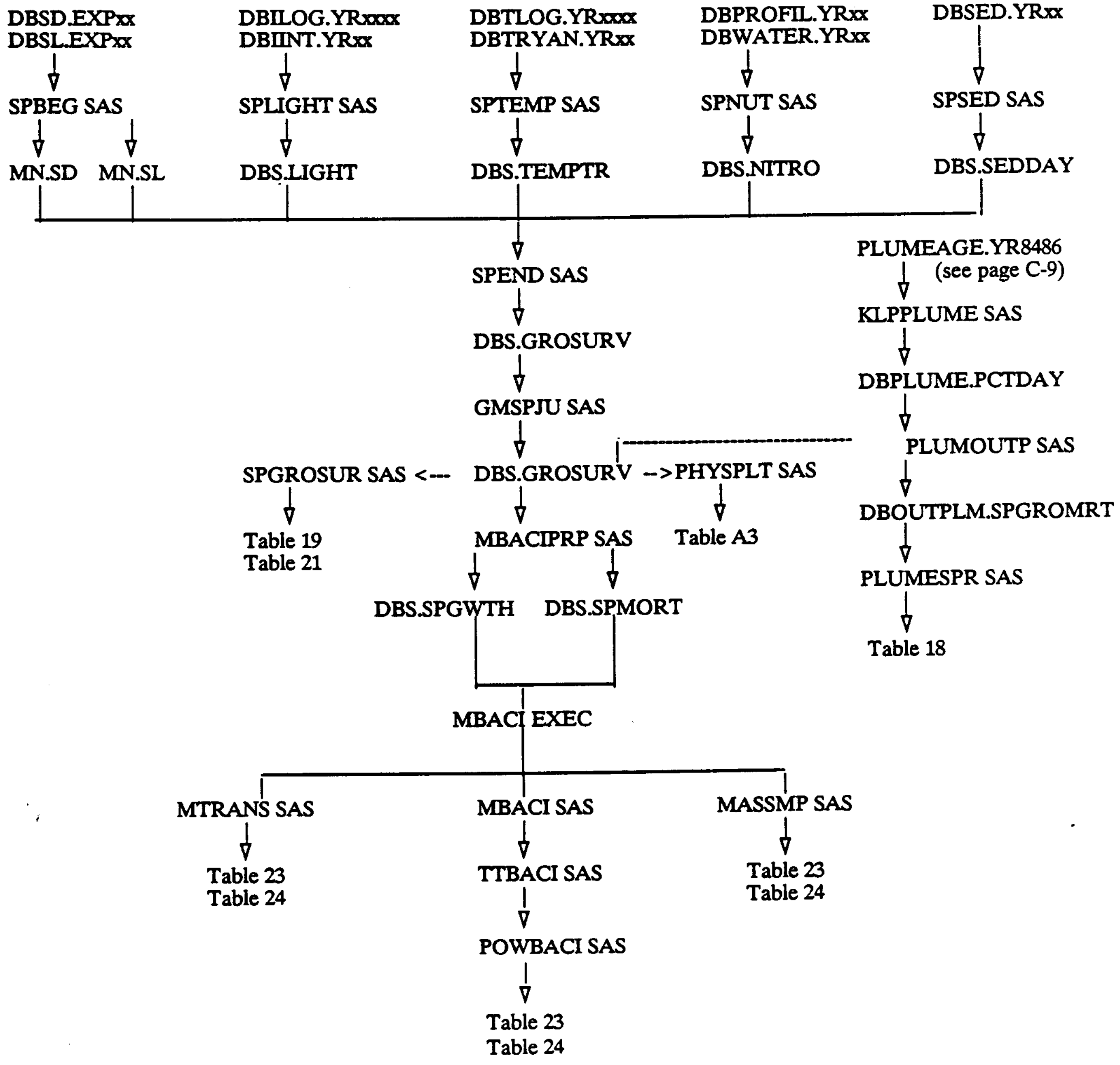
DBTLOG.YRxxxx --> GMTEMTST SAS
DBILOG.YRxxxx --> GMLTST SAS



Programs and data bases used in sporophyte mortality and growth.

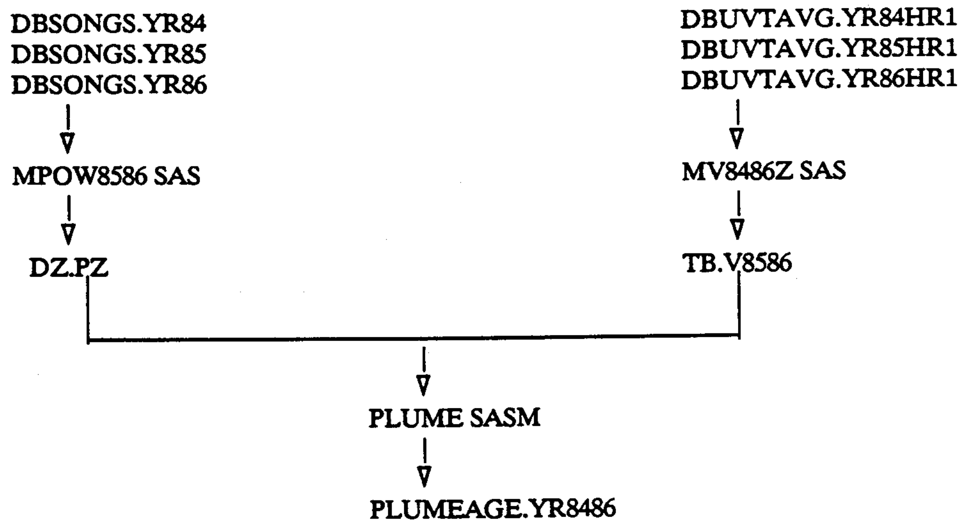
Table 18, Table 19, Table 21, Table 23, Table 24, and Table A3 (in part).

DBTLOG.YRxxxx --> GMTEMTST SAS
DBILOG.YRxxxx --> GMLTST SAS



Flow chart for creating PLUMEAGE.YR8486

Used in flow charts of Tables 15 and 18.



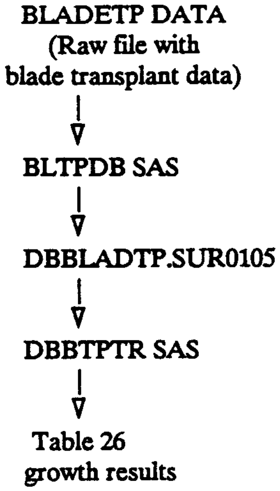
Analysis of white sea urchin densities near KEP SOKU45 and SOKD45 stations.

Table 25.

DBURCNT.SUR01 to .SUR07
DBMACCNT.SUR01 to .SUR11
↓
DBMACMN4 SAS
↓
DBMACSTA.SURV0118
↓
URMACTAB SAS
↓
Table 25

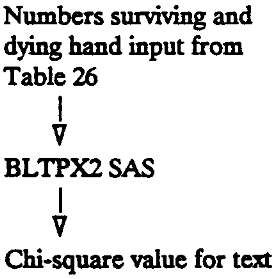
Programs and data bases used in analyses of 1986 blade transplant experiment.

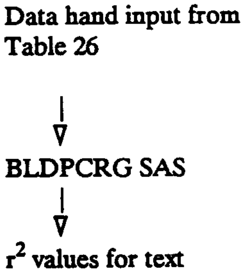
Table 26.



Comparison of mortality of blades in SMK, SOKN and SOK.

Regressions of blade mortality and growth against irradiance, temperature and seston flux.





Programs and data bases used in juvenile growth.

Table 31, Table 32.

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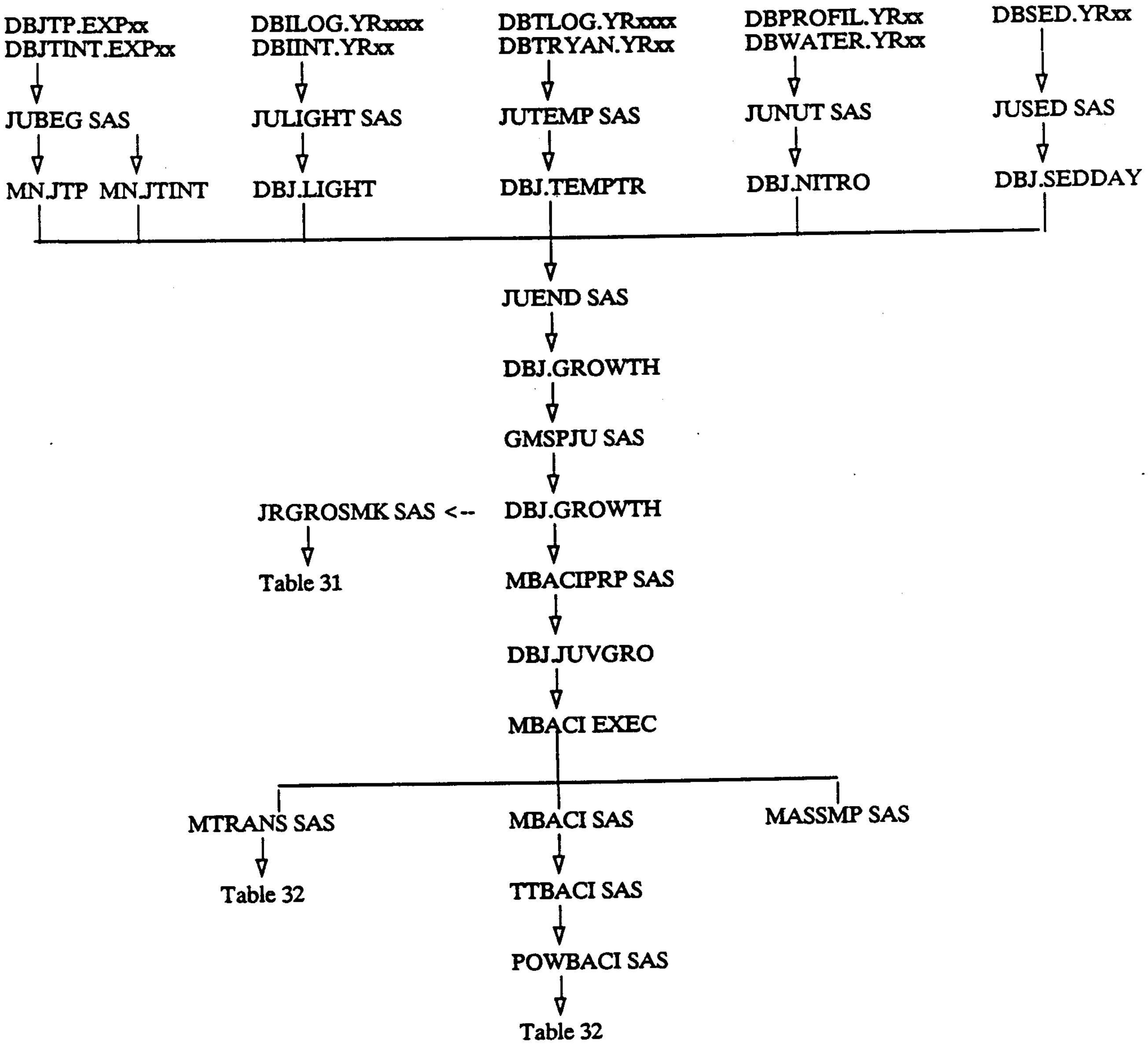
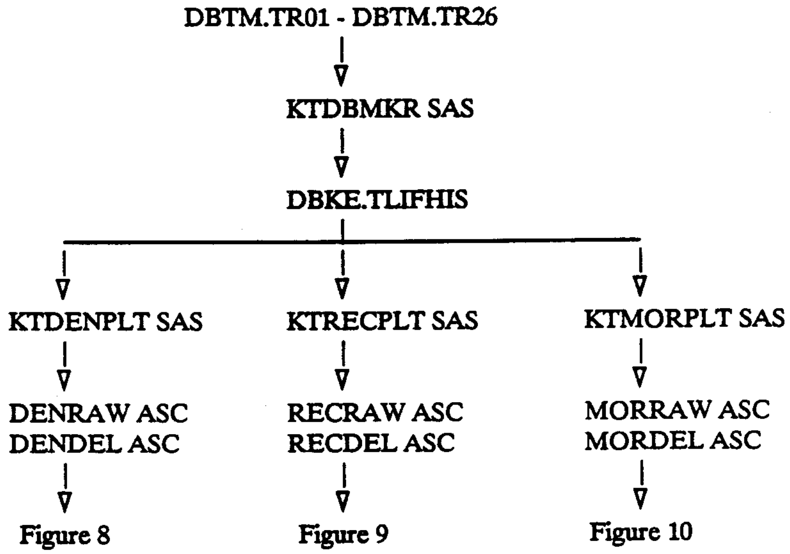
DBILOG.YRxxxx --> GMLTST SAS



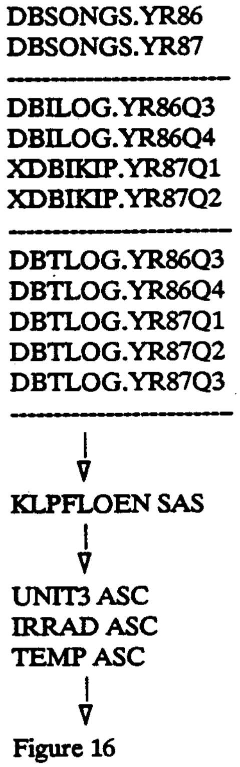
Programs and data bases used in producing plots of adult kelp transect density, recruitment, and mortality data.

Figure 8, Figure 9, Figure 10.



Programs used to prepare Figure 16 depicting discharge volume at Unit 3 and irradiance and temperature values near SONGS.

Figure 16.



Programs and data bases used in productivity of sporophytes, and analysis of seston flux.

B. Table A1, Table A2, Table A3 (in part).

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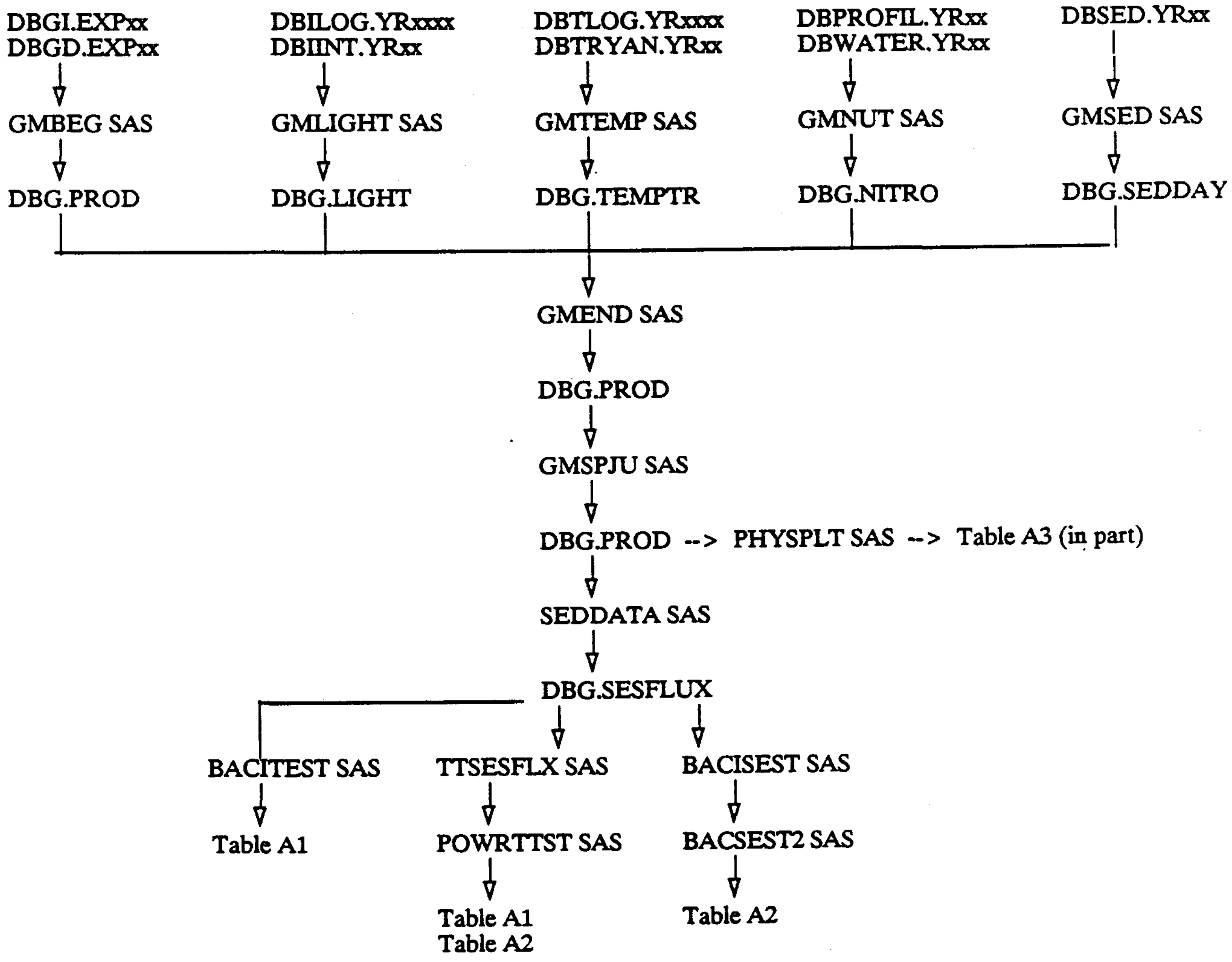
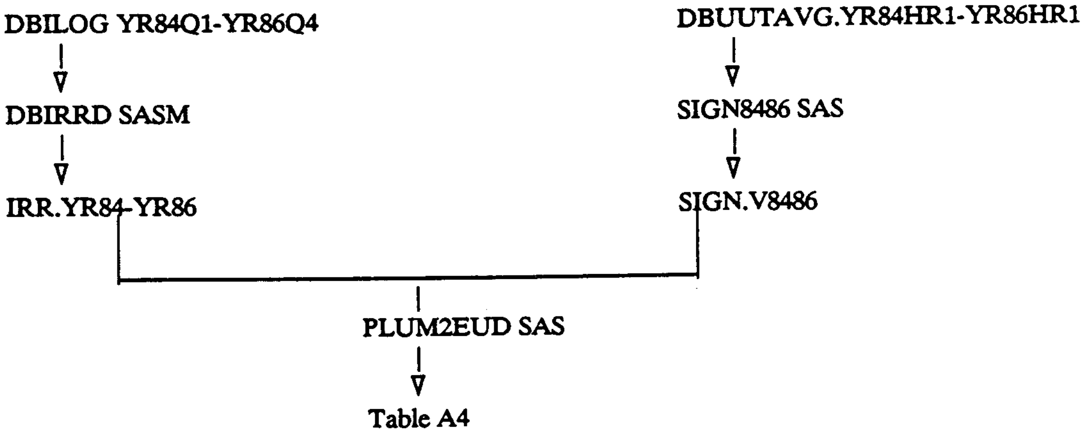
DBILOG.YRxxxx --> GMLTST SAS



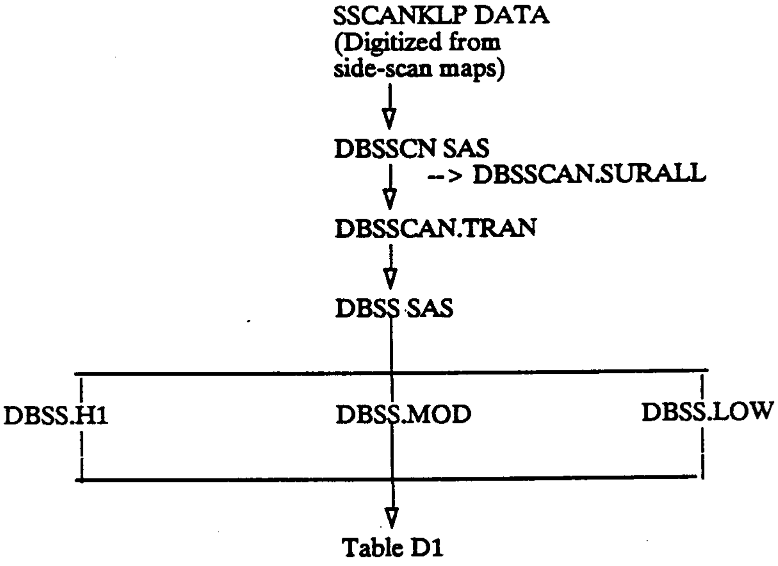
Programs and data bases used in analyses of extinction.

Table A4.



Programs and data bases used in analysis of side-scan SONAR kelp data.

Table D1.



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Appendix D. Analysis of side-scan SONAR data.

Side-scan SONAR was done over a fixed area in both SMK and SOK on 25 surveys from 1978 through 1989. The area surveyed in SOK is referred to as SOK-3 on the side-scan maps and is a somewhat smaller area than was surveyed by down-looking SONAR. It extended from the MRC X coordinates 0 to 2000, and from the Y coordinates -500 to -2000. Other areas that might be included as part of SOK were surveyed at times, but are not included in this analysis because they were not mapped on all surveys. The area of SMK is called either SMK-2 or SMK on side-scan maps and extends from the MRC X coordinates -3500 to -5500 and from Y coordinates of 0 to -1500.

For each survey, areas with some kelp greater than one meter tall, moderate to high kelp density greater than one meter tall, and high kelp density greater than one meter tall, were demarcated on maps (Reitzel *et al.* 1987 b). We digitized these areas.

In our analysis we break the data into Before and After surveys, with surveys with midpoints on or after May 1, 1983 being classified as in the After period. We then calculated the difference between the log transformed SOK (impact) and SMK (control) areas. We used log transformations because untransformed data were not additive. We then applied the BACIP t-test after verifying that assumptions of the test were not violated.

The results show that the area with kelp in SOK experienced a substantial and statistically significant reduction, relative to the area with kelp in SMK. This is true whether we consider the area with some kelp, moderate to high density kelp, or just high density stands (Table D1). The percentage losses range from about 50 to 70% with the largest loss being estimated for the highest density category.

Table D1

Results of BACIP tests on areas with different kelp densities based on side-scan SONAR data. All data were log (x + 1) transformed because untransformed data were not additive. Means are backtransformed, and percent change is based on a multiplicative model.

	MEAN VALUES					
	BEFORE		AFTER			
CATEGORY	CONTROL	IMPACT	CONTROL	IMPACT	P	% CHANGE
High Density	326,685	559,672	341,826	187,288	0.0001	-68.0
Moderate to High Density	543,912	962,392	534,101	433,335	0.0001	-54.1
Kelp present at non-negligible density	602,943	1,171,000	761,519	745,886	0.0001	-47.4

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[illegible] 5KB

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APPENDIX E

ADDITIONAL TECHNICAL INFORMATION AND RESPONSES TO QUERIES REGARDING KELP

Prepared by:
James R. Bence
Stephen C. Schroeter
John D. Dixon
Thomas A. Dean

August 1989

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ADDITIONAL TECHNICAL INFORMATION AND RESPONSES TO QUERIES REGARDING KELP

1.0 Introduction

A number of issues have been raised during the drafting of the MRC's summary of the effects of SONGS on kelp that need to be addressed. Our purpose here is to review the available evidence in an attempt to answer these questions. There appears to be general agreement that SONGS has reduced light levels on the bottom and increased seston flux in SOK and that this has affected giant kelp. Concerns center on whether one can estimate the size of SONGS' effects based on a comparison of the dynamics of SOK with SMK, and this is the subject emphasized here.

We believe that the use of SMK as a control forest was reasonable, that the evidence that SMK and SOK tracked one another well in the Before period is convincing, and that the relationship between SMK and SOK changed after SONGS Units 2 and 3 began operations. Of course, a variety of natural factors have localized effects, and this adds uncertainty to estimates of the magnitude of the losses due to SONGS. Natural variability in the relationship between SOK and SMK is perhaps the major potential source of error in the estimated losses due to SONGS, being even more important than sampling variability. However, the results of the MRC's studies need to be acted on, and such actions require a single best estimate of losses. Although we have provided such estimates, we caution that the actual long-term losses could easily be larger or smaller than our estimates. Furthermore, the errors are probably asymmetrical. We have no way of estimating the magnitude of the error, but suspect that our estimates of losses may be 50%

lower, but they probably can be no more than 10% higher. This is partly because the upper bound of potential increase in SOK is limited by the availability of substrate, especially during good years for kelp, as have occurred recently. Nonetheless, the estimates are reasonable ones, mechanisms for the proposed SONGS effects have been identified, and alternative factors cannot account for the bulk of the estimated losses.

2.0 Concerns Regarding Kelp

2.1 Substrate availability

One possibility raised by reviewers was that there was insufficient substrate at SOK to support a kelp bed 150% larger than existed in the After period (the bed size predicted if there were no effect of SONGS). The argument suggests that the available substrate at SOK would be saturated with kelp well before the predicted levels were achieved. Discussion in the main text, along with additional information given below suggest that this is not the case.

A lack of "saturation" of available substrate at SOK in the After period was indicated by SONAR data that show that the average area occupied by moderate to high density kelp during the After period (starting in May 1983) was substantially lower than the maximum values seen over the ten year period these data were collected (Figure E-1). When the area occupied in SOK is plotted against the area occupied in SMK, it is clear that for areas of moderate to high density, SOK generally tracked SMK both in the Before period and in the After period (Figure E-2). That is, surveys with higher values at SOK also yielded higher values at SMK.

However, less area was occupied in SOK, relative to SMK, during the After period than in the Before period. This indicates that substrate which supported kelp in the Before period in SOK was not occupied in the After period.

A lack of saturation is also suggested by the spatial patterns observed in the After period, as indicated by both SONAR maps and aerial photos. Most of the upcoast offshore portion of SOK, which had substantial kelp populations throughout the Before period, had little or no kelp in the After period. Furthermore, the area occupied in SOK tracked the area occupied in SMK rather than approaching an asymptote.

It is possible that an asymptote in the area occupied by moderate to high density kelp (greater than 4/100 m^2) would be reached somewhere between the present area and the predicted area, if there were no SONGS effect. Assuming that there would be no increase in substrate, an increase in area of dense kelp at SOK that was equivalent to the observed increase in SMK in the After period would require that about 80% of the available substrate at SOK be covered with kelp, in densities in excess of 4/100 m^2. We have no reason to suspect that 80% coverage could not be achieved. However, it is conceivable that saturation occurs below the 80% level, and we have no way of precisely estimating the saturation level for kelp. We do know that at SMK in the After period, an average of 63% of the available substrate was occupied by densities of kelp greater that 4/100 m^2, and that there was no indication of saturation. If we use this 63% value as a conservative estimate of the maximum level of substrate coverage achievable at SOK, then the relative losses of kelp at SOK can still be estimated at about 50%. This is well within what we feel are the prescribed margins of error for our "best" estimate of 60% losses.

There were also some questions raised about the possible effects of shifting sand on substrate availability in SOK. Sand patches in SOK unquestionably shift from time to time, and there is little doubt that sand can kill adult kelp and prevent kelp recruitment. Some anecdotal evidence also suggests that there may be more sand movement in SOK than SMK. However, there is no evidence that the incidence of burial by sand increased in SOK in the After period.

2.2 Competitors and grazers

It was also suggested that although there may be sufficient hard substrate available at SOK, that much of it may be unsuitable for kelp recruitment and survival because of the presence of high densities of competitors (understory kelp species) or grazers (urchins). While the potential importance of these factors is clear, there is little evidence to suggest that either is responsible for other than a small fraction of the relative decline in kelp observed at SOK.

We have data from 1988 that indicate that there was in fact an increase in understory algal abundance at SOK and a decrease in abundance at SMK. Densities of *Pterygophora* averaged almost $6/m^2$ in SOK and were as high as $30/m^2$ in the inshore, downcoast portion of SOK. *Cystoseira* densities increased to an average of almost $4/m^2$ in SOK and were also highest in the inshore, downcoast part of the bed. However, it is unclear whether this was a cause or an effect of the disappearance of kelp in SOK. The lack of an overlying canopy at SOK may have promoted the recruitment of these "lesser" kelps.

Whatever the cause of the increase in understory at SOK, it is probable that these algae had little impact on the recruitment of giant kelp, especially in the upcoast offshore portion of the bed where giant kelp losses were heaviest. While the negative effects of dense stands of understory algae have been documented in other kelp forests (Reed and Foster 1984; Dayton *et al.* 1984), our data indicate no negative effects of these algae on kelp recruitment in SOK or SMK in the past. Analyses of transect and kelp recruitment data from 1978 through 1986 (Schroeter *et al.* 1988) indicate that there were no significant negative correlations between the abundance of understory algae and kelp recruitment.

Also, densities of understory algae in upcoast offshore SOK during 1988 were not particularly high: $2.8/m^2$ for *Pterygophora* and less than $1/m^2$ for large *Cystoseira*. The combined density of these two understory algae was lower than that observed in this part of the bed in the late 1970's for *Pterygophora* (Dean 1980) when we were unable to demonstrate an effect of these algae on *Macrocystis* recruitment, and extremely low relative to other kelp forests where interspecific competition has been demonstrated.

Even if we accept that there may have been an adverse effect of understory algae on kelp at SOK in 1988, increased understory during the After period still cannot explain the decline in SOK relative to SMK from 1983 through 1986. The higher densities of understory algae did not become evident until after the 1986 recruitment.

There is also no doubt that sea urchins can influence both the survival of adult kelp plants and the recruitment and survival of small plants. Work by MRC researchers established an effect of white sea urchins on the recruitment of small kelp plants, and showed that red sea urchins generally influence the mortality of kelp when the sea urchins form moving fronts (Dean *et al.* 1984). In that work, done from 1978-1981, it was shown that a feeding front of red sea urchins caused mortality within SOK, and that white sea urchins, located along the offshore margin of the kelp forest acted to inhibit the recruitment of giant kelp in some parts of that area of SOK.

Sampling at fixed quadrats indicated that the density of red sea urchins was generally much higher in SMK than in SOK both in the Before and during the After period, and that the densities of red sea urchins were about the same in upcoast SOK, and substantially lower in downcoast SOK, during the After period in comparison with the Before period (Technical Report F). Observations of red sea urchins indicated that they formed feeding fronts within SMK during 1986-1987, but not within SOK (Dixon *et al.* 1988).

Sampling at these same stations indicated that the density of white sea urchins substantially increased both in offshore SOK and offshore SMK. The increase was small in upcoast SOK and much larger at the sampling stations in downcoast SOK and in SMK (Technical Report F, Figure 4r). Similar observations were made by Elliot (1988). The above provide no evidence that sea urchin populations had a larger effect in SOK than in SMK during the After period.

2.3 Density estimates from SONAR and transect counts.

Patterns in density seen in these two data sets are somewhat different. This is expected given the differences in methodology. There are several reasons why such differences occurred: 1) The SONAR data cover a much larger portion of the area and therefore provide better estimates of density. This is especially true for SMK, since there were only four transects within SMK totalling 1200 m^2 compared to some 2.6×10^5 m^2 of SONAR tracks. 2) the transects were not located randomly, but were placed on hard substrate areas, with some at the edges of the kelp forests to be sensitive indicators of recruitment to new areas. 3) Down-looking SONAR can detect plants only once they have approximately 6-8 fronds and exceed two meters in height. After a recruitment when many smaller plants are present, divers on transects count many of the small adults that are undetected by SONAR.

An examination of the Down-looking SONAR records indicates that the recruitment event that caused adult density to peak on transects in SMK in 1985 (due to recruitment of smaller plants in 1984) also occurred in the SONAR data, but to a much reduced extent and was somewhat delayed. This is what we expect for a technique that estimates the density of larger plants, after self-thinning has occurred. It is reassuring that these two methods show interpretable trends that support one another.

2.4 Estimates of SONGS effects based on frond or biomass density.

Clearly the number of plants in a given area does not incorporate all the ecologically important information that could be collected. One very large plant probably contributes more (however we care to define contribute) than a single small plant. However, density is clearly an important variable, and it is the variable that the MRC predicted would be impacted by the power plant (via interruption of the production of new plants). Studies of kelp forest fish have shown that water column fish densities are indeed associated with the number of plants in a given area. Perhaps this could be improved by also including biomass in some way, but it is not obvious that biomass alone would be a better predictor of kelp forest fish densities or many other parameters of interest. As is true for plant density, it is clear that frond density or biomass does not encompass all the information one might desire. A single large plant is not the equivalent of many smaller ones, and a kelp forest made up of a few large adult plants is likely more prone to disturbances than a kelp forest of many smaller adult plants.

The above said, there is no evidence that the decline in density at SOK relative to SMK in the After period was compensated for by an increase in the average size of an adult plant in SOK. Some data on frond density is supplied by SCE. In most cases, these data appear sufficient to estimate the mean number of fronds per plant in SOK and SMK (exceptions are in SMK in 1986 when there were no plants measured and in both kelp beds in December 1988 when only 10 or fewer plants were observed). Estimates of plant density on the other hand, do not appear to be representative, especially at SMK where only 240 m^2 was sampled. This is equivalent to less than one of our transects, and we are reluctant to use density data from four transects to estimate absolute values of density in SMK. Because the SCE estimates of number of fronds per m^2 are a product of plant density and number of fronds per plant, the estimates of frond density also were poor estimates of bedwide frond density.

We can, however, use SCE estimates of the number of fronds per plant, along with our estimates of plant density, to give rough estimates of frond density at SOK and SMK. The SCE data set involves counts of the number of fronds per plant for plants greater than 2 m in height. These include counts of many newly recruited plants. As one might expect, the average number of fronds per plant decreased in SMK relative to SOK in 1983 and 1986, when there was more recruitment at SMK. It is not possible to examine the frequency distribution of sizes, but we suspect that the mean number was lower at SMK because of the addition of small plants.

The biggest difference in average number of fronds per plant between the two beds occurred in late 1986. During this time (omitting the Sept. 1986 0 reading from SMK), the largest difference in number of fronds per plant was in November or December, at which time the plants at SOK had, on average, twice as many fronds per plant. At the same time, there were a large number of newly recruited plants in both beds that were mostly 2 m or greater in height. Most of the plants present were young of the year (greater than about 10 to 1, young of the year to established adults). Densities at SMK at this time were about three times higher than in SOK (Main Text: Figures 7 and 11, pages 136-139 and 152-154). Thus, even with selection of data that maximized differences in frond density, the increases in plant density more than compensated for decreases in number of fronds per plant.

It is still somewhat interesting to speculate whether an increase in plant size could compensate for decreases in density at SOK. There is some evidence that such compensation occurs in sheltered kelp beds to the north in Santa Barbara and along the Big Sur coast. Also, the canopy in the offshore portions of Barn kelp, prior to the die off in 1980, was formed by low densities of large plants. However, it seems unlikely that such a circumstance could occur at SOK.

An increase in plant size can result from three possible mechanisms 1) a decrease in the rate of frond loss 2) an increase in the frond initiation rate, or 3) a decrease in the mortality rate of adult plants. The only available evidence on frond mortality/initiation rates suggests that the net rate of frond addition may be lower at SOK compared to SMK. In 1986-87, adults transplanted to SOK lost fronds while those at SMK gained fronds (Main Text: Table 33, page 122). The difference in net change among the beds was significant. Also, there are no data indicating that mortality rates were lower in SOK than SMK. In fact, the tendency is for the opposite to be true.

Even if there is some future decrease in adult mortality rate at SOK, it is unlikely that the increase would be large enough to compensate for a decrease in plant density. Unlike kelp beds in sheltered areas to the north, or presumably in offshore Barn kelp, mortality rates of adults in SOK are high, with the average adult surviving for less than 2 years. This probably results from the exposed nature of the bed (relative to sheltered sites in Santa Barbara and Big Sur), and the unstable cobble bottom. It is extremely unlikely that a substantial bed could form at SOK that was largely composed of plants more than 4 or so years of age.

2.5 Reduced recruitment of small plants

It has been argued that our estimated reduction in recruitment of young plants in SOK was due to a combination of factors including 1) a reduction in recruitment inshore at SOK; 2) a depth specific El Nino effect which caused a lack of recruitment inshore, and; 3) an improper comparison of shallow areas within SOK with a combination of shallow and deeper sites in SMK. The evidence strongly argues against this interpretation.

There is little question that the reduction in the density of adult plants in SOK is largely due to the reduction in the production of smaller plants, and not to a substantial increase in mortality. (One or both of these factors must be responsible.) One can argue about individual results and comparisons, but the overall pattern is striking. There was a substantial decrease in the recruitment of blades and juveniles in SOK relative to SMK. There was also a similar reduction in the production of adult plants. We did not see such changes in the mortality of adults, with the exception of inshore upcoast SOK. It has been shown that SONGS increases the concentration and flux of seston near the bottom in SOK, and that this leads to a reduction in irradiance reaching the bottom. These environmental changes have been tied to kelp biology. The production and success of small plants is positively related to light levels and negatively related to seston flux. Finally, we have shown that the production and success of small sporophytes are lower during times when they are more often exposed to plume waters.

The conclusion that the reduction in density of giant kelp stems from a reduction in the production of small plants comes from a variety of independent sets of field and laboratory data. Although the offshore reductions in recruitment of blades, juveniles and adults were not statistically significant alone, the estimated reductions were substantial, and the lack of significance could easily have stemmed from low statistical power. Failure of recruitment offshore was also indicated by examination of small life stages on cobbles and by transplant experiments. The reductions in recruitment offshore certainly contributed to the overall reduction in recruitment estimated for SOK.

Reductions in recruitment in SOK were not depth related. The sizes of the reductions in recruitment in SOK were approximately equal inshore and offshore. Inshore effects were significant while offshore effects were either nearly significant or not significant. We did not test for differences between inshore and offshore, but given the nearly identical size of the reductions in the two areas (see Main Text: Table 11, page 100) it is obvious that no statistically significant difference exists.

The lack of a depth related effect was also observed at SMK. In preliminary analyses, we distinguished inshore and offshore SMK. Because this reduced samples sizes in SMK (where there were fewer stations to start with), and because pooling the stations did not substantially influence the results, this procedure was not followed in later analyses (Schroeter *et al.* 1988).

The failure of recruitment at SOK (both inshore and offshore) appeared to be unrelated to the El Nino. We saw lower recruitment of young plants in SOK than in SMK throughout most of the After period, including 1986 and 1987 (see Main Text: Figures 11 and 12, pages 152-157). It is unlikely that factors related to the 1982-1984 El Nino could be inhibiting recruitment of young giant kelp at these times.

2.6 Potential Positive effects of SONGS' Plume

Arguments have been advanced that the long-term effects of SONGS' diffusers may be less than that suggested by the observed reductions in light and increases in seston flux and concentration associated with the plume. The theory is that the negative effects are more than compensated for by artificial upwelling created by the diffusers, which move bottom water toward the surface and by moving offshore water inshore. In fact, the MRC predicted that such upwelling would occur (Murdoch *et al.* 1980).

The available physical evidence argues that such artificial upwelling is much smaller than was originally predicted and only has a measurable effect near the surface, and not on the bottom (also see Main Text: 5. Discussion, pages 68-76). Nutrient concentrations and water temperature were negatively correlated, and the relationship was largely independent of depth (Technical Report K). Analyses of bottom temperature found no significant BACI effects suggesting that any effect of upwelling is likely to be small (less than a few tenths of a degree C). Analyses of surface temperature suggest that effects there are small also. There is some indication that the nearest station to the diffusers (about 600 m from the diffusers) has lower temperatures during the winter when it is classified as being in the plume. (These analyses were done by H. Elwany for S. Swarbrick as part of the compliance study.) This effect during winter months is less than 0.5 degrees, and over all months the effect is negligible.

There is no evidence the clearer makeup water is colder and richer in nutrients. The plume analyses described above in fact indicate that it is slightly warmer than downcoast water during the winter. However, the possibility that the temperature-nutrient relationship is different in the plume has not been explored.

The possibility of an increase in water clarity upcurrent of the diffusers was addressed in some detail in Technical Report K. There is, in fact, evidence that such an effect exists. However, the data are unavailable to make sound quantitative estimates of this effect. Our best estimate is that the increase in irradiance upcurrent of the plume is about half of the decrease in irradiance downcurrent of the plume.

It has been argued that the appearance of giant kelp inshore and about one km upcoast of the diffusers during the past few years may be due to the action of the diffusers. We do not think that it is reasonable to conclude that SONGS is responsible for the recruitment of this kelp, or that we can assume that a kelp forest in this area will become a permanent fixture of the local environment. Analyses of the physical environment indicate that the SONGS plume does influence areas this far from the diffusers. However, our estimates of the effects on irradiance suggest that the overall change in irradiance is likely to be small. The available evidence suggests that any small artificial upwelling effect that does exist is unlikely to occur at this distance from the diffusers (see above). Analyses of the density of giant kelp on hard substrate just upcoast of the diffusers provided no evidence for an increase in the kelp population there. Thus, it seems unreasonable to expect positive effects further from the diffusers. Finally, giant kelp existed in the rather extensive stands in the inshore area upcoast of diffusers in 1950 (Deysher 1978). Most of this apparently disappeared during the 1957-58 El Nino. Kelp has reappeared in many shallow areas throughout Southern California during the past few years. Thus it seems most likely that the appearance of giant kelp in this relatively shallow water north of San Onofre during the 1987-1989 period is a response to large-scale changes. The evidence discussed above suggests that giant kelp populations in this shallower area is even more dynamic than the kelp populations in SMK and the main part of SOK, and its appearance should not be regarded as good evidence for a positive effect of the power plant.

2.7 Validity of SMK as a Control

It is known that nearby kelp forests can display qualitatively different dynamics and it was a concern about the possibility of such "time by location interactions" that caused the MRC to emphasize a mechanistic approach in its kelp studies. Nevertheless, evidence that SOK and SMK tracked each other well in the Before period definitely strengthens any inferences based on comparing their dynamics in the After period. Above we noted that side-scan data demonstrate that area with moderate to high kelp density tracked well in both the Before and After periods. Other concerns are addressed below.

It has been argued that the long term dynamics at SOK and SMK, as evidenced by aerial photos, argue against SMK representing a good control for SOK. The areas covered by kelp canopies as seen in these photos has been digitized (see North 1988) and plotted through time in Figure E-3. We are somewhat hesitant to use these data as either evidence for or against a SONGS effect. Canopy coverage as observed from an aerial photograph is much more variable and dynamic than counts based on SONAR or diver surveys. Significant variation can occur because of seasonal growth and die back of fronds. The detected canopy coverage can depend upon short-term weather conditions. As a result, the areas given probably have significant error. Some of these errors have been compensated for by selecting photos that represent maximal coverage in a given year. However, this creates a somewhat different problem. Comparisons of SOK and SMK in some cases use surveys separated by 6 months or more. Thus, temporal patterns are confounded with spatial patterns of canopy.

These potential sources of error aside, we feel that the aerial photo data provide information on canopy cover and probably reflect well the broad scale patterns in canopy cover over time. General trends in kelp abundance as seen in the SONAR and transect data are generally seen in the canopy plots: SMK and SOK track each other relatively well over time, peaks in canopy generally occurred coincident with or shortly after peaks in density, and there was generally higher abundance at SOK in the Before period and at SMK in the After period. Also, the aerial photos clearly show a loss of kelp in the upcoast-offshore portion of SOK that occurred during a period when kelp populations elsewhere were flourishing.

While these general patterns are the same for canopy and density data, there is no reason to expect that there should be a strong correspondence between density and canopy cover in a given survey. These are quite different parameters that reflect different characteristics of the kelp population. As a graphic example, we noted an almost total disappearance of kelp canopy in SOK and SMK in late summer 1983 (Schroeter and Dixon 1984, Figure 44) . At the same time, we did not notice a large increase in plant mortality nor a decrease in plant density.

The aerial photo data provide some evidence for a time by location interaction with regard to canopy cover in the Before period. There was a larger canopy cover at SOK from 1974 to 1977 and larger cover at SMK from late 1977 through early 1981. This could be the result of sampling error, or could be real. However, even if real, this does not indicate that there was a *similar* interaction with regard to plant density. In fact, evidence from side scan SONAR records indicate that from 1978 through 1981, the area covered by high density of kelp was always greater at SOK than SMK.

2.8 El Nino effects

If during events such as El Nino, the change in the physical environment was substantially different at SOK than that at SMK, the latter would be a poor control area. Some evidence arguing against a differential effect of the El Nino at SOK and SMK was given in 2.4 above. Additional evidence is reviewed below.

Reviewers have suggested that the apparent effects of SONGS were due to adult mortality resulting from exposure to warm, nutrient poor water during the El Nino. The argument suggests that the effects were worse at SOK because there was less upwelling there. Neither the physical nor biological data support this hypothesis. The records indicate that temperatures in the two kelp forests changed in the same manner from the Before period, through the El Nino, and throughout the remaining part of the After period. Temperature and nutrient concentrations were highly correlated throughout.

Adult mortality rates were higher at inshore SOK than in SMK during the El Nino. However, there was no indication of higher temperatures at SOK, and the higher mortality can best be ascribed to either an effect of SONGS or an interactive effect of El Nino and SONGS.

No differences in mortality were observed in offshore portions of SOK and SMK during the El Nino or later in the After period. Therefore, the loss of kelp in the upcoast offshore portion of SOK, which account for most of the 60% relative decline in kelp at SOK in the After period, cannot be associated with losses during the El Nino.

The effects of storms on the two kelp forests also appear to be similar. There was approximately equal rates of mortality of adult kelp at the two kelp beds during the extreme storms of 1983.

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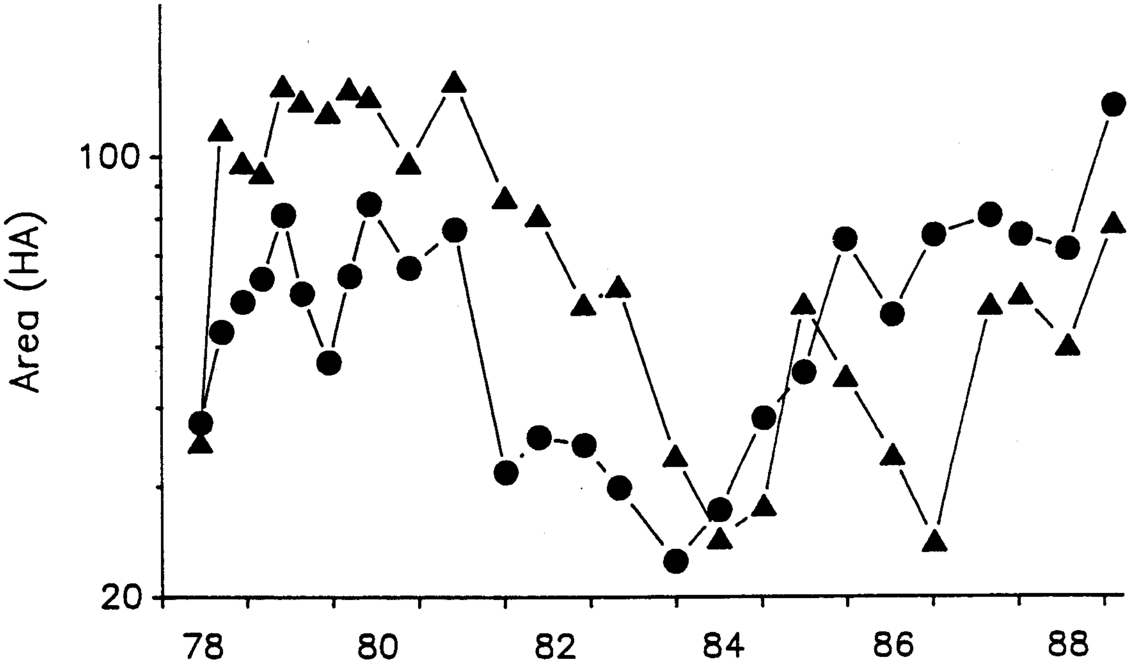
APPENDIX E - FIGURES

Figure E-1: Area covered by moderate to high density giant kelp as detected by side-scan SONAR at San Onofre kelp bed (indicated by ▲) and San Mateo kelp bed (indicted by ●).

Moderate to High Density Kelp



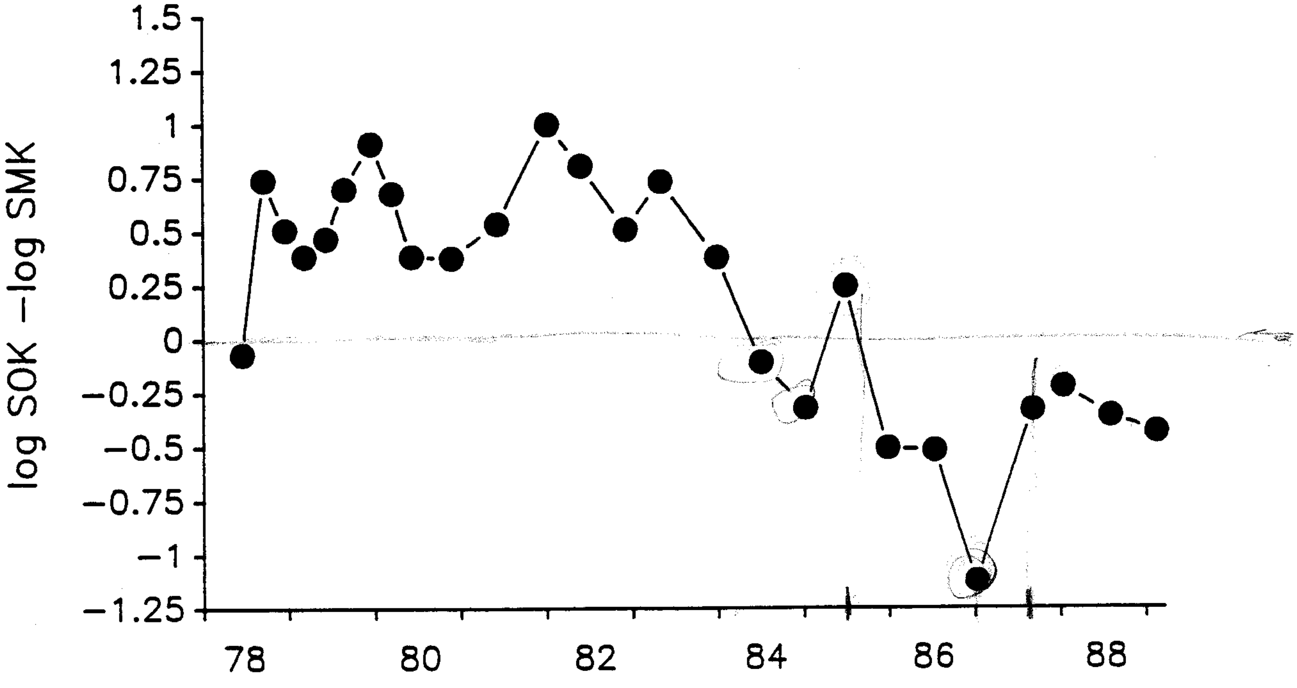


Figure E-2: Area occupied by moderate to high density giant kelp in SOK plotted against the area occupied by moderate to high density giant kelp in SMK.

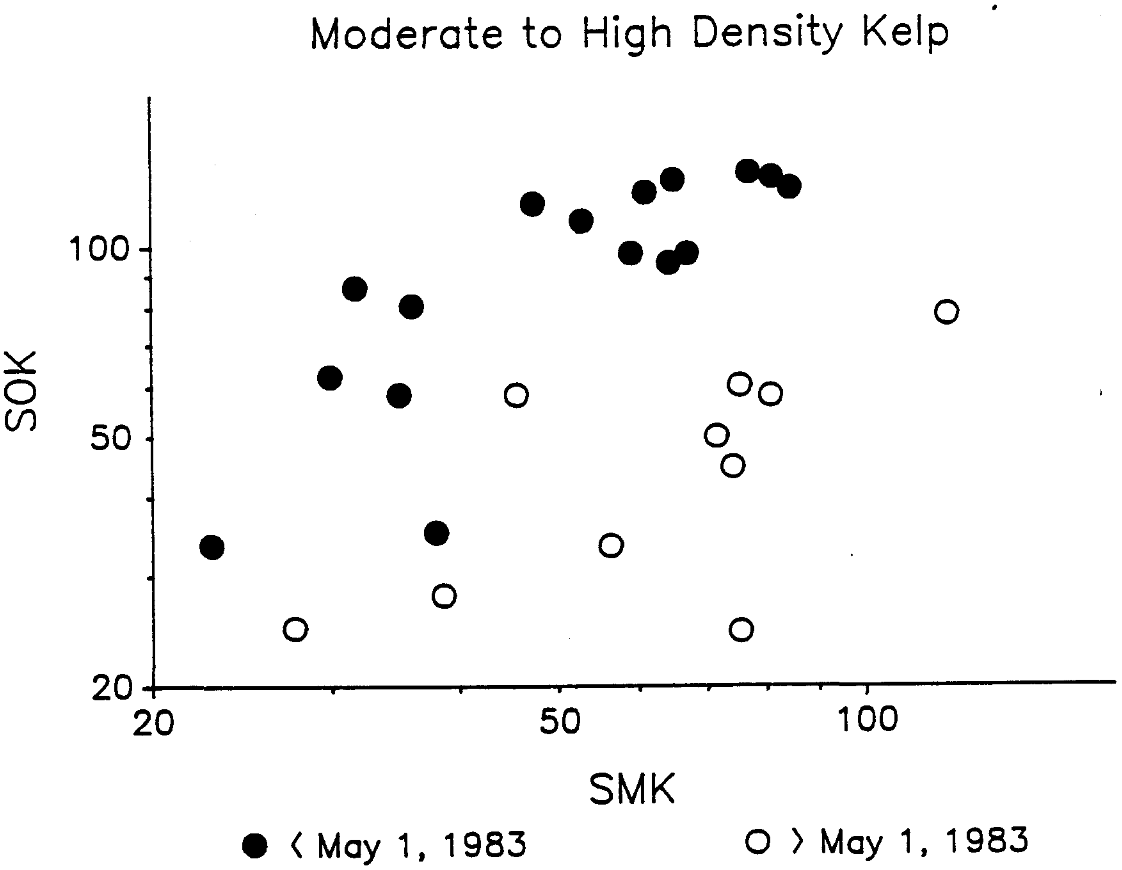
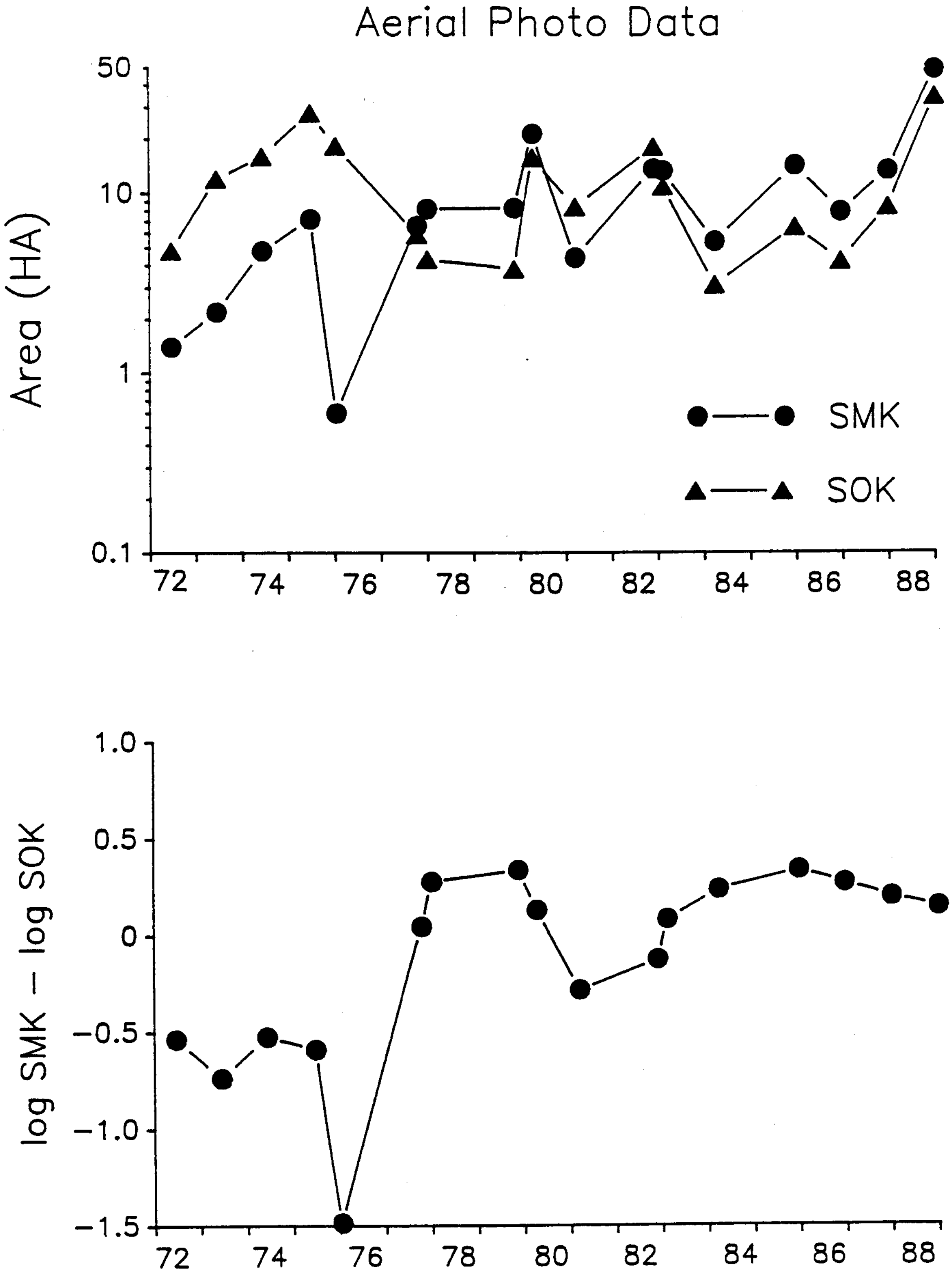

Moderate to High Density Kelp
SOK
100
50
20
20
50
100
SMK
● < May 1, 1983
○ > May 1, 1983

Figure E-3: Area covered by a surface canopy of giant kelp in SOK and SMK. Based on digitized aerial photo data reported in North (1988).


Aerial Photo Data
Area (HA)
50
10
1
0.1
72
74
76
78
80
82
84
86
88
SMK
SOK
log SMK – log SOK
1.0
0.5
0
–0.5
–1.0
–1.5
72
74
76
78
80
82
84
86
88