



The Effects of Discharges from the
San Onofre Nuclear Generating Station
on the Giant Kelp, Macrocystis pyrifera:
I. Background Information and the Biology of Kelp

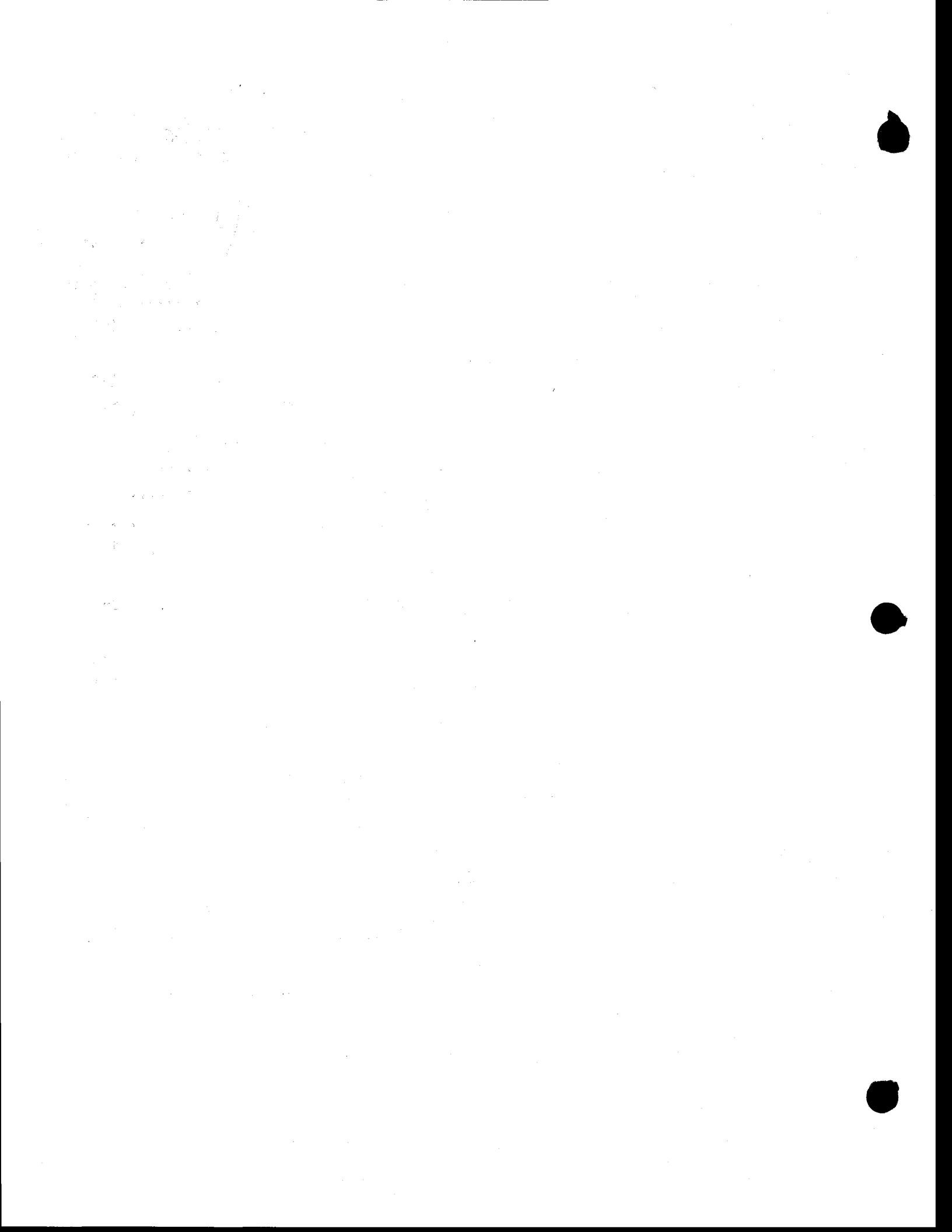
Final Report of the UCSB Kelp Ecology Project
for the Period
April 1978 through September 1987

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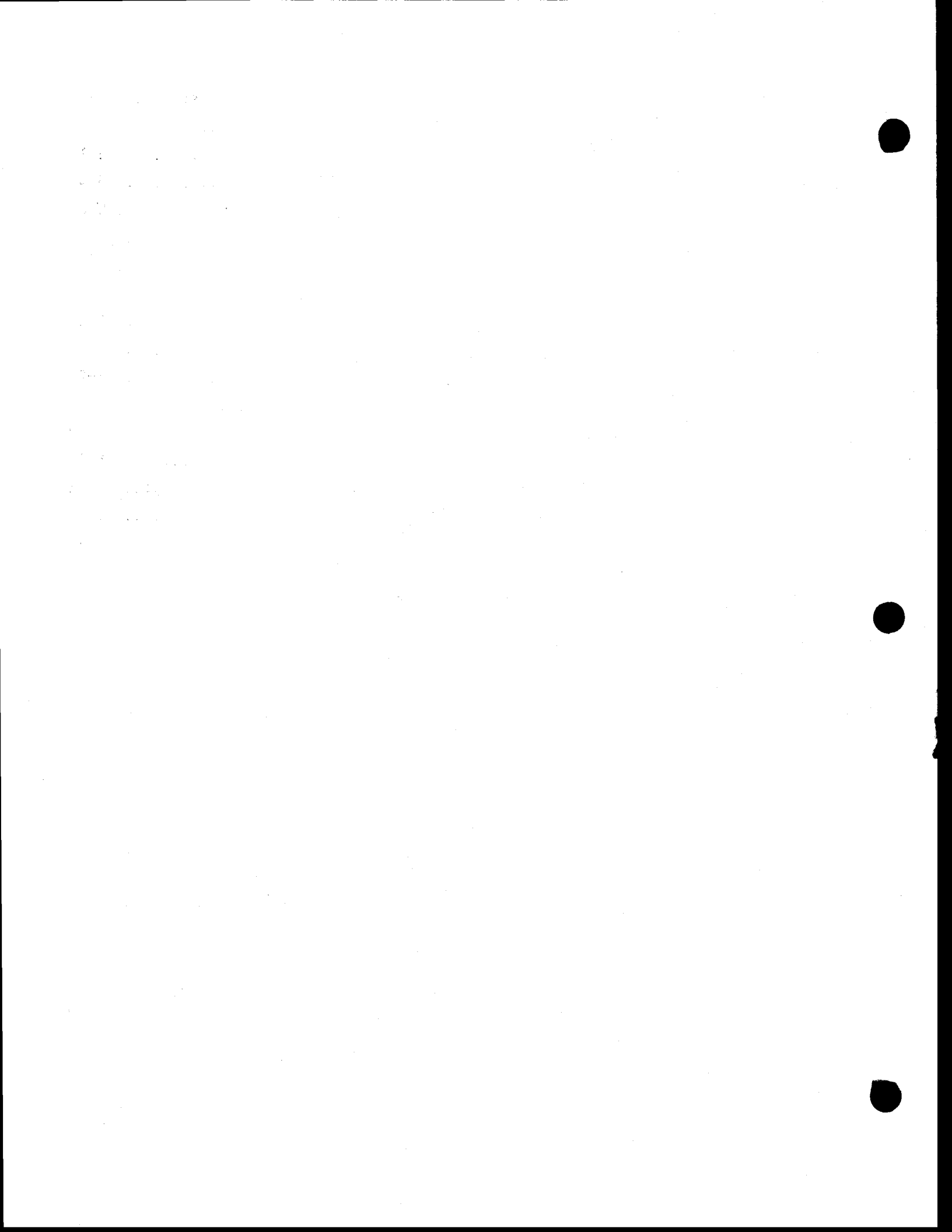
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I. Background Information and the Biology of Kelp

1.0 Introduction

1.1 Purpose

The UCSB Kelp Ecology Project has conducted studies at San Onofre since 1978. The primary goal of these studies has been to determine the effects of the San Onofre Nuclear Generating Station's (SONGS) Units 1, 2 and 3 on the giant kelp, Macrocystis pyrifera.

The final report for the project will consist of 2 documents. The first document is presented here and provides a description of the biology of kelp. It includes background information pertinent to the evaluation of the effects of SONGS. It is not intended to be an exhaustive review of the literature. More complete reviews have recently been published (Dayton, 1985; Foster and Schiel, 1985; North et al., 1986 . Schiel and Foster, 1986). This study focuses on the giant kelp, Macrocystis pyrifera, although much of the information on general life history attributes is also applicable to other laminarian algae, including the local subcanopy species Pterygophora californica. Studies in the San Onofre region are stressed because these are of direct interest in evaluating the effects of SONGS. An evaluation of the effects of SONGS on kelp will be presented in a separate document presented jointly with the USC Kelp Invertebrate Project and with ECOsystems Management Associates. A detailed description of our overall study plan and the underlying rationale for this plan are outlined later in this chapter. First, we present a brief overview of the life history of kelp, a history of the kelp forests



near SONGS and a description of these kelp forests in relation to other kelp forests in the region.

1.2 Life History of Kelp

The giant kelp, Macrocystis pyrifera, is a key species in the nearshore subtidal ecosystem in Southern California. The kelp forest habitat is structurally dominated by Macrocystis, which provides shelter and food for hundreds of animal species, including some which are valuable to both sport and commercial fisheries.

The life history of giant kelp consists of an alternation of generations between a microscopic gametophyte stage and the more familiar sporophyte stage (Fig. 1.1). Large sporophytes produce specialized reproductive blades called sporophylls, which are located near the base of the plant. Meiosis occurs in sporophylls, and the resulting haploid zoospores are released into the sea. Spores which are able to successfully settle onto hard substrates metamorphose into male and female gametophytes. Under favorable conditions, these produce sperm (antheridia) and eggs (oogonia), respectively. The diploid sporophyte results from the fertilization of an egg. Laboratory observations indicate that the egg and embryo are generally retained by the female gametophyte. The young sporophytes which grow from the female gametophyte initially develop into single blades. These plants continue to grow and produce the morphologically complex adults. Adult sporophytes can have over 100 fronds, many of which reach the water's surface from depths of 15 m.

For the purposes of this study, we have divided the macroscopic sporophyte portion of the life cycle into four different categories: 1) blade, 2) juveniles, 3) subadults, and 4) adults. For the most part, categories are based on morphological



characteristics of the plants that correspond roughly to size. Blade stage plants are those individuals large enough to be distinguished in situ as Macrocystis (approximately 2.5 cm) but which have not yet fully differentiated into two fronds. Juveniles are defined as plants with two or more fronds (usually approximately 40 cm in height) but with a height less than 1 m. Subadults are plants greater than 1 m in height but without haptera protruding from above the primary dichotomy (Fig. 1.1). Once these haptera appear, plants are classified as adults. Adult plants generally have 6 or more fronds, with the longest frond reaching to the surface from depths of 13 m.

1.3 A History of the Kelp Forests Near SONGS Prior to the Operation of SONGS Units 2 and 3

There are three kelp forests located along the coastline in the vicinity of SONGS (Fig. 1.2). These are San Mateo Kelp (SMK), 4 to 5 km northwest of SONGS, San Onofre Kelp (SOK), directly offshore of the generating station, and Barn Kelp (BK), about 11 km downcoast (southeast) of SONGS. The historical records of these forests have been reviewed previously (Deysher, 1978; Dean, 1980a; and SCE, 1981) and are summarized below.

The areal extent of kelp forests in the vicinity of SONGS has 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 downlooking sonar. Each method has its drawbacks and consequently the areas of kelp forest estimated by the various methods are not comparable in a quantitative sense (Dean, 1980a, p. 10). However, these records provide a semi-quantitative history of the sizes and shapes of the kelp forests.



The history of SOK, SMK and BK are summarized in aerial maps of canopy area (prior to December 1978) and areas of surface frond abundance (from December 1978 to 1982) (Fig. 1.3). A more detailed account of the size of the individual kelp forests from 1974 to the beginning of operations of SONGS Units 2 and 3 in 1983 is given in Figure 1.4.

In 1911, kelp forests were almost continuous along the coast line from San Diego to Point Conception, wherever suitable substrate existed, including the area under study. SMK, SOK, and BK apparently have persisted for over 40 years as indicated by surveys in 1934 and in the early 1950's (Deysher, 1978). In the 1958 and 1959 El Nino period, an estimated 90% of the kelp canopies (formed by fronds of adult sporophytes which reach the surface) located along the mainland coastline of Southern California disappeared (North, 1973). Canopies at SOK and SMK disappeared completely during this time and BK was reduced in size. It has been hypothesized that the die-off was related to either abnormally high water temperatures (North, 1971), extremely low nutrient concentrations (Jackson, 1977), or both. The die-off may also have been exacerbated by pollution (Wilson et al., 1978).

San Onofre Kelp and San Mateo Kelp did not become reestablished for more than 10 years after the die-offs, in 1970 and 1972 respectively. The kelp forests generally flourished for the next several years until another partial die-off of the forests occurred in the summer of 1976. Other Southern California kelp forests were also in a state of decline in the summer of 1976 (R. McPeak, Kelco Corp., personal communication), but the die-off of kelp was much more dramatic at SOK, SMK, and BK than elsewhere.

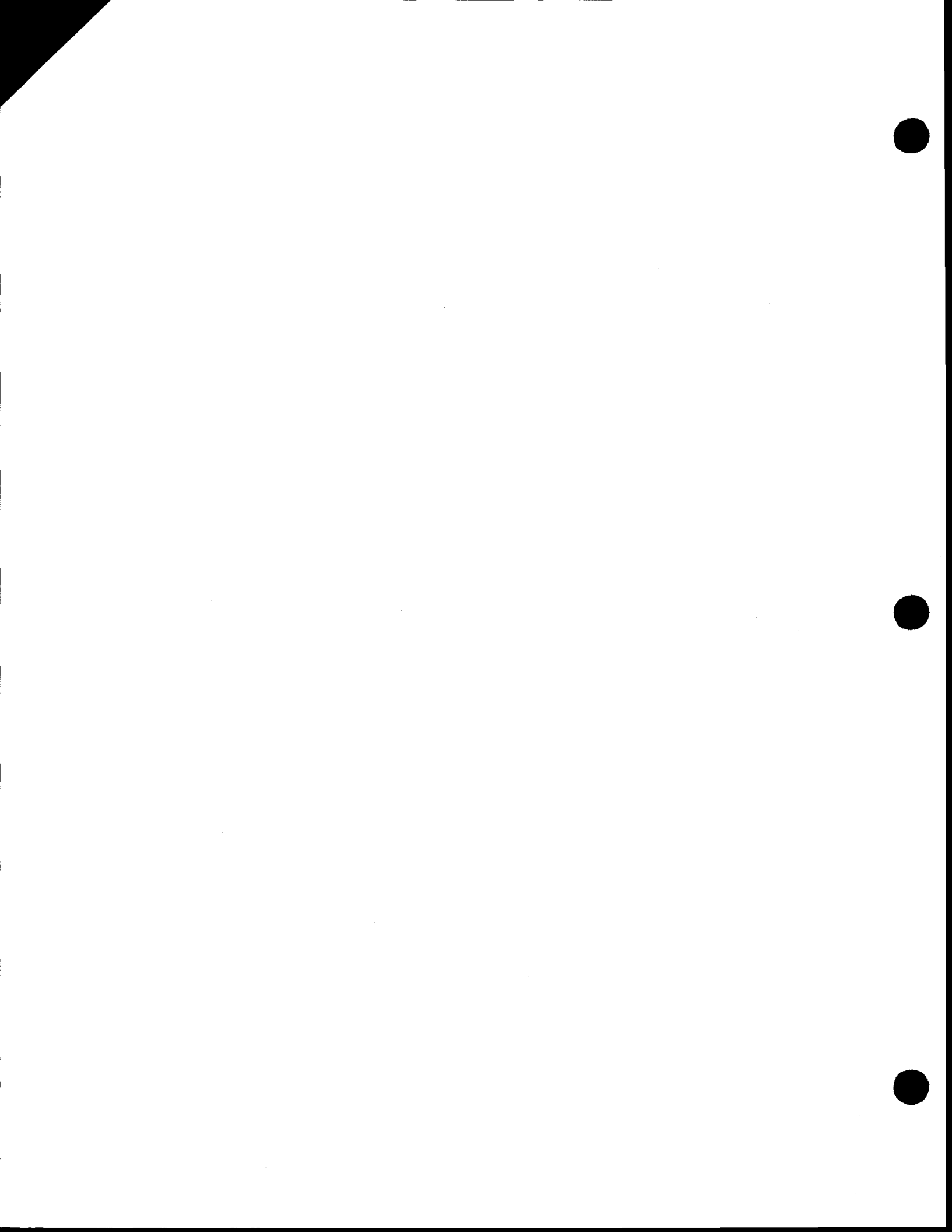


San Onofre Kelp and San Mateo Kelp began increasing in size again in 1977 and increased sharply in 1978 and 1979 following widespread recruitment events in the spring of 1978 and winter 1979. During these times, divers noted large numbers of blade stage Macrocystis throughout much of SOK and SMK, with densities of small plants generally exceeding $100/m^2$ (Dean, 1979, p. 71). In "non-recruitment" years, densities of blades are less than $1/m^2$.

not general for recruitment "events"

From late 1979 until early 1982, both SOK and SMK declined slightly. However, the most striking event to occur in the kelp forests near SONGS between 1979 and 1982 was the decline and eventual disappearance of BK during 1980. This was unexpected since BK had been the most persistent kelp forest on the coastline near SONGS from 1950 through 1980. Unlike SOK and SMK, BK persisted through the 1958-59 die-off. The decline in BK apparently began in the spring and summer of 1980. The sharpest period of decline was between June and November 1980, after which only a few scattered plants remained at the site. The cause of the die-off is not known, but several hypotheses exist. First, the kelp forest was comprised almost entirely of extremely large and, presumably, very old plants. There had not been any significant recruitment to the population in at least 5 years (based on diver observations) and probably longer (based on the large sizes of the holdfasts and large numbers of fronds per plant). The plants may simply have become old and senescent and reached the end of their normal life expectancy. However, there is no evidence that mortality rate of adult sporophytes increases with age, and similar events are unreported for other kelp forests in the absence of obvious contributing factors.

A second hypothesis is that adult plants were killed and further recruitment was restricted by heavy sedimentation within the kelp forest. Kuhn and Shepard



(1984) noted that there was extensive landslide activity and cliff erosion along the shoreline adjacent to Barn Kelp in February 1978 and again in February 1980. Enormous amounts of sediment were deposited offshore creating a series of sand bars. We noted extensive sand movement onto several of our stations in Barn Kelp. While some areas did not get covered with sand, a layer of fine sediments covered the kelp fronds and hard substrata in the region. We suspect that the die-off resulted from the direct burial and resulting death of adult plants, an increase in grazing pressure on the remaining individuals, an inhibition of recruitment due to the covering of much of the available hard substrata by sediments, and a lack of recruitment due to a declining source of spores.

Whatever the cause of the BK die-off, it is clear that it was unlike previous catastrophies in that it was obviously a very localized event. No other kelp forests from Point Conception to San Diego experienced such a decline at that time.

A major El Nino event occurred beginning in fall 1982. Associated with the El Nino were severe storms with exceptionally high surf in winter 1982-83. Many of the kelp forests were severely thinned by the storms (Dayton et al., 1984). The San Onofre and San Mateo Kelp forests were somewhat less affected by the storms than the others. Exceptionally high temperatures and low nutrients prevailed in Southern California kelp forests throughout most of the period from fall 1982 through fall 1984. A brief "relaxation" of this pattern occurred in spring 1983 when there was an intensive upwelling event. There was recruitment of kelp associated with the upwelling, but existing adult kelp grew slowly during 1983 and 1984 and canopies of kelp were severely depleted throughout Southern California at this time. The warm waters were also associated with a die-off of sea stars throughout Southern California kelp forests. During 1985 and 1986, oceanographic and climatological patterns returned to more normal conditions.



1.4 A Description of the Kelp Forest Communities in the SONGS Area

The substrate in the kelp forests near SONGS consists primarily of cobbles and boulders ranging from about 5 cm in diameter up to almost a meter in diameter. The cobbles are interspersed with patches of sand. Consolidated reef outcropping areas are rare except at Barn Kelp where some extensive reefs occur. The kelp forests in the vicinity of SONGS are dominated by a canopy of Macrocystis pyrifera and an understory of other algae, primarily Pterygophora californica and Cystoseira osmundacea; occasionally, large blooms of Desmerestia ligulata occur. Most of the giant kelp in these forests occurs between the depths of 10 m and 16 m. The inner margins of the kelp forests are bounded largely by sand. The outer margins are less clearly defined. Some portions are bounded by sand or by extensive aggregations of sea urchins on hard substrata.

The algal turf community is dominated by Acrosorium uncinatum and encrusting coralline algae. Although dominance is high, the species list of algae in these kelp forests is quite extensive given the lack of relief. Unpublished lists (R. Fay, personal communication) indicate that over 120 species of algae are present.

The principal macroinvertebrates in the kelp forests are the sea urchins, Strongylocentrotus franciscanus and Lytechinus anamesus, the sea stars Patiria miniata and Pisaster giganteus, the gorgonian coral, Muricea californica, and a variety of gastropod molluscs (Kelletia kelletii, Conus californicus, Pteropurpura festiva).

A brief description of the regional physical and chemical oceanographic factors that are most important to kelp is given below. A more complete description is given in Reitzel et al. (future publication).



Temperatures on the sea floor in the kelp forest range from 10°C to 20°C and average between 15°C and 16°C. Surface temperatures occasionally reach 23°C. Temperatures vary with depth, but daily mean temperatures are generally highly correlated among various locations at any given depth. Temperature stratification occurs regularly in the summer and fall. The upwelling of cool water occurs on an irregular basis but is most frequent in the spring. Nutrients (especially NO₂ and NO₃) are inversely correlated with temperature, with peaks in nitrogen occurring during upwelling events.

Irradiance reaching the sea floor in the kelp forest varies both temporally and spatially. Much of the spatial variability can be explained by changes in depth, shading by the kelp canopy, and proximity to fine sediments that can be resuspended by waves. Temporal variability is largely determined by changes in the extinction of light within the water column rather than changes in incident irradiance at the water's surface. Extinction rates are often higher near the bottom as the result of resuspension of sediments by waves. Irradiances (300 nm - 700 nm) on the sea floor in the kelp forests range from above 10 E/m²/d to undetectable levels (<0.05 E/m²/d) but are generally between 1 and 2 E/m²/d (about 5% of surface irradiance).

Longshore currents in the kelp forest average about 4 cm/s. There is a strong tidal component to current speed and direction, but on average, currents run in the downcoast (equatorward) direction about 60% of the time. In the San Onofre Kelp forest, current directions tend to be canted inshore when currents are running downcoast and offshore when currents are running upcoast (poleward). The kelp forest itself can substantially alter current direction and reduce current velocity.



Waves are important both as a direct source of mortality to kelp and also indirectly due to the resuspension of bottom sediments. The San Onofre and San Mateo Kelp forests are substantially blocked from northerly swells by the Channel Islands (Pawka and Guza, 1983) and are more susceptible to the large southerly swells which tend to occur in late summer and fall.

1.5 Comparisons of Kelp Forests in the SONGS Area with Others in Southern California

There are few published descriptions of the kelp forests along the Southern California coast. However, based on the existing records and on personal diving experience, all 3 kelp forests in the SONGS area appear to be quite different from other forests in Orange and San Diego Counties. Most other kelp forests along this coastline are found growing on consolidated substrates rather than on cobble bottoms. Also, maximum densities of adult plants are lower at SOK and SMK than in other regions such as Pt. Loma, La Jolla and Del Mar. The average adult densities in canopy areas at SOK and SMK are approximately $0.1/m^2$ (Section 11.0), while in other forests densities are usually between 0.2 to $0.3/m^2$ (North, 1971, p. 46; Rosenthal et al., 1974; Dayton et al., 1984). We suspect that the differences in plants' densities are causally related to substrate availability.

SOK and SMK also differ from other forests in that the understory algal populations are not as diverse. In kelp forests elsewhere, Eisenia, Laminaria, Gelidium and other brown and red algae are important understory components (North, 1971, pp. 50-52; Neushul, 1971, p. 267). These species are relatively rare at SOK, SMK, and BK. SOK and SMK appear to have larger populations of urchins than elsewhere. Commercial urchin divers (Dave Roody, personal communication) indicate that none of the kelp forests between Pt. Loma and San Onofre has as large a population of red urchins, S. franciscanus, as SOK and SMK have. Our own diving



experience suggests that white urchins (Lytechinus anamesus) are much more abundant at SOK and SMK than elsewhere.

In spite of their dissimilarities, the kelp forests between La Jolla and SMK appear to undergo somewhat similar fluctuations in size, with peaks in abundance of Macrocystis occurring about every 3 to 4 years. North (1971, pp. 42 and 43) described this pattern for the kelp forests between Del Mar and Oceanside. The cycles appear to result from sporadic recruitment of Macrocystis. From 1978 through 1983, high densities of newly recruited plants appeared 3 times (in 1978, 1981, and 1983) at San Onofre and San Mateo Kelp forests with little or no successful recruitment in the interim periods (Dean, 1983). Rosenthal et al., (1974) noted two recruitment "events" in their 6-yr study at Del Mar. It also appears that these recruitment events may be somewhat synchronous among the kelp forests in San Diego and Orange counties. In the years that we noted good recruitment at San Onofre, Dayton (personal communication) also noted good recruitment at Pt. Loma. Similarly, dives made in the Laguna Beach area in 1981 suggested good recruitment occurred there as well as at San Onofre. In 1983, successful recruitment of kelp was prevalent all along the coastline from Palos Verdes to Pt. Loma, as indicated by a survey of kelp researchers in this region. However, the lack of recruitment in "off" years at Pt. Loma and La Jolla may not be as dramatic as in other San Diego area kelp forests. We have always been able to find a few newly recruited plants each summer at La Jolla and Pt. Loma while on occasion (e.g., 1980), there were no newly recruited plants at SOK (see Section 9.0).

The histories of the kelp forests in the southern portion of the Southern California Bight indicate that the large-scale patterns of kelp abundance may be driven by oceanographic conditions that exist over the entire area. For example,



the large-scale die-offs in El Nino years, such as occurred in 1958-59, and the recruitment events of 1978, 1981, and 1983, were all widespread phenomena. Superimposed on this large-scale picture are the changes brought about by more localized events. For example, the disappearance of BK in 1980 was an isolated event. Patterns of kelp abundance over time and space are thus a result of both "bight wide" and local events.

1.6 The Operation of the San Onofre Nuclear Generating Station

A general description of the San Onofre Nuclear Generating Station and the discharges from its 3 generating units is given in _____ (pending MRC report). The generating stations are currently in operation and produce a maximum of 2,636 megawatts. Unit 1 was placed into operation in 1968. Once-through cooling water for Unit 1 is discharged through a single port about 800 m from shore and about 1 km from the San Onofre Kelp forest. Units 2 and 3 began low-level testing in 1982 and were first put into commercial operation in August 1983 and April 1984, respectively. Each of the latter units discharges about 830,000 gal/min of cooling water through diffuser-type discharge pipes. The diffusers run perpendicular to the shoreline and extend offshore 1,800 m to 2,500 m. Portions of the San Onofre Kelp forest are within 200 m of the diffusers. It is the discharges from Units 2 and 3 that are of primary concern with regard to possible adverse effects on kelp. Intakes for all 3 units are located, approximately 900 to 1,000 m offshore and at least 700 m from SOK.

1.7 History of the Project and Rationale for Our Approach

The Kelp Ecology Project was begun shortly after the founding of the Marine Review Committee (MRC) in 1975. Since 1978, the project has been contracted through the University of California, Santa Barbara. The primary purpose of the project has



been to determine the effects of SONGS on populations of kelp in the San Onofre Kelp forest. However, the project has undergone several shifts in emphasis. The first several years of the project were aimed at predicting the effects of Units 2 and 3 on the San Onofre Kelp forest. This approach was implemented by determining the effects of the existing Unit 1 discharge on various life-history stages of kelp. These studies involved transplanting the life-history stages of interest to stations at various distances from the Unit 1 discharge. Transplanting was necessary because there were no naturally-occurring kelp populations in the vicinity of Unit 1 at that time. The results of the Unit 1 studies were combined with observations on the life history of kelp in the SOK forest to make our predictions of the effects of Units 2 and 3 (Dean, 1980b). Briefly, our predictions indicated a potential reduction in the number of sporophytes produced from gametophytes and a reduction in the growth rate of juvenile plants when Units 2 and 3 began operating. These effects were primarily related to reductions in irradiation expected as a result of the operation of SONGS.

In 1980, we began to shift the emphasis from predicting the effects of Units 2 and 3 to the development of a pre-operational baseline, prior to the beginning of the operation of the new units. This baseline consists of life-history data gathered from both natural and experimental populations. The data are to be used in a Before-After/Control-Impact pairs (BACIP) design (Stewart-Oaten, 1984). Biological parameters were measured at stations near and far from the diffusers before the completion of Units 2 and 3 and were measured at these same stations after Units 2 and 3 became operational. We have defined the beginning of the operational period as January 1983, when Unit 2 first reached a level of 50% operating capacity. A significant change in a variable (relative to the control) after Units 2 and 3 began operation would indicate an effect of the power plant.



In the early phases of our pre-operational baseline studies, we emphasized using a station (or stations) in the upcoast portion of SOK as the "impact" site and a station (or stations) in the downcoast portion of SOK as the "control" site. However, predictions concerning the effects of SONGS on turbidity (Reitzel, 1980) indicated that SONGS Units 2 and 3 would have approximately equal impact at both up- and downcoast SOK. Thus, we were required to use stations in the nearby San Mateo and Barn Kelp forests as "control" sites.

The use of SMK and BK as controls presented several problems. First, we knew that the histories of the kelp forests (and especially BK) were quite different from one another. Second, the physical environment at SOK may be quite different from the other two kelp forests because SMK is located just offshore of a point of land (San Mateo Point) and BK is somewhat deeper, on average, than SOK. Thus, it did not appear as though SMK and BK would be ideal control sites. This point was even more strongly emphasized when BK disappeared in the summer of 1980.

The potential problems in a BACIP design created by the lack of an ideal control, along with other considerations (see Stewart-Oaten, 1981), caused us to redirect our approach. In 1981, we decided to continue to gather pre-operational data for BACIP, but also attempted to better understand the relationship between the physical/chemical environment and kelp. This "mechanistic" approach can be used to relate observed changes in biological parameters with changes in physical variables that may be altered by SONGS. In this way, we can demonstrate a potential SONGS' effect and also supply a direct causative link between the biological effects and SONGS operations. Therefore, our efforts over much of the last several years of the contract were aimed at developing mechanistic models for growth and mortality of kelp in its various life-history stages and, at the same time, providing data for the BACIP design. These mechanistic studies are the primary focus of this document.



Our general approach for both the mechanistic and BACIP studies was to deal with each life stage on an individual basis. We did this because the various life stages live in very different microenvironments and respond differently to various environmental factors (Neushul, 1978). For example, gametophytes live on the bottom where sedimentation is high and irradiance levels are relatively low. Adult plants, on the other hand, have most of their tissue in the upper portions of the water column where irradiance is relatively high and sedimentation is low. We could not simply assess the impact of SONGS following the fate of the adult kelp population because adult kelp are long-lived and recruitment is episodic. Although there may be impacts on recruitment, these may not be reflected in adult population densities for some time.

We have used different methods to study the different life-history stages. This was necessary because of both the large range in size displayed by the different life-history stages (from 5 μ to >15 m in height) and the large differences in the lengths of time a plant remains in the various stages (from several days to several years). The small gametophyte and sporophyte life stages were studied in the laboratory and in situ using "outplanting" techniques. Small plants were cultured in the laboratory and populations of known age, size and density were subsequently transplanted into the field. Outplanting techniques and laboratory studies were necessary because these life-history stages were too small to easily observe in the natural marine environment.

We studied the growth of juvenile sporophytes by transplanting laboratory-recruited plants or naturally-occurring plants which we obtained from various kelp forests. We used these sources because natural recruitment at SOK was rare and juveniles were not always available. The outplant and transplanting techniques also



allowed us to obtain control over many environmental factors. For example, we could study the growth of juveniles over several seasons at the same place and under similar conditions with regard to the density of competing adult Macrocystis and understory algal species. In addition, we were able to place plants at chosen locations so that we could obtain measures of growth, mortality, etc., under a wide range of environmental conditions.

The following chapters outline pertinent information on the biology of kelp with each life-history stage discussed in a separate chapter. These studies are combined with descriptions of the changes in physical factors, and with changes in kelp populations, especially with regard to the natural recruitment of kelp and subsequent changes in adult population densities. Evaluation of the effects of SONGS is based on the evidence compiled from all of these sources and, as indicated, is presented in a separate document.