State of California, Edmund G. Brown Jr., Governor

California Coastal Commission
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File San Onofre

September 5, 1980

Harold R. Denton Director
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Denton

The attached report from Professor William Murdock, the Coastal Commission's appointee to the San Onofre Marine Review Committee, represents his preliminary assessment of key MRC findings to date for your consideration prior to publication of the FES for Units 2 and 3 operating license.

As noted in his letter of transmittal, Dr. Murdock's preliminary assessment of the plant's effects on the marine environment is his personal view, not the official position of the MRC. He consented to try and summarize work completed to date at the Coastal Commission's request, in order to give the NRC staff an indication of the nature of the MRC's findings which will not be formally presented to the Commission until later this year. Because this timing might preclude your staff's consideration of their report concluding whether major design or operational changes in the cooling system are necessary, it is hoped that these tentative predictions will prove useful.

Following a meeting between our staffs and Professor Murdock, it was agreed that technical material supportive of the conclusions presented could also be made available, if necessary.

Please let me know if I can be of further assistance.

Sincerely,

MICHAEL L. FISCHER
Executive Director

cc: Dino Scaletti
William Murdock

Attachment

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An Interim Assessment of Predictions of Effects of SONGS Units 1, 2 and 3

William W. Murdoch

July 31, 1980

Introduction

This document is a response to a request from the California Coastal Commission that I transmit to them, in my capacity as the Commission's representative on the Marine Review Committee, my assessment of the predictions concerning SONGS' ecological effects on the marine environment. There are several important points to notice about this assessment. (1) It is my own personal interpretation of our results and is not an official MRC statement. (2) The results and calculations on which it is based have not been reviewed by the MRC. I obtained from our contractors the most up-to-date information I could, and there has not been time to subject all of this information to formal MRC scrutiny. (3) MRC will produce at a later date the final predictions. These in some instances will represent modifications of the present ones, since the contractors are still making refinements in their predictions. They may also differ as a result of criticisms and comments obtained during the MRC reviewing process. This assessment therefore presents interim predictions.

I have chosen to concentrate on two major aspects: fish and kelp. I expect that MRC eventually will make predictions about other ecological groups. However, the effects on these two parts of the community seem to me the most important, and at the moment they also provide the best basis for prediction. In each case there is always a range of possible predictions, and I have chosen what I consider to be the most likely outcome.

Predictions

1. Fish

There is likely to be a large reduction in the annual production of nearshore species in the SONGS area (equivalent to more than 80% of the annual production in numbers of these species along 50 km of coastline). This is expected to lead to about a halving of total production, in weight, of nearshore sport and commercial fishes in the 4 fish blocks covering about 45 km of coastline near SONGS. This is equal to a loss of harvestable production of sport and commercial nearshore species equivalent to about 210% of the annual harvest (84 tons) of these species in these 4 fish blocks. (These numbers must not be taken as precise estimates of losses. Rather, they give an idea of the general size of the losses to be expected.) These losses should result in detectable reductions in the standing stock of these species near SONGS, and in a pronounced local reduction in certain species, such as kelp bass and California corbina. Note: although the losses are equivalent to 210% of the annual harvest in these blocks, because adult fish move extensively the losses would actually be spread over a larger area. If no eggs or larvae are killed by the plume or discharge, the above estimates are reduced by about one-third to almost one-half.

Over the past 15 years in Southern California the catch of some nearshore species has declined and the catch per unit effort of nearshore species in general has declined. This suggests that the stocks and production of these species are declining in the face of harvesting and environmental degradation (though other causes could also be operating). It also suggests that the stocks in this area will not be able to compensate for the additional losses imposed by SONGS.

These calculated fish losses are so large that, even with quite extensive movement of adults, we would expect to see local depressions in nearshore fish stocks. It is possible, however, that extreme mixing of larval populations,

especially via large scale on- and off-shore movement of water masses, may smear out these local effects. The result of such extreme mixing would be that the absolute losses of production would be greater than predicted, but they would be spread out, thinly, over a very large area.

2. Kelp

Historically San Onofre Kelp bed (SOK) has exhibited two states: (a) the "normal" state in which much of the available substrate is covered by kelp, as is now the case, but the degree of cover varies; (b) periods following catastrophic die-offs of adult plants, during which the bed is non-existent, at very low coverage, or is recovering.

(a) It is likely that SONGS will alter the normal state by reducing the density of kelp plants in the offshore portion of the bed. This is the major area of the bed. The reduction is likely to vary from moderate (significantly less than half) to severe (sometimes more than half).

(b) SONGS will lengthen the periods during which the bed is absent, or very sparse, following catastrophic die-offs.

If these predictions are borne out, SONGS will have a significant adverse ecological impact on SOK.

3. Other Systems

There is evidence that SONGS will have effects on other groups of organisms - for example, on local mysid populations, on organisms living in soft and on hard bottoms, and, directly, on shrimp that live in the kelp bed. The details of these predictions are not yet available.

Basis for Predictions

1. Fish

I. The affected fish species

SONGS Units 1, 2 and 3 are most likely to affect significantly fish species that live as adults mainly nearshore (within about 4 km of shore), and produce planktonic (drifting) eggs and larvae in the same zone. Most species of fish in the SONGS area are of this type. However, most individuals, and most of the total tonnage (biomass) of fish are anchovies. Anchovies also extend well offshore. There are several hundred billion anchovies in the California Bight, they move enormous distances, and SONGS will not significantly affect the population of this abundant species, although the Plant will kill large numbers of anchovies. They are not considered in the analyses below, which concern nearshore species only. A numerically small group of nearshore species has planktonic larvae but lay their eggs on the bottom or carry them internally. This group is excluded from subsequent analyses.

We will be concerned mainly with those nearshore fish that produce both planktonic eggs and planktonic larvae. These species are the most numerous near shore and fall into one of two groups. (1) "Forage" or fodder-fish. These species eat plankton, small bottom-dwelling organisms, mysid shrimps, etc., and are themselves food for sport and commercial species. The major species in this category are queenfish (Seriphus) and white croaker (Genyonemus). In calculating the likely effect of losses of this group upon sport and commercial species, it is assumed that 10 pounds of fodder-fish can produce 1 pound of sport and commercial fish. (2) Sport and commercial (S-C) fish are the second group. Among nearshore species, halibut

and white seabass are the main commercial species while kelp bass and sand bass, and halibut, are the main sport species. These 4 species make up almost all of the 1975 S-C catch of nearshore species. The angler catch, per unit effort, of nearshore fishes has in general declined in Southern California since the mid-1960s, as has the sport catch of certain species, such as kelp bass and halibut.

II. Mechanisms of SONGS' effects

There are five known or suspected mechanisms through which SONGS can affect fish populations. These are:

(1) Killing juvenile and adult fish as they are taken into the intakes of the cooling system (via impingement and entrapment).

(2) Killing planktonic eggs and larvae that are taken into the intakes or are caught up (entrained) by water jetting out of the discharge or diffuser systems.

(3) Loss of fish from special habitats (e.g. kelp).

(4) Loss of fish food that is moved by the cooling system.

(5) (Sub)lethal effects of discharged organochlorines.

Only the first 2 mechanisms will be discussed.

III. Estimation of probable losses of fish

(1) Direct kill of juveniles and adults in intakes

Unit 1 kills 16.7 tons of fish per year. The fish are deposited on land.

The intake structure of Units 2 and 3 has been modified to reduce the fraction of fish taken into the intakes. In addition, a fish-return system has been devised to return those caught back to the ocean. This system has not been tested. The fish study group feels that the fish return system is likely to kill or fatally injure most fish that pass through it. If the new

systems are 50% efficient, the total intake mortality will double. If they are completely inefficient, total intake mortality will increase 5-fold since the volume taken in by all 3 units will be 5 times that taken in by Unit 1, and the new structures provide about 5 times as much attractive "reef structure". Probably the annual fish kill will fall between 2 and 5 times that of Unit 1, or 33-84 tons. The present average annual losses comprise: 10.2 tons fodder-fish, 4.9 tons S-C fish, and 1.6 tons of "trash" fish. These losses, scaled upwards to all 3 units operating, will be equivalent to 16-18 tons of harvestable S-C fish production.

These losses already produce measurable effects on queenfish. The population of this species within ½ km of the intake (and perhaps as far as 2 km) has fewer young fish and fewer females than more distant populations. Young and female fish are precisely the groups taken in selectively by the intakes. Two-thirds (by weight) of the fodder-fish taken in are queenfish.

(2) Killing of planktonic fish eggs and larvae in intakes and discharge

Nearshore species spend 2-4 months as planktonic eggs or larvae and throughout this stage can be caught up by the intakes or discharge water. This is the major source of mortality. It is estimated by a somewhat complex procedure involving a model of fish mortality, and I will describe the methods only briefly. There are a number of steps in the procedure.

(a) The density of eggs and larvae of various ages, in water at various depths and distances offshore, is estimated from samples. (There is a tendency for older larvae to occur inshore and nearer the bottom, at diffuser and intake depths.) Next, the rate at which SONGS will withdraw water from each of these locations is estimated (from a model of SONGS hydro-dynamic behavior). This gives the number of eggs and larvae that will be entrained. Finally, an

assumption is made about the fraction of entrained eggs and larvae that will be killed. All of those passing through the intake are assumed to die. 5-10% of those entrained by discharge water are assumed to die from shear pressures and a further 5-10% are assumed to die because the diffuser plume transports them to an unsuitable environment.

These various estimates allow calculation of the expected number of eggs and larvae that will be killed per unit time (say, each day), immediately after the plant is turned on.

We cannot assume this kill rate will continue indefinitely. For example, some water that has been affected by the plant may remain in or return to the vicinity and mix with "new" water that moves into the area. When this happens, the local density of eggs and larvae will be lower than elsewhere, and fewer eggs and larvae will be killed per unit time.

A detailed model of the current regime in the SONGS area could be used to estimate the rate of replenishment of water in the area, and hence the local density of eggs and larvae exposed to SONGS. Such a model was not available when the present calculations were made.

(b) Instead, a model was used that simply assumed that SONGS will draw eggs and larvae only from some specified region along the coast. Inside this region, all eggs and larvae are assumed to be equally vulnerable (good mixing is assumed). No egg or larva outside the region can be killed by SONGS and no eggs or larvae can leave the region. The model has the following features:

- Eggs are produced in this region at a constant annual rate that is the same as elsewhere. (This is essentially the conservative assumption that, even if SONGS kills many plankters and subsequently lowers adult density in

the region, reproductive fish will move in from elsewhere.)

• The model calculates the chance that an egg or larva of a given age, within the region, is killed by SONGS before it reaches the next age class (which is 2.5 days older). This is done for all age classes up to the point when the larva becomes a juvenile (4 months in queenfish, for example). Since eggs and larvae die off extremely rapidly due to natural causes, most of them are not killed by SONGS but die of natural causes. This natural death rate is taken into account by the model.

• The chance of any individual being killed by SONGS before it moves out of its age class depends on the size of the region chosen (the chance is smaller when the region is bigger because within 2.5 days a smaller fraction of the water in the region passes through SONGS). Clearly, if a very small region is chosen, a given individual can be exposed to risk on different occasions since the same parcel of water passes through SONGS many times. In this case, the density is rapidly depleted, the fraction killed is high, and most larvae do not grow very old. On the other hand, the number killed is somewhat smaller.

• Since the natural mortality rate is high, there are always many fewer older larvae than younger larvae and eggs. This is reflected in the predicted SONGS kill. For example, under one set of assumptions, SONGS will kill in a year 53 billion eggs and 8 billion larvae of nearshore fish.

Clearly the choice of the size of the "affected region" is somewhat arbitrary. Choosing a very small region (say 1 km) is equivalent to assuming virtually no currents along the shore, and hardly any replenishment of the waters around SONGS by "new" water. This will overestimate the degree of

local suppression, but will underestimate the number killed - larvae from elsewhere that in reality would get to SONGS are not counted. On the other hand, choosing a very large region (say several hundred km long) is equivalent to assuming that fish eggs and larvae move huge distances in their lifetimes. This would maximize the number killed, but (especially since thorough mixing is assumed) it would spread the effect out very thinly. (Notice that this decision corresponds to real events. 25 km was chosen as a compromise between smaller regions within which complete mixing can be assumed, and larger regions within which all doomed fish larvae are certain to have been produced. SONGS will kill billions of eggs and larvae, and the degree of movement of eggs and larvae will determine whether there is a severe local depression or a less severe, but much more extensive depression.)

The result of the model's calculations is a predicted number of eggs and larvae killed per year (breeding season) in each age class.

(c) These predicted losses of eggs and larvae are then converted into an equivalent number of 13 month old fish. (An age of 13 months is chosen primarily because this corresponds in size to that of the average fodder fish eaten by S-C fish.) The idea here is as follows: An egg has roughly 1 chance in a million, under natural conditions, of becoming a 13-month old adult. Therefore, if SONGS kills an egg, this is equivalent to killing only one-millionth of a 13-month old fish, because in all likelihood the egg would have died anyway. However, if SONGS kills a 4-month old larva it has killed the equivalent of .4 of a 13-month old adult, because a 4-month old larva under natural conditions has a 40% chance of becoming a 13-month old adult. It is predicted that SONGS will kill the equivalent of one to several million

13-month old adults of nearshore fish species.

IV. Conversion of losses to biomass (weight of standing stock of fish)

Among nearshore planktonic spawning species, 86% of the larvae are fodder-fish and the remaining 14% are sport and commercial (S-C) fish. The losses of 13-month old "adult-equivalents" were divided between these two types of fish in these ratios.

Next, numbers lost were converted to a weight (biomass) lost for each group (S-C fish live longer than forage fish and are larger, so the conversions are different). The idea here is that, once SONGS has been operating for several years, the numbers of 1, 2, 3, . . . year old fish are all affected and, each year there is an average loss of fish weight, spread over all ages, in each species. The estimated loss of harvestable S-C biomass is obtained by counting only fish 3 or more years old.

V. Total loss of sport-commercial fish biomass

From the calculations in III, some S-C fish biomass is lost directly as a result of the death of S-C eggs and larvae. However, S-C fish depend on fodder-fish and, since the biomass of the latter is reduced, there is now less food for S-C fish. In general, it is believed that 10% of fodder-fish biomass gets converted to S-C biomass by predation by S-C fish. One estimate therefore assumes this conversion rate. However, since the S-C fish have been reduced, some fodder-fish may now escape predation, and a more conservative (extreme) assumption would be that only 1% of the lost fodder-fish biomass would have been converted to S-C fish. Thus we assume a range of conversion

of lost fodder-fish to potential, but unrealized, S-C biomass.

VI. Loss of annual harvestable production

Each year, each fish population produces a certain tonnage of "new" biomass, through reproduction and growth. In a perfectly balanced fishery, each year this same amount of tonnage would be consumed - by natural deaths plus the fish harvest. The annual production of a typical S-C population is reckoned to be about 60% of the standing tonnage (biomass). Thus, when the equivalent of 100 tons of S-C biomass is lost as larvae and eggs, this is equivalent to a loss in harvestable production of 60 tons. Similar calculations are possible for fodder-fish.

VII. Some results

The following tables summarize the range of predicted losses.

Table 1 shows losses of nearshore planktonic spawning species caused by killing eggs and larvae. The assumptions are that intake losses are 100% of those taken in, that 10% of those taken up by Unit 1 discharge die, and that 20% of those taken up by the diffusers die. (Assumed losses of 5% and 10%, respectively, reduce total losses by relatively little.)

Table 1

Size of Region	Total number of eggs and larvae killed	Number of 13-month old "adult equivalents"	% reduction of annual production in numbers of 13-month old equivalents
5 km	5.72×10^{10}	1.64×10^{6}	>99.9%
25 km	6.15×10^{10}	8.00×10^{6}	>97.8%
50 km	6.25×10^{10}	1.39×10^{7}	85.1%

Over a wide range of possible affected regions (5-50 km), SONGS is predicted to kill most of the annual production of adult fish. This is expected to result in a detectable reduction of these nearshore species around SONGS. Species with a small range of movement as adults (such as corbina and kelp bass) are expected to show pronounced local reductions in density.

Using the 25 km region as an "intermediate" sized region, it is predicted that the standing stock biomass of fodder-fish older than 1 year of age will be reduced by over 360 tons and that of harvestable S-C fish will be reduced by 300 tons.

These losses in S-C standing stocks are equivalent to 180 tons per year of harvestable production. This is equivalent to 210% of the 84 ton 1975 S-C catch of this group of species in the 4 California Fish and Game Fish Blocks near SONGS (these blocks cover about 45 km of coastline). This loss is also 33% of the 1975 total finfish harvest of 540 tons. The actual losses, of course, might be spread over a larger area.

VIII. Total losses to mechanisms 1 and 2

Total losses of harvestable production, if these two effects were additive, would be 186-198 tons. This is 221-236% of the 1975 nearshore S-C harvest.*

IX. Compensation

It is possible that reductions in larval fish density caused by SONGS would lead to higher survival of the remaining fish larvae (for example, by

*These numbers must not be taken as precise estimates of losses. Rather, they give an idea of the general size of the losses to be expected. If larvae move very little along the coast the local effect will be marked, but fewer total will be killed. If movement is very great, local effects will be less, but more larvae will be killed.

making more food available to each larva). There is, at the moment, no good evidence for such compensation in marine larval fish, and there are a priori reasons for suspecting such compensation would at best be weak. First, fish larvae are already very sparse. Second, it is likely that "chance" (density independent) factors dominate the mortality of these small organisms. Third, much of their food will be killed along with the larvae themselves. Fourth, the general decline in catch per unit effort of nearshore fish stocks in Southern California suggests that the populations do not have large reserves of compensation.

X. These predictions have not taken into account in a precise way the large scale on- and offshore movement of water. The reason is that no complete model of nearshore oceanographic currents exists. It is possible that these large scale movements will cause extreme mixing of water, and of larval populations, along the coast. If this is the case, the probability that a larva, at any point beyond the immediate vicinity of SONGS, will reach SONGS, is small. However, with extreme mixing, this probability would not decline very much as one moved away from SONGS. That is, larvae would be pulled in that arose from eggs produced over a very large area. This would have 2 results. First, we would be less likely to see any local depression in fish populations. Second, our estimated number of larvae killed would be an underestimate. In essence, we would then have a larger absolute reduction in potential production, but it would be spread very thinly over a very large area - perhaps hundreds of kilometers. This does not mean the effect is not important. The accumulation of such effects could gradually reduce fish stocks and fish production over a very large area.

2. Kelp

I. We begin by looking at the dynamics of the kelp bed in the absence of SONGS effects.

(a) "Normal" conditions

It appears that, even in the absence of catastrophic events, the kelp bed is rarely in a "steady-state" or equilibrium condition. It is instead dominated by physical and oceanographic conditions that are highly variable. In the present study, only by the end of 1979 did SOK cover most of the cobble substrate available. Typically the amount of kelp (number of plants and areal extent) on any section of the bed fluctuates in response to changes in bottom conditions, storms that kill adults, grazing by sea urchins and probably fish, and growth and periodic recruitment. Patches of kelp within the bed increase and decrease and even disappear and reappear under normal conditions.

Recruitment of new adult plants is a major dynamic event that is sporadic, in response to seasonal and annual variation in physical conditions. Although kelp has a complex life cycle (Figure 1), for present purposes there are only two important processes affecting recruitment of adults: (i) the ability of the tiny male and female stages (gametophytes) to reproduce and hence produce the extremely small first stage of the actual kelp plant (called a sporophyte); (ii) the ability of juvenile plants to grow up into adult kelp plants. Experiments have shown that light is a primary factor (although not the only factor) controlling these two processes, and SONGS Units 2 and 3 are expected to alter light levels in SOK.

We need to look briefly at the dynamics of the life cycle.

(i) Reproduction and the production of juveniles

The adults produce minute propagules (zoospores) that settle on the

bottom and become tiny male and female stages called gametophytes. Each plant produces extremely large numbers of these propagules, perhaps continually. Thus it is probable that there are gametophytes present, most of the time, at very high densities, on suitable areas of the bottom close to adult plants. The critical factor is the occurrence of suitable physical conditions (probably a combination of light and nutrients) that allow gametophytes to reproduce. The gametophytes that do reproduce, produce microscopically small kelp plants (sporophytes).

Gametophytes are killed off by a variety of factors - abrasion, burial by sediments, and grazing by animals, and only a small fraction of them survive as sporophytes. Even so, after a successful reproductive "set", there are thousands of tiny sporophytes per square meter of cobble substrate. Unfortunately, it is extremely difficult to study these tiny plants in natural conditions. Quantitative studies have been done only on larger plants that have reached a height of more than 10 cm. At approximately this size they become juveniles (Figure 1). Once again, a variety of factors kill most of the sporophytes as they grow up to be juvenile plants.

Of the processes described above, we believe SONGS will mainly affect reproduction and, in particular, will alter the frequency of successful reproductive "sets". Reproduction requires adequate light, and probably also a high level of nutrients in the bottom water. When these conditions prevail, the gametophytes absorb sunlight and nutrients each day, until they are able to reproduce. Field experiments show that very few sporophytes ever appear from gametophytes planted out more than 40 days previously. Thus, in the field, 40 days is the maximum period during which this stage can accumulate the sunlight needed for reproduction. Over this period they

need an average of at least .43 Einsteins per m^2 per day. (Under good field conditions it is likely that the average successful gametophyte manages to accumulate enough light in about 20 days.) The critical question, in any given year, is therefore: during the period in which gametophytes are present, what is the probability that enough light can be accumulated during successive 40-day periods? (We call such adequate 40-day periods "light windows".)

Suitable conditions for reproduction occur mainly in the spring, although occasionally also in the fall. It appears that adequate conditions for reproduction occur, on average, only approximately once every 3 years. At any one time the bed is thus generally dominated by a "cohort" of adult plants from a single "set" of reproduction.

As discussed below, SONGS is predicted to alter the frequency at which conditions become suitable for reproduction. However, SONGS is not expected to have much effect on the number of sporophytes or juvenile plants that arise from any given successful reproductive set. There are several reasons for this.

(1) Each adult plant produces enormous numbers of gametophytes. Thus, unless the density of adult plants is catastrophically reduced, we assume that there will be enough gametophytes present to replenish the bed even when adult density is low. (This is equivalent to assuming there is density "compensation" in the survival of these small stages.) There must be some very low density of adult plants at which replenishment through a single reproductive set is not possible, but we make the conservative assumption that it is very low, lower than is encountered during "normal" conditions.

(2) With respect to light levels, reproduction is all-or-nothing. When adequate light is available, the number of tiny new plants (sporophytes)

produced is independent of the light level. The number produced appears, instead, to be associated with the amount of nitrogen in the bottom waters, and this is not expected to be affected by SONGS.

(3) The survival of sporophytes to the juvenile stage is again determined by a range of factors (abrasion, sedimentation, grazing). We do not know enough about these factors to predict whether or not they will be changed significantly by SONGS.

(ii) Survival from juvenile to adult stage

Survivorship of this stage is strongly influenced by light. Juveniles suffer a higher death rate than adults, so anything that prolongs the juvenile stage reduces the eventual number of adults. Light affects the growth rate, and the slower the juvenile plant grows, the more likely it is to be killed by physical disturbances, grazing, and other mortality factors.

Light is associated with slower plant growth via two mechanisms. First, light affects the growth rate directly, as in all plants. Secondly, some factor associated with the light level (perhaps the amount of suspended matter in the water) also affects the degree to which the plant is fouled by encrusting animals that slow the plant's growth. The lower the light levels (and the more turbid the water), the greater is the degree of fouling and the lower is the growth rate.

[Specifically, a multiple regression of growth rate (Δ log length in cm/day), versus irradiance ($E/m^2/d$) and percent cover by *Membranipora* (a bryozoan that is a major fouling organism), explained 99% of the variance in growth in experimental juvenile plants at 4 locations at different distances from the SONGS Unit 1 discharge.]

The growth rate of juvenile kelp plants is highly variable. Some plants in a group develop from juvenile to adult in less than 3 months, while others take more than 13 months. The average plant takes about 9 months and most take between 7 and 13 months. The survivorship from juvenile to adult stage is also highly variable, and depends on, among other factors, both the initial number of juveniles and the number of adults present. The fraction surviving tends to be higher when (a) fewer juveniles are present initially, and (b) when fewer adults are present. These relationships lead to an important result: except when very low densities of juveniles are present, the final number of adults present is roughly constant. (This means there is strong "compensation" or "density-dependence". If some factor reduces juvenile density, the number of adults produced may be relatively unaffected.)

Summary of "normal" kelp dynamics

A final piece of information completes the picture of "normal" kelp bed dynamics. It takes about 14 months for an average plant to become an adult, and the average adult plant survives for about 12 months. That is, if we start out at some point in time with a cohort of adults produced by a successful reproductive "set" some 14 months earlier, we can expect roughly half to die within 12 months. By the end of 2 years roughly 25% of these adults will remain alive, and by the end of 3 years, roughly 12½% will remain alive. At this time, on average, we could expect another cohort of adults to appear. In reality, of course, the dynamics would not follow this average pattern, but would vary around it. For example, deaths occur mainly in winter storms, which vary in their severity from year to year, and reproductive sets will sometimes be spaced 1 or 2 years apart, and sometimes 4 or 5

years apart.

The number of kelp plants in the bed thus fluctuates, rising rapidly after a successful recruitment event, and declining thereafter. However, the canopy area of the bed will not clearly follow this pattern since the surviving plants will continue to grow. The canopy area can thus increase even though the number of plants may be decreasing.

(b) Catastrophes

We know nothing about the frequency of catastrophes in the SONGS area before the 1950's. Certainly the kelp beds in the general area were more extensive and continuous when they were observed at various times earlier in the century than they have been since. It is likely that much of the cobble in this area has been covered by sediments since then. We do not know, however, if the beds were severely reduced between these infrequent observations.

Two catastrophic die-offs have occurred since 1956. The first, in 1958-59, was associated with high summer temperatures (but may have been caused by associated low levels of nutrients). At this time 90% of Southern California beds were destroyed. SOK was not re-established for a period of 12 years (by 1972). In 1976, again a year of unusually high temperatures, SOK suffered a partial die-off, being reduced to less than 10% of its former extent, and only in the offshore segment did plants remain. Recruitment occurred about a year later, and recovery of the canopy took almost 2 more years.

There are two means by which kelp disperses and, hence, beds recover or become re-established. First, the adult plant casts its microscopic

offspring varying distances. Many offspring probably fall very close (a few meters) to the plant. However, observations at SOK show that some offspring may be dispersed one or two hundred meters from the bed. (We do not know if these were offspring from plants attached in the bed, or from plants that became uprooted and drifted from the bed.) Secondly, adult plants torn up in storms drift and sometimes cast spores on suitable substrate far from their point of origin. Re-establishment of a bed therefore depends on chance events, and seems more likely when a source of "colonists" is close by. This is why the longshore continuity of beds is important. Recovery of a kelp bed that has been drastically reduced, but not exterminated, depends mainly on local reproduction. Observations at SOK, in the very successful reproductive seasons of 1978, suggest that a large "set" of new plants can arise from quite a sparse kelp bed, and that recovery can be rapid if the catastrophic die-off is followed quickly by successful recruitment. By contrast, the 1958 catastrophe suggests that major catastrophes can be followed by very long recovery periods because no or extremely few plants survive locally.

II. <u>The probable effects of SONGS Units 2 and 3</u>

SONGS discharge will affect the kelp bed mainly by increasing the amount of material suspended in the water (i.e. the turbidity). This will reduce the light available to kelp for both reproduction and growth, and will be associated with increased fouling of kelp plants. As noted above, we have established quantitative relationships between light and reproduction and among light, fouling, and growth of plants (and hence their survival).

The second necessary piece of information is the probable levels of light that will prevail in the kelp bed once Units 2 and 3 are operating. These were calculated in 4 steps. First, ambient light levels near the bottom were recorded. Second, a computer simulation model of water movements near SONGS, including those caused by SONGS' intake and diffuser systems, was developed. This was based on information obtained from current meters placed in the ocean near SONGS, and from a physical model of SONGS-induced water movements produced for Southern California Edison. Third, measurements of natural turbidity levels were made. This information allowed prediction of expected levels of turbidity in the kelp bed. Finally, measurements of light and turbidity levels in the field yielded a strong quantitative relationship between light and turbidity. As an example, the calculations predict that in spring, in the (most important) offshore half of the bed, light levels on average will be reduced by from 25% to 55%, with a roughly 40% reduction being most likely. No significant reduction in light is expected in the inshore segment. The offshore half of the bed has been the most persistent during catastrophe, has the densest canopy cover, and constitutes 70% of the total SOK canopy cover.

These changes in light levels are predicted to influence both reproduction and the survival of juvenile plants.

(i) Reproduction A 40% reduction in light would reduce the number of 40-day "light windows" occurring in spring, on average, by 20%. That is, other factors being held constant, we can expect, on average over the long term, that the chances of successful reproduction will be 80% of what they would otherwise be.

(ii) Growth and Survival From our quantitative relationships established earlier, a 40% decrease in irradiance should produce rather more than a doubling of the degree of fouling of kelp plants. The combined effect of decreased light and increased fouling is a predicted decrease of more than 50% in the juvenile growth rate. This would result in the juvenile stage taking more than twice as long (roughly a year extra) to become an adult. If the observed mortality rates were to continue over this period, the number of adults produced would be reduced by more than 70%.

We need to interpret the growth and survival prediction with caution. It was obtained in the following way. (1) The growth and survivorship of a natural population of juveniles in SOK were followed during 1978 and 1979. About 25% of juveniles in open areas, away from the influence of adults, and in areas of low juvenile density, survived to the adult stage and took 9 months, on average, to grow from juveniles to adults. This gives us the growth rate and the fraction being killed per month under optimal conditions.
(2) The influence of reductions in light, and increases in fouling, on juvenile growth rate, was measured by placing juveniles at various distances from Unit 1 discharge and correlating their growth over a 10-week interval with local light levels and degrees of fouling. (Fouling is caused by some factor associated with lower light levels.) This experiment gave the quantitative relationships among growth, light and fouling mentioned above.
(3) From these relationships, and the predicted light levels under SONGS in spring, the new growth rate of plants was calculated, and hence the additional number of months in the pre-adult stage was predicted. It was then assumed that in these extra month of pre-adult growth, plants would continue to die

off at the same rates as have been observed under optimal light conditions at SOK.

A number of factors may operate to increase the survival of plants above that predicted.

(1) During the "extra" months of pre-adult development, plants will be killed and their density reduced. There may therefore be an increase in the survival rate of the remainder (we do not know this occurs; all we have seen is increased survival when the initial number of juveniles is small). Using observed data, this could decrease the average adult density to about 25% instead of over 70%. Even if compensation were perfect, and the number of adults produced remained the same, the adults would be produced about a year later than would otherwise be the case, again resulting in lower average kelp density. There is also evidence that, once pre-adult development has been prolonged too much, juvenile kelp plants cannot develop into adults, which would reduce the possibilities for compensation.

(2) The predicted decrease in light in SOK, caused by SONGS, is based on only one set of measurements of turbidity, in spring, and on spring currents. But juvenile growth can occur all year, and at other times of the year the decrease in light may be smaller.

(3) The experiments measuring the effect of light and fouling were, of necessity, done inshore at Unit 1 discharge depths. Kelp may respond differently offshore. Furthermore, the discharge from Units 2 and 3 may lack some unknown chemical factor that may be present in the discharge of Unit 1.

(4) The effects of light on kelp growth are well established, and reductions in growth associated with fouling have been observed in 2 years. However, the quantitative relationship used in the prediction is based on only 1 10-week experiment. There is no large body of reliable data based on many repeated experiments that can be used for quantitative prediction.

(5) The calculations use only averages - for length of development, survivorship, etc. This is a sensible approach, but of course all of the processes are variable and any particular outcome cannot be expected to correspond exactly to average conditions.

Against these caveats must be placed the fact that whenever there was uncertainty, the calculations have erred on the side of caution. For example, the calculation of the reduction in light, caused by turbidity, makes conservative assumptions. The quality of light available to kelp under the SONGS plume is likely to be lower, but this has been ignored in the calculations. There is some experimental evidence that sea urchin populations will be enhanced, and that grazing will be increased (possibly important also in catastrophe dynamics, see below); this has not been taken into account.

At this stage, the most reasonable interpretation of the result, in my view, is that the offshore segment of the bed will likely suffer moderate to severe reduction of kelp survival, although not in all "cohorts" (where any reduction of 50% or more is considered severe).

These predicted effects on reproduction, growth and survival will influence both "normal" kelp density and catastrophes.

(a) Effects on "normal" dynamics

The major effect predicted is a moderate to severe reduction in the offshore portion of the bed, in the number of adults present, and in the canopy cover of the bed, on average, compared with what they would otherwise be. The 20% reduction in the probability of a successful reproductive set implies that the average length of time between the recruitment of cohorts of adults can be expected to increase by about 25% (i.e. we expect to miss some recruitment events that would otherwise occur). This would tend to reduce further the density of adult kelp plants present on some occasions.

(b) Effects on "catastrophe" conditions

The offshore portion of the bed has been the most persistent, and is expected to be most severely affected during "normal" dynamics. In years when SONGS-induced kelp reduction in this segment is especially severe, the bed would probably be more vulnerable to catastrophic events. Partial die-offs would be expected to be more severe. The speed of recovery, via reproduction, is predicted to be reduced, both because of the greater reduction in adult density and because reproductive "sets" are predicted to be less frequent. Thus we predict somewhat more frequent and longer periods when the kelp bed will be absent or at very low densities.

Other variables

SONGS Units 2 and 3 will also affect temperature, nutrient levels, and sedimentation rates. Surface water temperatures within SOK will only occasionally reach 1°C above ambient and will generally be less than 0.5°C above ambient, and then only in the extreme upcoast-offshore corner of

the bed. Bottom and mid-depth temperatures at SOK are not likely to be affected.

Units 2 and 3 may cause an increase in the surface nutrients in the kelp bed.

Kelp die-offs have been associated with unusually high summer temperatures, and a 1°C increase at such a time could, in principle, be associated with severe mortality. However, the cause of such die-offs may actually be low nutrients, which the SONGS plume may correct to some extent. In fact, temperature and nutrients probably interact to affect kelp, in ways we do not understand. Although we cannot make firm predictions, we expect that SONGS' effects on temperature and nutrients will have no significant impact on SOK.

Sedimentation is likely to be increased in SOK, and the nature of the sedimentary material changed somewhat. Sedimentation can kill gametophytes, and is probably a major cause of death in the field. However, no correlation was found in the present study between sedimentation rate, as measured in sediment traps, and sporophyte density or sporophyte length. The traps do not provide a good measure of the rate at which all particle sizes sediment out, nor is it known what particle sizes most affect kelp. Thus we are not in a position to comment on the likely importance of possible alterations in sedimentation rates caused by SONGS.

<u>A note on methods</u>

The information discussed above was obtained by various methods.

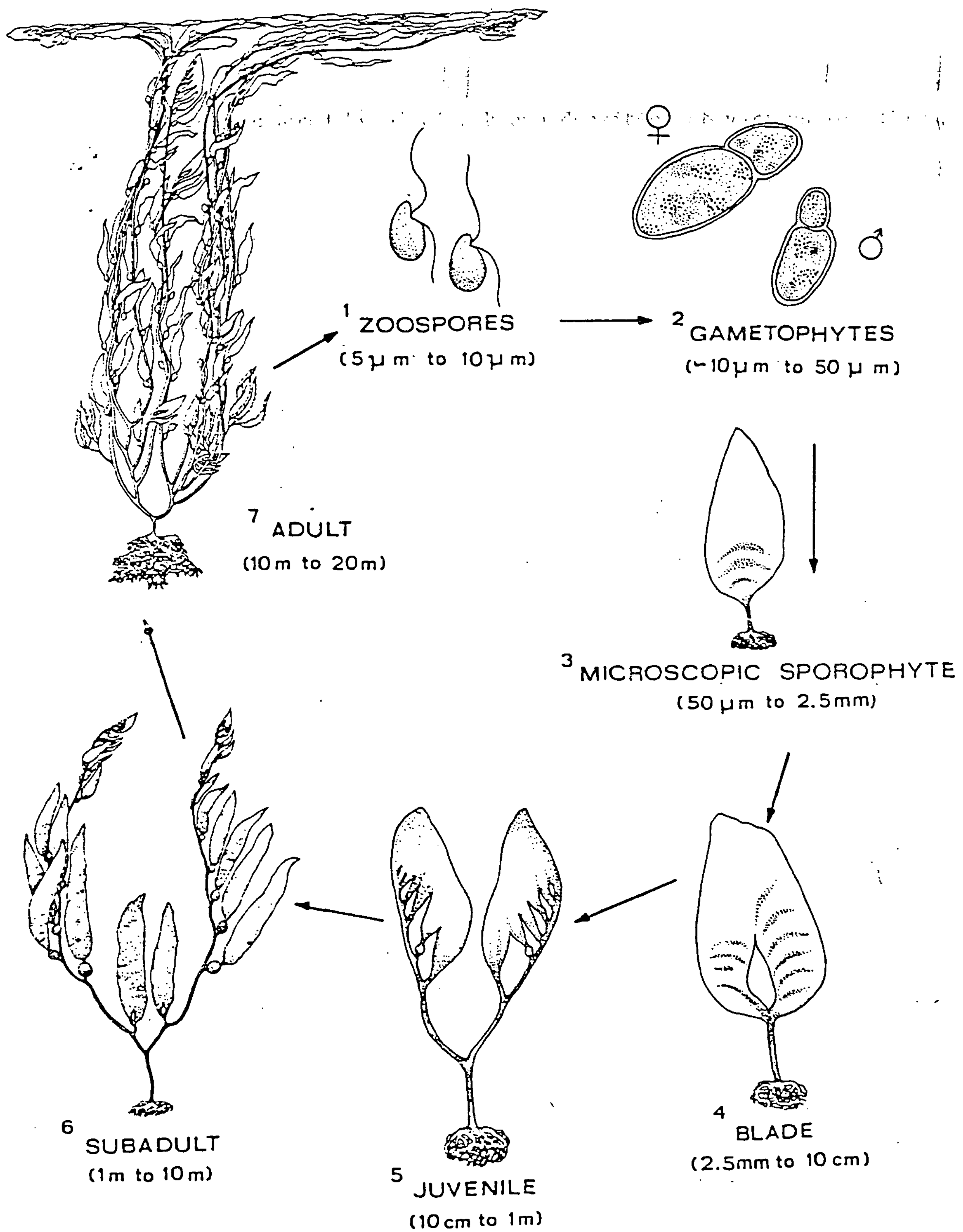
(1) Kelp cover was measured by sonar scanning.

(2) The density, growth and survival of juvenile and adult kelp plants (and some other biological variables) were measured along transects

in SOK.

(3) The reproductive success and survival of microscopic stages were measured by placing known densities at various locations, including some close to Unit 1 discharge. Temperature, light and sedimentation rates were also measured at these stations.

(4) Growth, blade loss, and survival of juvenile kelp plants were measured in groups of plants set out at various stations, including some close to the Unit 1 discharge. Light, temperature, and degree of fouling were also measured.



1 ZOOSPORES
(5 µm to 10 µm)
2 GAMETOPHYTES
(~10 µm to 50 µm)
3 MICROSCOPIC SPOROPHYTE
(50 µm to 2.5mm)
4 BLADE
(2.5mm to 10 cm)
5 JUVENILE
(10 cm to 1m)
6 SUBADULT
(1m to 10m)
7 ADULT
(10m to 20m)