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TECHNICAL REPORT
TO THE
CALIFORNIA COASTAL COMMISSION

H. Mitigation

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REPORT SUMMARY

The San Onofre Nuclear Generating Station (SONGS) has substantial adverse effects on local fish populations and organisms living in the San Onofre Kelp Forest; it is also calculated that local losses of fish larvae lead to reductions in some adult fish populations in the Southern California Bight. These effects could be mitigated by a combination of techniques that prevent losses and replace lost resources. This report evaluates the feasibility of more than 30 possible techniques for mitigating the effects of SONGS and provides background information for the mitigation recommendations made in the Marine Review Committee's Final Report to the California Coastal Commission.

In its Final Report, the MRC presents two options for mitigating the effects of SONGS. **Option 1: Changes to the Cooling System** responds to the directive in CCC Permit 183-73 that the Committee be responsible for "recommending ... any changes it believes necessary in the cooling system for Units 2 and 3" (Condition B.4). The Committee considered two changes in the cooling system, conversion to cooling towers or moving the discharge; Dr. Fay is the only Committee member recommending the construction of cooling towers, and no member recommends moving the discharge. **Option 2: Prevention and Mitigation** responds to the CCC's 1979 resolution requesting the MRC to study promising mitigation measures and to recommend measures "to assure there would be no net adverse effect on the marine environment." Option 2 consists of five different techniques for reducing or mitigating fish losses and one technique for mitigating the impacts to the San Onofre Kelp Forest community: (1) avoid operations during periods of high abundance of fish larvae, (2) reduce the volume of water flowing through SONGS,

(3) construct an artificial reef, (4) restore a coastal wetland, (5) reduce the in-plant loss of juvenile and adult fish by installing sonic devices, mercury lights or other devices, and (6) create a kelp bed. Different combinations of the first four techniques could each result in complete mitigation of the Bight-wide fish losses. The Committee unanimously recommends the adoption of Option 2.

In this summary, loss prevention techniques are discussed first, followed by techniques for replacing lost resources. The last chapter of this report, Chapter 13, discusses the MRC's mitigation recommendations; since Chapter 13 briefly discusses the advantages and disadvantages of the most promising techniques, it provides a useful summary for the reader who does not require a detailed review of all of the techniques evaluated.

Loss prevention

Although many different loss-prevention techniques have been developed to reduce impacts associated with power plant cooling systems, most development and testing has focused on power plants that are much smaller than SONGS or are not located on the coast of a temperate ocean, making it difficult to evaluate the feasibility of using these techniques at SONGS. In spite of this, several techniques merit further consideration, and it seems feasible to reduce the losses associated with the operation of SONGS.

Intake

Fish larvae, juveniles and adults are entrained by the intake flow at SONGS; in addition, juvenile and adult fish are killed during periodic heat treatments of the cooling system. The loss of juvenile and adult fish could likely be reduced by installing sonic devices near the intakes and by installing sonic devices and mercury lights in the collection area of the Fish Return System (FRS). Sonic devices reduce entrapment by frightening fish away from the intakes; they would probably be most effective for transient schooling species such as northern anchovy. Mercury lights would attract fish that had already been entrapped into the collection bay of the FRS; they would improve the effectiveness of the FRS during normal operation, but their greatest value might be for reducing fish losses during heat treatments (which accounts for about 20% of the total biomass of fish killed in the plant). Both of these techniques would be relatively inexpensive to implement, but their effectiveness should be field-tested before they are required at SONGS.

Many fish are killed when they are impinged on or pass through the traveling screens. Some of these, especially larvae and juveniles, cannot actively avoid entrainment; to reduce the loss of these fish, they must be physically excluded by some type of barrier. The barrier could be located at the intake or at the traveling screens. At the high flow rates that occur at SONGS, using screens or other barriers (e.g. porous dikes, infiltration beds) to exclude fish at the intake would present problems with effectiveness, maintenance (especially the removal of debris), and increased pumping requirements. Small-mesh screens at the traveling screens would retain larvae and small fish, and other modifications might minimize impingement losses; however, this technique has many potential technical difficulties and questionable effectiveness, so it is not recommended.

Discharge

The turbid plume resulting from the discharge of water through the diffusers of SONGS Units 2 and 3 has caused the loss of resources at the San Onofre Kelp Bed (SOK), including giant kelp, kelp bed fish, and benthic invertebrates. Modifications to the diffusers could reduce the turbidity of the discharge plume or move the plume away from the sensitive kelp bed habitat. Modifications to the existing diffuser system would reduce turbidity by reducing the amount of turbid water entrained into the plume, but there is considerable uncertainty about the effectiveness of these modifications; there would likely be some remaining, but reduced, impact to SOK. Moving the discharge away from SOK would be costly (up to several hundred million dollars), but would certainly eliminate the impacts of SONGS' discharge on the kelp bed, and would have little adverse effect. (Moving the discharge would not reduce the impacts of SONGS on fish.) Within existing engineering constraints, and assuming that the new discharge would be a single-point discharge rather than a diffuser, the discharge could be moved somewhat farther offshore, or upcoast or downcoast from SONGS. Modifying or moving the discharge would require a variance from the thermal standards because less mixing with ambient seawater would result, and in some locations the plume would impinge on the shore.

Although moving the discharge would eliminate ongoing impacts to SOK, some residual impacts to the kelp bed might still need to be mitigated. Because an artificial reef with kelp could adequately mitigate impacts to the kelp forest community for a much lower cost, moving the discharge is not recommended.

Replacement of cooling system

Replacing the existing cooling system with closed cycle cooling would minimize impacts to marine resources by greatly reducing the amount of water used for cooling. However, the only closed cycle cooling systems that seem feasible at SONGS involve cooling towers, which have environmental (from salt drift and some discharges to the ocean), safety (ground fog), and aesthetic (high profiles, noise) costs as well as high financial costs ($500 million to $1 billion for construction and an additional $1 billion over the lifetime of the plant due to reduced efficiency of the towers). Also, some of the most suitable cooling tower technologies have not been demonstrated on the scale needed for SONGS, and there would be logistical problems (e.g. SCE does not own the land on which the cooling towers would be built).

Modifying plant operations

The loss of fish larvae could be decreased by reducing the volume of water that passes through the cooling system. Curtailing plant operations at specific critical times could result in a disproportionate reduction in impacts. Fish larvae are far more abundant during February through April than during the rest of the year. Eliminating the flow of water through SONGS in March and April could reduce the amount of fish larvae killed by SONGS by 2.5 billion larvae, cutting the estimated losses in half. The cost of this technique would be minimized by having SONGS' refueling and maintenance scheduled for this period, although there are technical and logistical difficulties with having SONGS refuel at the same time every year or every other year.

Reducing the flow of water through SONGS while the plant operates at full power would also reduce the number of fish larvae killed by SONGS. Reducing the volume of water flowing through the plant by about one-third appears feasible, although this would reduce the efficiency of the plant by about 2%. Reducing the flow by one-third from February to May would reduce larval losses by 26%, and cost about $5 million per year for both units.

The MRC has recommended, as one possible means of mitigating fish losses, decreasing the number of larvae killed each year by reducing the amount of time SONGS operates during periods of high larval abundances and/or reducing the flow of water through SONGS or other SCE coastal power plants.

Replacing lost resources

If losses cannot be prevented, then SONGS' impacts must be mitigated by replacing lost resources. We consider techniques that replace lost resources with identical resources (in-kind mitigation), and those that substitute different resources for lost resources (out-of-kind mitigation). The most promising replacement techniques are constructing an artificial reef and restoring a coastal wetland.

Artificial Reefs

Properly designed artificial reefs can support communities of fish, invertebrates and algae that are similar to those found on natural reefs. The production of sessile and sedentary reef organisms (such as invertebrates and algae) is increased by artificial reefs, but the amount of fish produced by (as opposed to attracted to) artificial reefs has not been determined. There is clear evidence that some aspects of production, such as recruitment and growth, are enhanced by artificial reefs, but there may also be negative effects from increased fishing mortality. Most concern about fish production on artificial reefs has focused on small artificial reefs and artificial reefs constructed from scrap materials; a large artificial reef constructed from quarry rock would likely circumvent the limitations of these small reefs. A large artificial reef could furnish many different types of habitats and microhabitats and an increased variety of food resources for fish. Fish that are transients on a small reef might remain as residents on a large one. Fishing mortality might be reduced on a large reef since it would not be as attractive to fishermen if fish densities are lower and fish are not concentrated in a small area. Thus, despite the unresolved question of fish production, it seems likely that an artificial reef that mimics the size, configuration and location of a natural reef would provide suitable in-kind mitigation for impacts to the natural reef. The MRC has recommended that an artificial reef be constructed as in-kind mitigation for impacts to the kelp forest community (see next section).

Using artificial reefs for out-of-kind mitigation will involve a higher degree of scientific uncertainty than their use for in-kind mitigation because (1) there are no quantitative data on the amount of fish produced on artificial reefs and (2) there is no agreed-upon method of determining the relative values of the fish killed by SONGS and reef resources. Nonetheless, properly designed artificial reefs certainly produce resources, and so represent, along with wetland restoration, one of the two best available techniques for enhancing marine resources. The MRC has recommended that a high-relief artificial reef be one possible means of mitigating fish losses, and has estimated (using methods described in Appendix D) that a 60-ha artificial reef would provide adequate mitigation for the fish losses caused by SONGS.

Kelp bed creation

Kelp beds are a valuable marine habitat in Southern California. For impacts that result in the degradation or destruction of a kelp bed, the creation of a new bed or restoration of the existing bed is the most straightforward mitigation technique. Restoration of the affected portion of SOK would not be suitable because the impact is ongoing; the creation of a new kelp bed is preferred.

Giant kelp (*Macrocystis pyrifera*) almost always attaches to a hard substrate, so attempts to create new kelp beds have focused on providing new hard substrate, such as an artificial reef. Giant kelp has grown on several artificial reefs, when the kelp either recruited naturally to the reef or was purposely transplanted, but very few new, self-sustaining kelp beds have been created. Thus, any attempt to create a new kelp bed as mitigation must recognize that there is uncertainty involved. However, steps can be taken to minimize the uncertainty. In particular, the location of the new *Macrocystis* bed and the design of the artificial reef appear to be important. Despite limited success in the past, it should be possible to create a persistent, self-sustaining kelp bed under the proper conditions. In addition, an artificial reef will produce other reef resources (see previous section). The MRC has recommended that a 120 ha artificial reef with kelp be constructed to mitigate for the estimated 80 ha of kelp lost from SOK.

Wetland restoration

SONGS has no direct effects on wetland habitats; wetland restoration could provide some in-kind mitigation for fish species that use coastal wetlands, but it would mostly provide out-of-kind mitigation. Coastal wetlands are rare and valuable habitats in Southern California, and there is a major effort by state and federal agencies to restore degraded wetlands. A restored wetland would produce marine resources, including fish; it could also provide important habitats for endangered species and migratory birds and valuable aesthetic and educational resources.

Coastal wetland sites in Southern California are in high demand and restoration/enhancement plans have already been developed for most sites. Thus, it may be difficult to find an appropriate wetland that could be restored as mitigation for SONGS' effects, and land ownership is a major factor in determining the feasibility of using wetland restoration for mitigation of SONGS' impacts. The small portion of the Huntington Beach Wetland owned by Southern California Edison is one alternative; although restoration of this wetland is technically possible, a number of obstacles would have to be overcome before it could be applied as mitigation for SONGS, including determining the amount of credit to be assigned for the restoration.

A difficult problem inherent in using wetland restoration as mitigation for SONGS' effects, once again, is assigning a value to dissimilar resources (e.g. midwater fish and wetland habitat) so that values of the lost and gained resources can be balanced. The scientific basis for any evaluation methodology has not been well developed, so some subjective evaluation will be necessary. The MRC has judged that restoring 30 to 60 ha of coastal wetland would be one possible means of mitigating the impacts of SONGS on fish.

Other Techniques

In some circumstances (i.e. where juvenile production is limiting), a fish hatchery could theoretically replace lost fish resources by providing juvenile fish that could be released in the wild. The use of hatcheries to enhance marine fish stocks is a recent development, and its feasibility is just beginning to be evaluated. There are at least two serious technical problems that limit the feasibility of using a fish hatchery as mitigation for fish losses caused by SONGS. First, few marine fish have been raised in a hatchery situation. It seems likely that nearly all species *could* be raised in a hatchery, but probably not within reasonable limits of time and money. Second, little is known about the critical factors limiting many marine fish populations. For example, despite a large production of hatchery-reared smolts, the success of enhancement programs for salmonids in British Columbia, Washington and Oregon has been limited. It is clear that much more information about the life histories of marine fish, the processes underlying the dynamics of the populations and the nature of potential bottlenecks, is necessary before it can be determined whether a hatchery could even *potentially* enhance a population. Blindly restocking a population from a hatchery has a high likelihood of failure.

Three other potential out-of-kind mitigation techniques are coastal land acquisition, information acquisition, and water quality improvement. These could be appropriate for mitigating impacts to resources (such as midwater fish) that are difficult to replace in kind. However, they do not conform to generally accepted mitigation guidelines and are not part of the mitigation package recommended by the MRC.

Monitoring

All of the techniques for replacing resources impacted by SONGS must be considered experimental because their successful use in mitigating similar impacts has not been demonstrated. For this reason, it is crucial to monitor *any* implemented technique. The criteria for success of each implemented technique must be clearly defined so that subsequent monitoring can unambiguously determine success or failure. Equally important is a contingency plan so that a failure of the original mitigation plan results in its modification or the substitution of a new plan that prevents an unnecessary loss of resources.

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CHAPTER 1

INTRODUCTION

This report evaluates the feasibility of techniques that could potentially be used to mitigate the adverse effects of the San Onofre Nuclear Generating Station (SONGS) on the marine environment. Initially, one aim of the MRC was to provide information to the CCC concerning possible changes in the cooling system of SONGS to prevent or reduce any adverse effects. In 1979, the California Coastal Commission recognized that some effects might be mitigated without requiring changes in the cooling system (Fischer 1979). In this report, the feasibility of techniques that do not involve structural changes to the plant are considered along with those that do. The purpose of this report is to provide the technical support for the mitigation recommendations made by the MRC in its Final Report to the California Coastal Commission.

Before the feasibility of potential mitigation techniques can be evaluated, the impacts from SONGS must be identified. These are presented in the Final Report to the CCC, with supporting documentation in the Technical Reports; this information is summarized in Section 1.3.

After the impacts have been identified, techniques that could be used to mitigate them need to be defined and evaluated. Three sources have been used to identify the particular techniques considered in this report. First, studies initiated by the Marine Review Committee that were directly related to mitigation (Sheehy 1981, Thum *et al.* 1983, Ambrose 1986a, 1986b) or related to particular techniques (Lockheed Ocean Science Laboratories 1983a, 1983b, 1983c, Allen *et al.* 1984, Ambrose 1987a, 1987b, Ambrose *et al.* 1987, DeMartini 1987) were reviewed. Most of these studies focused on artificial reefs, although Ambrose (1986b) considered a wide range of techniques that could be applied at SONGS. Second, ideas were solicited from and discussed with many agencies involved with mitigation, especially the California Department of Fish and Game (CDF&G), the U.S. Fish and Wildlife Service (FWS), and the National Marine Fisheries Service (NMFS). Third, we examined the relevant literature; this was particularly important for identifying potential techniques for reducing losses (Section I). Throughout this process, an attempt was made to identify innovative new techniques.

Section I (Chapters 2 through 6) of this report discusses techniques that could *reduce* resource losses caused by SONGS by modifying the cooling system or non-structural changes.

Section II (Chapters 7 through 12) of this report discusses techniques that could create new resources to *replace* the resources lost due to SONGS. Chapters 8 through 11 evaluate artificial reefs, kelp bed creation, wetland restoration and fish hatcheries. Creating a kelp bed on an artificial reef (discussed in Chapters 8 and 9) could serve as in-kind mitigation for impacts to the San Onofre Kelp forest community. An artificial reef could also serve as primarily out-of-kind mitigation for fish impacts caused by SONGS, as could the other techniques evaluated. Chapter 12 discusses various other techniques.

The final section of this report, Section III (Chapter 13), discusses the technical basis for the MRC's recommendations, made in the Final Report to the California Coastal Commission, for mitigating the effects of SONGS. This section is intended to provide supporting documentation for the mitigation recommendations in the Final Report to the CCC.

1.1 Overview of mitigation

Many development projects, including the construction and operation of the San Onofre Nuclear Generating Station, result in environmental impacts. The concept of *mitigating* these impacts has developed as a means of allowing resource use, in spite of its impacts, while maintaining environmental quality. There is no universally accepted definition of mitigation, but definitions from the National Environmental Policy Act (NEPA) and the Fish and Wildlife Coordination Act (FWCA) are commonly used. Because the FWCA definition is directed specifically at fish and wildlife resources, it is reproduced here:

> "Mitigation" means (a) lessening wildlife resource losses to a project through loss prevention measures and (b) offsetting losses through the use of other structural and non-structural measures.
>
> "Loss Prevention" means designing and implementing a project to avoid adverse impacts upon wildlife resources.
>
> "Compensation" means completely (i.e., 100%) offsetting losses to wildlife resource values...

The Fish and Wildlife Service, as the federal agency charged with primary responsibility for evaluating impacts on wildlife, has developed an official Mitigation Policy (copy appended to Ambrose 1986b). The stated purpose of this policy is "to protect and conserve the most important and valuable fish and wildlife resources while facilitating balanced development of the Nation's natural resources" (USFWS

1981, p. 7644). The fundamental principles guiding the FWS policy are (1) that avoidance or compensation be recommended for the most valued resources; and (2) that the degree of mitigation requested correspond to the value and scarcity of the habitat at risk. Two fundamentally different types of mitigative compensation are distinguished. *In-kind* replacement of resources involves resources that are physically and biologically similar to those being altered and that play similar roles in ecosystem function, whereas *out-of-kind* substitution of resources involves resources that are physically and/or biologically dissimilar in any number of characteristics (Ashe 1982). In-kind compensation is generally preferred, especially for highly valued resources (USFWS 1981).

In California, the authority to require mitigation measures rests with the permitting agency, although a number of agencies (such as CDF&G, FWS and NMFS) serve in an advisory capacity by commenting on and helping to develop proposed mitigation plans. Although the different agencies in California do not have a formal, coordinated mitigation policy, the general philosophy used to evaluate mitigation proposals follows the federal guidelines established by FWS. Thus, loss prevention is generally the most desirable form of mitigation, especially when this can be implemented during the pre-construction phases of a project. In-kind/on-site replacement of resources is the most desirable form of compensation, with out-of-kind substitution of resources being generally less preferred. However, wetlands have been accorded such a high priority for preservation by both local and federal agencies that wetland restoration is viewed as a relatively valuable mitigative action, even if it is out-of-kind.

In spite of California's commitment to mitigation, its application in the marine environment is a relatively recent development. Most local coastal projects that have required mitigation have involved harbors, bays or wetlands (Table 1-1). These habitats are very different from the open coastal habitat around SONGS. Furthermore, habitat destruction has been the primary impact of these projects, whereas the impacts of SONGS are more varied. In addition to habitat degradation, the entrapment of fish at SONGS results in the direct loss of resources, even though it does not alter the midwater habitat.

1.2 Monitoring

A significant obstacle to recommending and evaluating possible mitigation techniques in the marine environment has been the lack of relevant information. Perhaps some uncertainty is inevitable, since coastal mitigation is a relatively new phenomenon, but the problem is certainly exacerbated by the general absence of follow-up or monitoring studies for techniques that have been implemented. Without a critical evaluation of a technique, no progress can be made towards more effective implementation of that technique in the future. Furthermore, without follow-up studies the successfulness of a particular technique cannot be determined. Follow-up studies are particularly important in a situation such as the open coast, where few mitigation techniques have been implemented previously.

I have considered monitoring or follow-up studies to be an important, integral part of most recommended techniques. In some cases, such as pneumatic guns and mercury lights, the follow-up studies will be needed to confirm that they provide the amount of mitigation projected; once this has been confirmed,

Table 1-1
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Examples of west coast marine mitigation projects. Modified and updated from Thum 1985.

PROJECT TITLE	DATE	TYPE OF HABITAT IMPACTED	TYPE OF MITIGATION ON/OFFSITE IN/OUT OF KIND	FORM & LOCATION OF MITIGATION	REFERENCE
Terminal 91 Mitigation Reef Port of Seattle	1986	Elliot Bay hard bottom 10-50' deep 7 acres	Onsite(?) Inkind (entire community)	Construct an artificial reef of quarry rock (+ concrete), 7 modules (5-10' high), 3.5 acres rock, covering 7 acres, 10-40'deep	Greg Hueckel, (206) 753-2545
Port of Long Beach Major Fill "Pier J"	1986	Long Beach Harbor soft benthic semi-enclosed, 35-50' deep	Offsite Inkind	Restore degraded wetland and shallow water habitat by dredging and restoring tidal flow, Seal Beach Wildlife Refuge	Jim Slawson, NMFS (213) 548-2518
Port of L.A. Major Fill "Pac-Tex"	1986	Long Beach Harbor soft benthic semi-enclosed 35-50' deep	Offsite Inkind	Restore degraded wetland and shallow water habitat by dredging and restoring tidal flow, Batiquitos Lagoon	Bob Hoffman, NMFS (213) 548-2518
Port of Long Beach Minor Fills	1984	Long Beach Harbor soft benthic semi-enclosed 35-50' deep	Offsite Inkind	Restore degraded wetland and shallow water habitat by dredging and restoring tidal flow, Upper Newport Bay	Jim Slawson, NMFS (213) 548-2518
THUMS Reef	1982	soft benthic 35' deep	Onsite Out of kind	Construct an artificial reef of quarry rock, 14 modules, 35' deep, Long Beach Harbor	Jim Slawson, NMFS (213) 548-2518
Chart House Restaurant Fill, San Diego Bay	1981	Intertidal sand less than 1 acre fill	Onsite Out of kind	Construct an artificial reef of concrete pipe of a size equal to the area lost to fill, 4 modules?, 15-25' deep	Tomas Firle, Port of San Diego (619) 291-3900

Table 1-1
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PROJECT TITLE	DATE	TYPE OF HABITAT IMPACTED	TYPE OF MITIGATION ON/OFFSITE IN/OUT OF KIND	FORM & LOCATION OF MITIGATION	REFERENCE
Ready Missile Test Facility	1977-1978	Western Arm Mugu Lagoon 3.8 acre fill	Onsite In & out of kind	Restore degraded wetlands by removal of fill and construction of a permanent channel opening to restore tidal circulation, 190-400 acres, Mugu Lagoon (Lugover Road)	USFWS reports (1979/1980) Coastal Society Symposium 1980 Mugu Symposium (1983) PN 77-99
Southern Pacific Railroad Bridge Santa Ynez River Estuary	1985	Santa Ynez River Estuary 4.1 acre fill	Onsite Inkind	Restore degraded wetland/estuary habitat by excavating tidal channels, removing fill and installing culverts (includes pre and post project studies). Santa Ynez River	CE and FWS letter on PN85-142 Dames & Moore SP RR documents
San Diego Bay/Bridge by Naval Nimitz Drive	1977-1978	San Diego Bay	Onsite In & out of kind	Placement of rock riprap and concrete plates to increase hard bottom habitat, 0-8' deep, improvements to public fishing area at edge of park, Cabrillo Landing	FWS/NMFS letters/files
Ventura Harbor Maintenance Dredging (excavation of channels boatslips/ placement of piers	1978 1980 1983	Santa Clara River Estuary	Onsite/Offsite In & out of kind	Create California least tern nesting site (with controlled access), create/revegetate dune habitat along Spinnaker Dr. (out of kind), placement of rock riprap (inkind).	CE public notices and and monitoring
Los Angeles Harbor Kelp Transplant Project	1977	Inner Los Angeles Harbor fill	Offsite Out of kind	Establish a kelp bed on San Pedro Breakwater by transplanting adult plants and sporophytes to artificial substrates attached to the breakwater.	D.W. Rice LA Harbor (213) 519-3400

additional monitoring will not be necessary. Specific objectives have been defined for most other techniques, with monitoring needed to confirm that the technique has achieved its objective. I have discussed the objectives and an outline of the monitoring needed along with each recommended technique.

Note that there are other recommended monitoring programs that are not related to mitigation techniques. These programs are discussed in Chapter 20 of the MRC's Final Report to the California Coastal Commission.

1.3 Summary of resource losses

The operation of SONGS has affected organisms through two main mechanisms: (1) killing organisms, especially immature and adult fish, that are taken into the plant with the cooling water, and (2) creating a turbid plume that affects the kelp, fish and invertebrates in the San Onofre Kelp Bed (SOK). These losses are discussed in detail in the Final Report to the CCC and the associated Technical Reports; we briefly summarize the impacts in this section and Table 1-2.

The MRC has measured adverse effects on the kelp community in SOK, including giant kelp, fish, and large benthic invertebrates. The area covered by moderate to high density kelp in SOK has been reduced on average by about 80 hetares (ha), or 60% below the abundance that would have occurred in the absence of SONGS. Fish living near the bottom in SOK (e.g., sheephead, barred sandbass and black surfperch) have been reduced by about 70% (roughly 200,000 fish weighing 25 MT) below the abundance that would have occurred in the absence of SONGS. The abundances of 13 species of snails and of the white sea urchin were

Table 1-2

Summary of SONGS effects on the marine environment (from Final Report to the CCC).

RESOURCE	EFFECT		Substantial Adverse Effect?
	Abundance near SONGS	Other	
Fish stocks in Bight	--	Bight-wide reductions of several % in a number of spp, several hundred MT. (Via larval intake losses)	yes
Midwater fish	Reductions in queenfish and white croaker (30-70% out to 2-3 km for queenfish) and 29 of 37 spp/station combinations		yes
Bottom fish	Increases in 5 of 8 spp and 36 of 52 spp/station combinations	Intake Losses: 1.27×10^6 (19-51 MT)/yr	no
Kelp bed fish	200,000 (25 MT) reduction near bottom. Increases in 3 of 4 spp in canopy, reductions in 5 of 6 spp on bottom (72% reduction in biomass)		yes
Fish larvae	No change (reduction in anchovy)	Intake Losses: 5.2×10^9 larvae/yr	yes
Kelp	Reduction of 80 ha (60%)	--	yes
Kelp Bed Biota	20-90% reduction in gastropods, 40-75% reduction in white urchins	--	yes
Soft Benthos	Widespread and extensive increases in existing species	--	no
Mysids	Increase	Intake Losses: 6.5×10^9 (20 MT)/yr	no
Plankton	No change (minor increases)	Intake Losses: 1350 MT zooplankton/yr	no
Sand crabs	--	None	no

also reduced substantially (30%-90%) below the levels that would have occurred in the absence of SONGS.

The MRC calculates that there is a substantial impact on the standing stock of a number of fish populations in the Southern California Bight. The reductions in standing stock are probably between one and ten percent, representing a loss of several hundred tons in standing stock.

The MRC has also measured a reduction in the local abundance of some midwater fish populations. The local abundance of queenfish has been reduced by between 30% and 70%, depending on location, out to a distance of 2-3 km from SONGS, relative to the abundance expected in the absence of SONGS. A similar reduction occurred in white croaker, but over a smaller area. In addition, SONGS kills at least 19 metric tons (MT) of fish per year in its intake system. This estimate was made in a period of depressed fish abundance, and over the long term the amount killed will be about 51 MT per year.

Other parts of the community that were studied and in which no substantial adverse effects were found are: the zooplankton, a range of animals associated with sandy bottoms (including invertebrates living in or on the soft sediments, semi-planktonic organisms and bottom-dwelling fish), and intertidal sand crabs. Some groups associated with sandy bottoms increased in abundance as a result of SONGS' operations.

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SECTION I

LOSS REDUCTION TECHNIQUES

CHAPTER 2

INTRODUCTION TO LOSS REDUCTION TECHNIQUES

All things being equal, the most preferred technique for mitigating an environmental impact is to avoid the impact. This section explores techniques that could potentially reduce the impacts of SONGS by preventing the loss of resources. One class of techniques considered here involves structural changes to SONGS, although non-structural techniques are also included. Structural changes are reviewed because the operating permit for SONGS (Permit 183-73) specifically indicates that modifications to the cooling system (including the construction of cooling towers) could be considered in order to reduce substantial adverse effects on the marine environment.

The only technique that would certainly eliminate all of the *local* biological effects of SONGS would be to stop the operation of SONGS. Although this alternative would eliminate *local* environmental effects, it would not minimize *regional* effects because power would have to produced at other generating stations, which might cause greater environmental impacts. Like SONGS, SCE's other generating stations use once-through cooling systems, so fish larvae and older fish lifestages would be killed during their operations. SONGS produces virtually no air pollution; when SONGS is offline, the power it would provide has to be produced by one of SCE's oil and gas plants in the Los Angeles Basin. Even though SCE would use the most fuel-efficient plant that is available first (B. Mechalas, *personal communication*), this would result in greater emissions in the Basin as well as higher costs. The South Coast Air Quality Management District is very concerned about increased emissions in the Basin, and would need to approve any arrangement to run SONGS less and Basin stations more (Mechalas, *personal communication*). In the context of the entire Southern Californian environment, shutting down SONGS would be expensive and would result in different, and perhaps more severe, environmental impacts.

A second loss-reduction alternative that would greatly reduce the impacts of SONGS on the marine environment is to convert SONGS from an open cooling system to a closed system (Chapter 5). The most obvious way to convert SONGS to a closed system is to build cooling towers. Cooling towers would reduce the amount of seawater taken in and discharged by SONGS, and so would virtually eliminate impingement and entrainment losses and losses due to increased sedimentation or turbidity. However, cooling towers are expensive, and would largely shift environmental effects from the marine environment to the terrestrial environment. Increased ground-level fogging, salt drift and other impacts would affect human safety and terrestrial organisms.

The remaining techniques for preventing resource losses can be categorized as structural changes to the intake system, structural changes to the discharge system, and nonstructural changes.

Structural changes to the intake system (Chapter 3) would be designed to prevent organisms from being taken into the plant or to return entrapped organisms to the ocean. Fish are most likely to suffer substantial losses due to entrainment or impingement. The Fish Return System is designed to minimize the loss of juvenile and adult fish, and it is reasonably effective (see Technical Report C). Therefore, the most important changes to the intake system would be those that reduce the entrainment of fish larvae. Changes that might reduce larval entrainment include: modifying the traveling screens, infiltration beds, porous dikes, intake barrier systems, and relocating the intakes. None of these techniques seem very promising.

Structural changes to the discharge system (Chapter 4) would be designed primarily to eliminate or reduce increased sedimentation and/or turbidity near the present diffusers. These techniques fall into two categories. One set of techniques modifies the existing diffuser system in order to reduce the amount of sediment it entrains. Several types of modifications seem promising, but there is uncertainty about their effectiveness. The second set of techniques changes the type and/or location of the discharge in order to avoid the sensitive hard bottom/kelp bed areas. Changing the location of the discharge would eliminate the effects of SONGS on the San Onofre Kelp forest community, but technical and regulatory obstacles would have to be solved and the cost would be high. (A third set of techniques, conversion to closed-cycle cooling, is discussed above and in Chapter 5.)

Nonstructural changes involve a wide variety of techniques that would reduce a variety of different impacts. Some of these techniques would reduce the number of organisms taken into SONGS (Chapter 3). The most promising nonstructural changes to the intake system include pneumatic guns and light systems to reduce fish impingement and heat-treatment losses. Other techniques would not be feasible at SONGS, including the following behavioral barriers designed to reduce the entrapment of juvenile and adult fish: electric fields, bubble curtains and water jets. Finally, there are changes to the operation of SONGS (Chapter 6) that could reduce losses. The most promising of these include reducing the amount of water passing through the cooling system at SONGS, and scheduling SONGS to be shutdown during periods of high abundance of fish larvae and/or high probability of kelp recruitment.

Some of the techniques evaluated in Section I have been discussed in previous reports to the MRC (e.g., Ambrose 1986), and there is a substantial body of general information about reducing losses (especially fish losses) at power plants. Southern California Edison has also sponsored a number of studies specifically directed at evaluating possible loss-reduction techniques (e.g., Schuler and Larson 1975, Lawler, Matusky and Skelly Engineers 1979, 1982, Thomas *et al.* 1980, McGroddy *et al.* 1981). In addition to these studies, a number of general works have been reviewed (e.g., Hanson *et al.* 1977, Hocutt *et al.* 1980, Dorn and Johnson 1981, Micheletti 1988).

This section is comprised of five chapters. This chapter (Chapter 2) summarizes the design and operation of SONGS. Chapter 3 discusses the intake system at SONGS, including existing technologies for reducing losses (velocity cap and Fish Return System) and potential techniques that might be effective. Chapter 4 discusses the discharge system, including possible modifications to the existing system. Chapter 5 considers the feasibility of replacing the existing cooling system with a closed-cycle cooling system. Finally, Chapter 6 discusses modifications to the operation of SONGS that could reduce resource losses. Each chapter includes a discussion of the technical feasibility of each technique and, where possible, a rough estimate of its cost and the amount of resources that might be saved. An attempt has been made to distinguish techniques that are feasible and reasonable from those that are not; the actual recommendations regarding mitigation are discussed in Section III.

2.1 Summary of SONGS Operations

The first step towards developing or evaluating techniques for reducing impacts from SONGS is to understand how the plant operates and how it interacts with the physical and biological environments. This section summarizes the relevant design and operation features of the San Onofre Nuclear Generating Station, and briefly discusses how the discharge affects the water around SONGS. Much of this information is reported in more detail elsewhere in the Final Report; in particular, physical oceanography is presented in Technical Report L. The more detailed description of the cooling system needed to evaluate the feasibility of some of the techniques evaluated here is presented in Appendix A.

SONGS uses an open cooling system; ocean water is used to cool the reactors in each of its 3 units. Unit 1 operates at 436 Megawatts (MW), while Units 2 and 3 each operate at 1100 MW. Unit 1 takes in seawater through a single intake located 907 m offshore at a maximum flow rate of 22 m^3/sec. The cooling water passes through condensers where the temperature is raised about 10.5°C and is subsequently returned to the ocean at a point discharge located 750 m offshore at a depth of about 7.6 m. Units 2 and 3 have separate intake structures located 970 m offshore and 200 m apart alongshore. Each of these units operates at a maximum flow rate of about 52.4 m^3/sec, raising the temperature about 9°C, and discharges water back through diffusers.

The diffuser systems for Units 2 and 3 begin about 1795 m and 1084 m offshore, respectively (Figure 2-1). The Unit 2 diffuser is located 220 m upcoast of the Unit 3 diffuser. Each diffuser is 750 m in length and has 63 discharge ports.

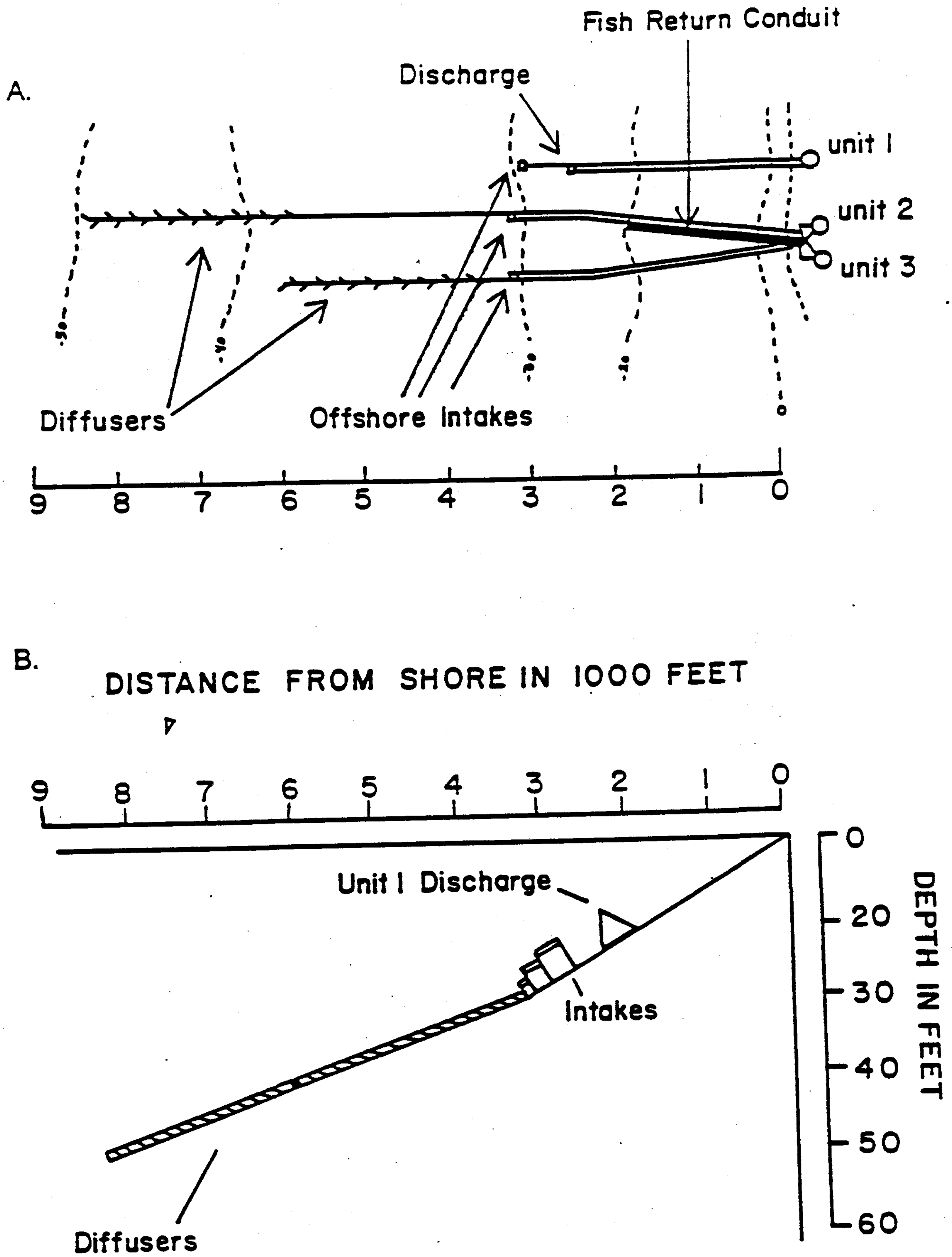

Figure 2-1: Expanded plan view (A) and side (cross-shelf) view (B) of the coastal region near San Onofre Nuclear Generating Station showing the placement of the intake pipes for all SONGS units, the discharge pipe for Unit 1 and the diffusers for Units 2 and 3.

The individual jets have an initial diameter of 0.5 m, each discharging 0.8 m^3/sec with an initial velocity of 4 m/sec. Ports extend 2.2 m above the bottom, are alternately aligned at angles of ± 25° from the diffuser lines, and tilt upwards at 20° from the horizontal (SCE 1981).

The diffusers were designed to provide efficient thermal mixing of the hot discharge water with the cool ambient water. In weak currents, ambient seawater is entrained in the discharge plumes at a rate that is 7 to 10 times greater than the cooling system flow, creating a total discharge plume flow rate of up to 550 m^3/sec for each of Units 2 and 3 (Fischer *et al.* 1979). The entrainment can rise to more than 20 times the discharge in strong currents. Thus, at least 90% of the water in the plume is entrained by the flow of water from the diffusers. The initial upward momentum, due to the tilt of each jet, and heated water carry the discharge towards the surface. In weakly stratified water, the plume will spread at the surface, achieving a thickness of 3-5 m within 1 km of the diffusers. In the summer months, thermal stratification is occasionally so pronounced that the plume never reaches the surface; due to rapid mixing with the cold bottom water, the plume reaches thermal equilibrium at mid-depths. The plume often extends several hundred m offshore from the end of the Unit 2 diffuser, but it can stretch up to 2 km beyond the diffuser. Due to the prevailing downcoast currents, the plume is frequently directed towards the San Onofre Kelp Bed.

The design of the diffuser has been optimized for thermal dispersion in order to meet state requirements for thermal discharges. Turbidity levels in the discharge plume were not considered in the design. However, the increased turbidity in the plume has negative effects on the marine environment.

The coast at SONGS is unprotected and the area is hydrodynamically complex. Local circulation patterns are determined by the interaction of water that flows into and out of SONGS with local currents, topography and kelp beds. Longshore currents are faster than 5 cm/sec about half the time, but are rarely faster than 25 cm/sec. Much of the flow is due to reversing tidal currents, and the mean drift is only about 4 cm/sec downcoast in summer and about 2 cm/sec downcoast in winter (Reitzel 1988). Flow patterns around the diffusers have been investigated empirically with the release of dyes (Eco-M 1987) and described by an analytical model (Eco-M 1988). Neither of these studies provides a complete description of the flow patterns around SONGS. The dye studies show only surface flow on a given day. The model uses a simplistic linearly increasing depth profile and a simple constant ambient current model and does not include the effects of nearby kelp beds. However, the studies seem to agree that some of the water that is entrained in the plume comes from inshore, but most comes from offshore.

The water in the plume is generally more turbid than the surrounding water. The higher turbidity in the plume results from the distribution of seston and the source of plume water. Seston concentration generally increases toward the shore and toward the bottom because these are the sources of seston. The plume is formed from water that is discharged from the plant and water that is entrained by the discharged water. Water that is discharged from the diffusers has a higher seston content on average than the surrounding water because the intakes are located inshore of the diffusers, where the water is more turbid. The sediment concentration of intake water is typically around 6 mg/l (range: 2-15 mg/l); at full flow, approximately 54 metric tons (MT) of sediment are transported through the plant per day. Water that is entrained into the plume comes from closer inshore and lower down than the ambient water it displaces. As the entrained water mixes with the discharged water, it warms up and rises in the water column, where it displaces the less turbid surface water.

The relative contributions of sediments from bottom water and inshore water, or discharged water and entrained water, are not known. However, it is clear that sediments in the intake water cannot account for all the sediments in the plume water. Measurements of sediments in the plume indicate concentrations of 7-12 mg/l, which is slightly higher than concentrations in intake water in spite of the fact that the intake water is diluted ten-fold by water that is entrained. If only water that was relatively sediment-free was entrained, the turbidity of plume water would be much lower than has been measured.

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CHAPTER 3

INTAKE SYSTEM

3.1 Loss reduction techniques now in use

SCE already employs two techniques to reduce the loss of fish at SONGS: velocity caps and a Fish Return System.

Each of the intakes for the three Units at SONGS is fitted with a velocity cap. The cap is a concrete slab supported 1.2 m above the opening of the intake for Unit 1, and 2.2 m above the opening for Units 2 and 3 (Figure 3-1). It is designed to produce a horizontal flow field; without a cap, the flow field into the intake would be vertical. It is supposedly easier for adult fish to avoid or escape from a horizontal flow field. The ability of juveniles to avoid entrapment depends on size and species. Larvae generally can not escape from the intake current, so the velocity caps have little effect on the entrainment rate of larvae.

Various reports (Thomas *et al.* 1980, Lawler, Matusky and Skelly Engineers 1982, EPRI 1984) have indicated that velocity caps reduce the entrainment rate of adult fish. Weight (1958) concluded that installation of velocity caps reduced annual entrapment by 95%. SCE (1974) found a 90% reduction in fish losses while a cap was in place compared to an 18-month period after the cap was removed. Schuler and Larson (1975) reported that a velocity cap reduced entrapment of anchovy by 85-90% in the laboratory. Thus, the general consensus has been that velocity caps reduce the entrapment of adult fish. However, several reports have indicated that the effectiveness of the caps may not be as great as claimed. For

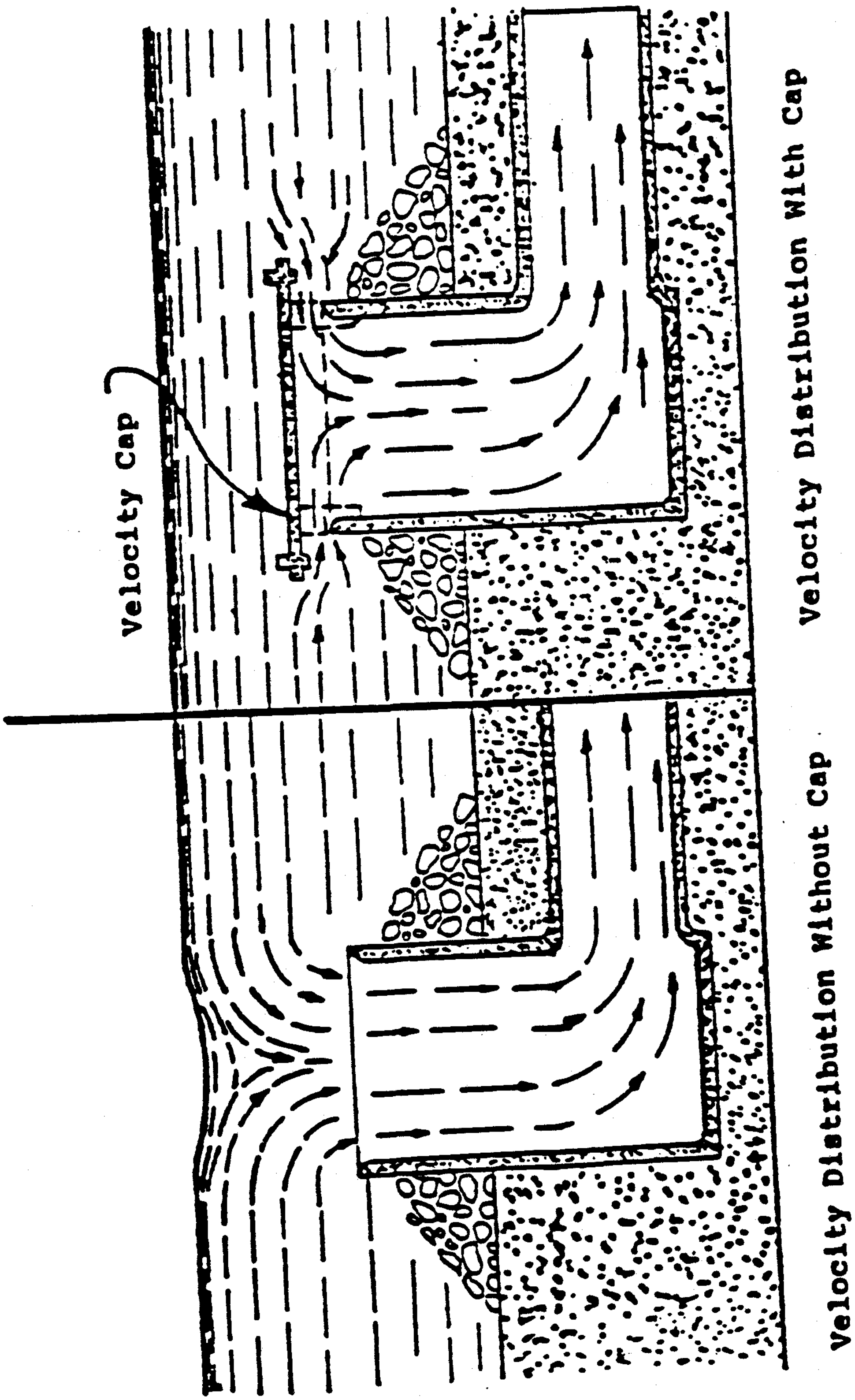


Figure 3-1: Schematic showing the change in flow pattern of the intake current when a velocity cap is placed over the intake pipe. Arrows indicate the direction of the current.

example, Sharma (1978) suggested that natural fluctuation in the density and distribution of fishes close to the intake, which was not addressed by Weight (1958), is the most important factor affecting fish entrapment, and Stupka and Sharma (1977) suggested that the velocity cap at SONGS may actually *enhance* fish entrapment.

The Fish Return System (FRS) is the second technique employed at SONGS to reduce the loss of entrapped fish. All of the fish entrapped at Unit 1 are eventually killed by being impinged on the traveling screens, passing through the screens and dying in the condensers, or being killed during heat treatments. Units 2 and 3 are each equipped with a Fish Return System that diverts fish before they are impinged on the traveling screens and returns them to the ocean. The FRS (Figure 3-2) consists of guiding vanes, vertical bar racks (louvers), a quiet area with a collection bucket, an elevator mechanism and a return sluice. The guide vanes are aligned with the incoming flow and ensure that the flow of water across the louvers is uniform. Uniform flow prevents turbulence, thus reducing the pump head loss through the system. The vanes are also designed to guide entrapped fish into the collection area by producing an even, steady flow through the louvers that is easier for the fish to sense and avoid. Turbulent flow can result in sudden bursts of high velocity flow across the louvers that could cause the fish to become impinged or injured. The louvers are located to one side of the incoming flow and are angled at about 20° towards the flow. The vertical slats of the louvers are 1/4" wide with a separation of 3/8". The louvers rotate periodically like a tank tread for cleaning. The louvers are rotated once a shift; rotation can also be triggered automatically by a pressure difference across the louvers (which would occur if material began to build up on the louvers). Small horizontal shelves located at about one-meter

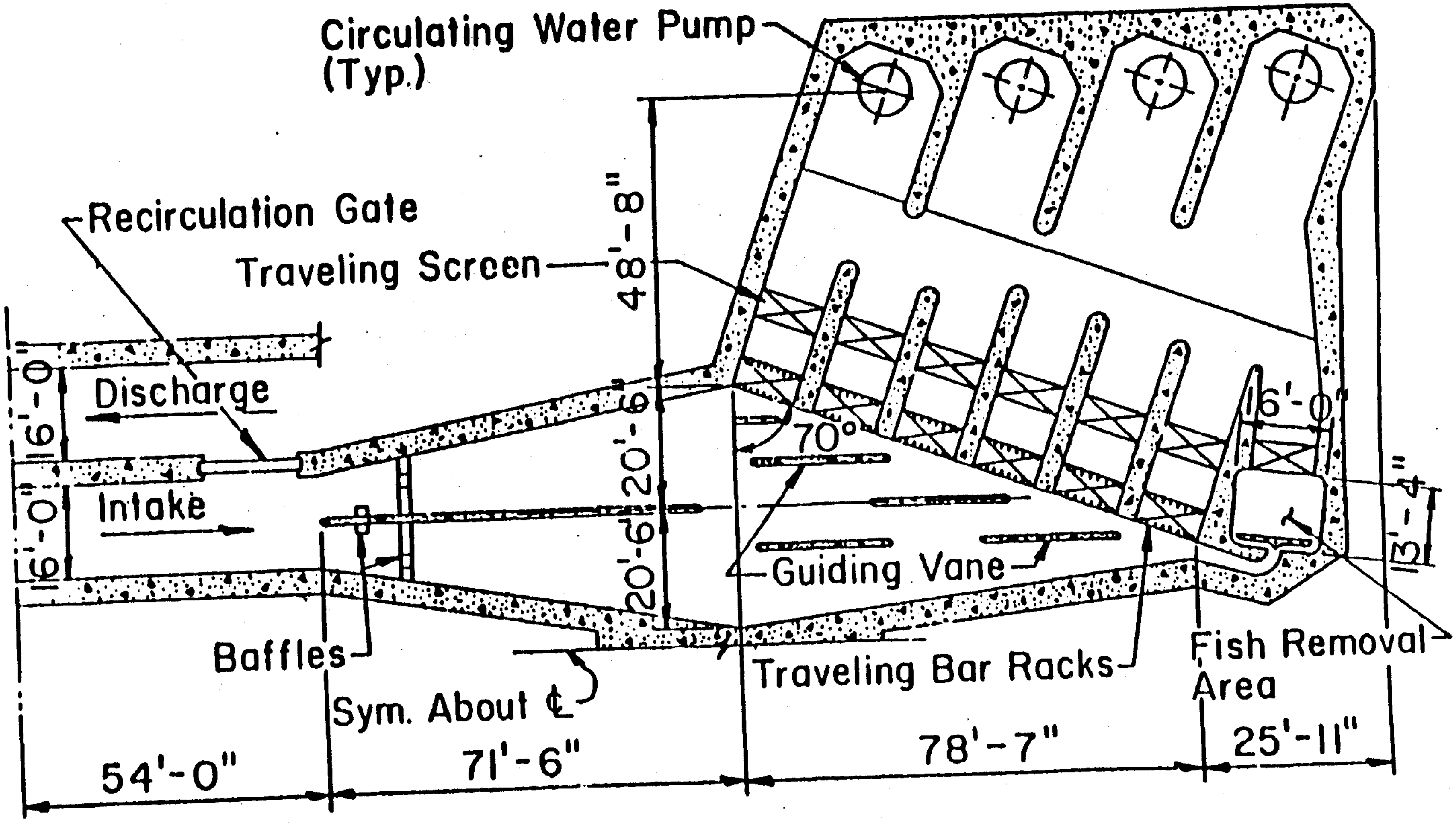


Figure 3-2: Schematic of the intake screenwell area showing the placement of the traveling bar racks (louvers), the traveling screens, and the collection area for the Fish Return System (fish removal area).

intervals on the louvers help lift the accumulating debris out of the water. Debris is washed with a high pressure spray into a sluice, and is eventually hauled away to a landfill. Traveling screens are downstream of the louvers in front of the pumps and catch debris that passes through the louvers.

Fish are guided along the vanes and louvers into a collection area where the flow is a quieter than the rest of the intake area. There is a traveling screen at the back of this area. The flow through the collection area is greater along the edges than in the center, so fish and debris (such as kelp fronds) can accumulate in a relatively quiet zone in the center of the collection area. The water in the collection area is about 9 m deep. A rectangular bucket, 6 m x 3 m x 1 m deep sits on the bottom of the collection area. The bucket doesn't quite fill the collection area; there is a gap of several centimeters on the sides and 1/2 m in the front and back. The top third of the bucket is mesh. During each 8-hour shift, the bucket is slowly (~1 ft/sec) lifted out of the water and dumped into a return sluice leading 650 m back to the ocean. The bucket is raised and dumped as many times as necessary to remove the majority of the fish from the collection area; when few fish have accumulated in the collection area since it was last emptied, the bucket might only be raised two or three times, but when there are many fish the bucket is raised six or seven times. The success of the FRS in returning fish alive to the ocean is evaluated in Technical Report C.

3.2 Structural changes

Many technologies have been developed and applied to power plant cooling water intakes; still more have been conceived that require further testing. A brief discussion of some of these techniques and their applicability to SONGS follows.

A wide variety of physical barriers to reduce fish loss have been proposed or implemented at hydroelectric dams, water diversion projects and irrigation canals as well as power plants. These barriers include stationary screens, vertical traveling screens (which are used at SONGS), horizontal traveling screens, vertical drum screens, horizontal drum screens, perforated plates, and rapid sand filters (Hanson *et al.* 1977); the most common or promising of these are discussed in this section.

3.2.1 Traveling screen modifications

Vertical traveling screens (Figure 3-3), such as those used at SONGS, form a continuous belt of screen panels that rotates vertically around two horizontal shafts; one shaft is located above the water and the other is submerged in the flow of water. Debris and impinged fish collect on the upstream side of the screens. (At SONGS, the louvers are upstream of the traveling screens, so the material that collects on the traveling screens has first passed through the slots in the louvers.) As the belt rotates, the debris and fish are carried out of the water and washed from the screens with a high-pressure spray into troughs, which carry it to a collection area. The screen belt rotates at regular intervals except during periods of heavy clogging, when the difference in the water level between the front and back side of the screen automatically triggers the rotation.

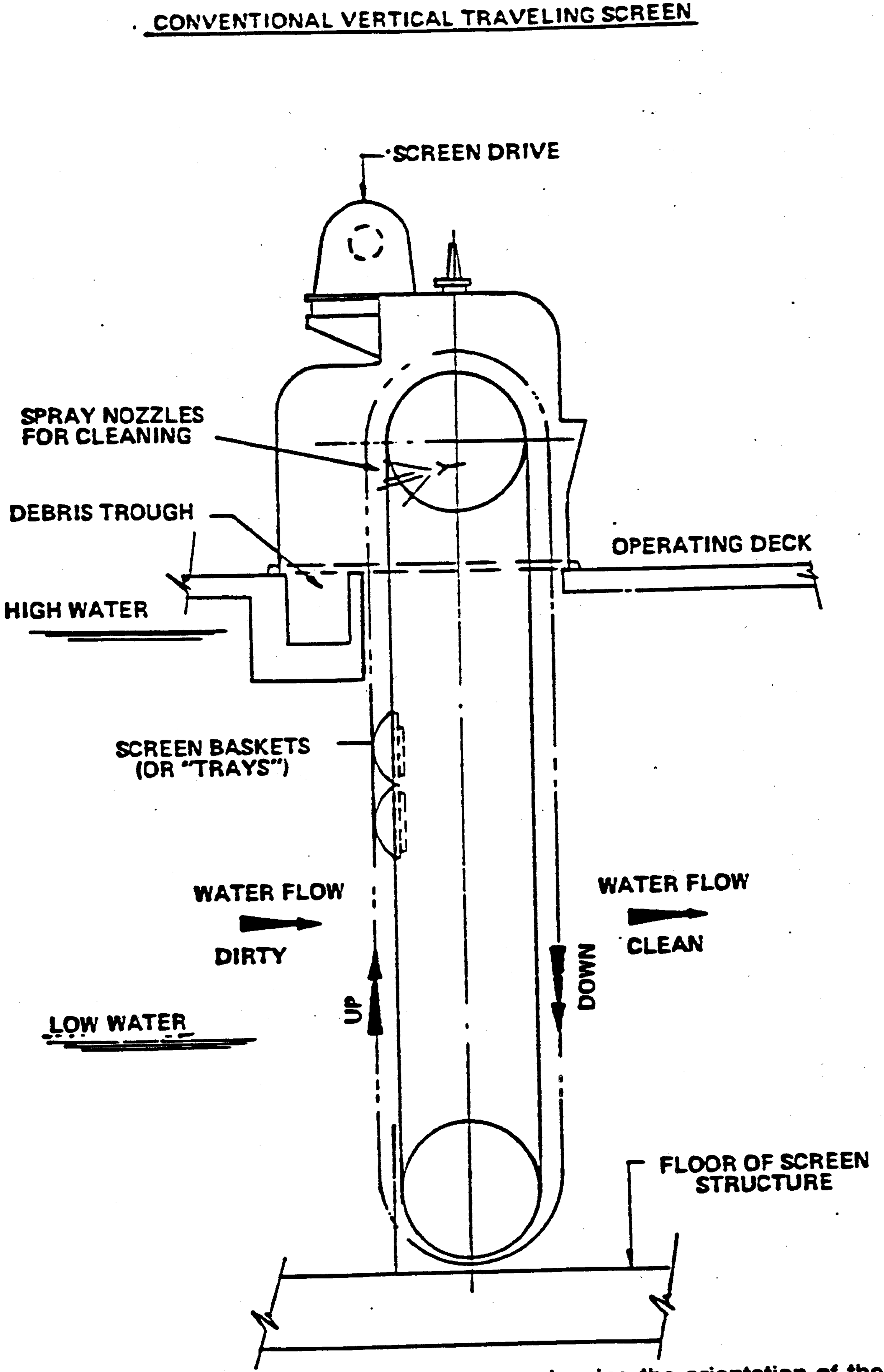


Figure 3-3: Schematic of a traveling screen showing the orientation of the screens, the direction of screen rotation and the placement of the debris trough and spray nozzles.

Fish that are impinged on or pass through the traveling screens at SONGS are killed. Several modifications could potentially enhance the survivorship of fish that contact or pass through the screens. The small fish that go through the screens could be retained by a smaller mesh screen (0.04"). The lip on the lower edge of each screen panel could be modified so that it retains several inches of water to help cushion the impact on fish as the screen rises out of the water. A separate low pressure spray could be added to remove fish and larvae before the high pressure spray removes attached debris; the more gentle spray would cause less trauma to the fish and larvae than the high pressure spray. Additional modifications could include retrofitting the screen drive and bearing systems to rotate and wash the screens continuously so that fish and larvae are not held against the screens for an extended period of time. Finally, a return conduit would need to be provided to return the impinged fish to the ocean.

A number of studies have evaluated the effectiveness of screen modifications in reducing mortality of impinged fish. Most of these studies have been conducted in freshwater, on the East Coast, or in the Pacific Northwest. The results show that when screens are modified, survivorship varies widely and is species-dependent. Survivorship ranged from 1% for bay anchovy at the Indian Point Nuclear Plant (Texas Instruments Inc. 1978) to an overall 97% immediate survival rate at the Surry Power Station in Virginia (M. Brehmer, *personal communication* to Lawler, Matusky and Skelly Engineers 1982).

A laboratory study of the survival of 6 larval species common to Southern California waters found that survivorship was highly variable as well as size- and species-dependent (Table 3-1; Edwards *et al.* 1981a). Survivorship varied from very low for kelpfish to >95% for large topsmelt (Edwards *et al.* 1981a). The effect on long-term survival was not tested, but is more relevant because abrasions and other damage due to impingement on screens may be debilitating even if they are not immediately lethal. Therefore, the effective survivorship may be substantially lower than the data presented indicate. In addition, some of the results were anomalous (e.g., much lower survival for large croaker at 15 cm/sec for 1-minute duration than at higher velocities, longer durations, or a smaller size).

Table 3-1

Mean impingement survival for six species of larvae, corrected for control survival (from Edwards et al. 1981a). Flow rate at the traveling screens at SONGS is 40 cm/second. – indicates testing not conducted.

			IMPINGEMENT SURVIVAL AT DURATION (MIN) AND VELOCITY (CM/S)					
			1 MINUTE			4 MINUTE		
SPECIES	SIZE CATEGORY	LENGTH (MM)	15 CM/S	30 CM/S	45 CM/S	15 CM/S	30 CM/S	45 CM/S
Topsmelt	Small	7.2-9.7	94	86	92	24	28	62
	Medium	13.3	87	69	34	69	40	27
	Large	18.3	100	98	98	100	99	100
Grunion	Small	9.0-12.6	41	55	57	33	40	21
	Medium	14.5-15.0	54	69	–	35	94	–
	Large	18.2-22.3	100	81	81	69	81	70
Anchovy	Small	18.0	40	–	–	–	–	–
	Large	31.8-37.0	–	56	31	–	66	52
Kelpfish	Small	14.1	7	0	–	–	–	–
	Large	18.9	48	9	24	0	0	–
Croaker	Small	17.8	96	97	98	97	97	100
	Large	23.1-24.8	8	98	–	100	100	–
Goby	Small	13.0	100	–	–	100	98	–

3.2.1.1 Potential reductions in losses

The studies of the effectiveness of screen modifications are not adequate for predicting precisely their effectiveness if they were to be used at SONGS. The relatively high survivorships for some species suggest that screen modifications might reduce fish losses. Furthermore, this technique appears to be one of the few structural changes that might significantly reduce larval losses at SONGS. However, there is considerable uncertainty about its effectiveness. Most of the studies have not been representative of the species or conditions that would be found at SONGS. The study by Edwards *et al.* (1981a) on fish larvae found in Southern California is relevant to SONGS, but the results were variable and sometimes anomalous, and the study only considered the immediate survival of the larvae used. In addition, no study has considered the impact of returning impinged fish through a conduit to the ocean. It seems likely that substantial physical damage would be incurred by a larva, or even adult fish, after being impinged on a traveling screen, washed off of the screen, dumped into a return conduit and flushed back to the ocean.

When used in conjunction with the FRS, modified screens would result in only a small reduction in the mortality rates of adult fish. Most (about 84%) of the adult fish that are entrapped by Units 2 and 3 are already diverted by the FRS before reaching the screens (Technical Report C). Even if SONGS' traveling screens were modified, the 800,000 fish (7.2 MT) that are impinged (see Technical Report C) would not all survive, since they would be stressed from impingement, handling, and the return trip to the ocean. We can make a very rough estimate of how many fish might be saved by using the data on survival rates of fish traveling through the FRS. Short-term (96 hrs) survivorship through the FRS ranged from 68% for small species (except for anchovy) to 100% for large species (Table 17 of Technical Report C); these values do not include mortality due to increased predation on diverted fish after their release to the ocean. The survival of fish impinged on modified traveling screens and returned to the ocean would probably be <u>much</u> lower than survival of diverted fish, primarily because the stress on impinged fish would be much greater. (Impinged fish also tend to be smaller than diverted fish, which probably makes them more vulnerable to physical damage during return and predation when discharged.) Assuming that one-third of the 7.2 MT of fish that are impinged annually at Units 2 & 3 would be saved by screen modifications, the savings would amount to approximately 2.4 MT of fish. An additional savings of adult fish could be realized by modifying the screens at Unit 1 because it has no FRS, so all entrapped fish are killed. However, the actual biomass of fish saved at Unit 1 would be less than that possible at Units 2 and 3 because the *total* biomass of fish entrapped at Unit 1 is only 4 MT (Technical Report C).

Perhaps the greatest promise for using modified traveling screens stems from their potential for saving fish larvae. The loss of fish larvae is particularly difficult to prevent, and modified traveling screens appear to be the most feasible structural modification to SONGS for reducing the loss of fish larvae at all three Units. However, it seems unlikely that many larvae could survive impingement on a screen, removal from the screen (even with a low-pressure wash) and return through a conduit to the ocean. Questions about the actual savings that could be achieved with modified traveling screens preclude recommending them for preventing larval losses.

3.2.1.2 Technical feasibility

Several technical difficulties are associated with modifications to the traveling screens. The pressure differential (head loss) across the fine mesh screen will be higher than for the existing screen. For example, the head loss across a clean 0.02" synthetic screen is typically three times that of a conventional 3/8" screen (Mussalli *et al.* 1981). This would lead to increased pumping costs and maintenance, and might require larger pumps. An additional consequence of the increased pressure differential across a finer-mesh screen is that the water level will be lower on the pump side of the screens than the current level, which could cause cavitation problems at low tides. Problems have also been encountered with the screen drive systems when continuous operation was attempted over extended periods (London 1980). The screenwell hydraulics might also need to be modified in order to provide a smooth approach flow to enhance the survival of fish and larvae (Lawler, Matusky and Skelly Engineers 1982).

3.2.1.3 Costs

Cost estimates for retrofitting a conventional traveling screen range from $13,800 to $110,000 for each of the six traveling screens at each Unit (Lawler, Matusky, and Skelly Engineers 1982; note that these and all of the following cost estimates in this report are given in 1988 dollars, with the conversions from earlier figures based on the Producer's Price Index), depending on whether or not fine mesh screening and continuous operation is included. The estimated maximum cost of $1.3 million for both Units does not include the cost of structural modifications, return conduit, or plant downtime, any of which could exceed the screen costs.

If required, larger pumps would involve a substantial expense. To change the pumping capacity, the pump impellor and/or speed would need to be changed, at a cost of several million dollars/pump (J. List, *personal communication*), plus downtime. In addition, pumping costs would be higher, slightly reducing the efficiency of the plant.

3.2.2 Infiltration beds

Infiltration beds (or artificial filter beds) consist of a horizontal network of collector pipes placed beneath natural sediments or other filter media (such as gravel) on the bottom of the source water body. Intake water is drawn through the infiltration bed. The primary advantages of this system are that the velocity of water withdrawn is extremely low and most animals, even small fish larvae and eggs, are physically excluded from entering the plant (Marcy *et al.* 1980). Filters of this type have been used for many years at sites where intake flow rates are low (Richards 1978), and a design concept has been developed for a 1000 MW power plant requiring a flow rate of 42 m^3/s (Strandberg 1974).

One of the major obstacles to infiltration beds is the accumulation of debris. A 125 m^3/min system at the Pennsylvania Power and Light Company's Montour Steam Electric Station was abandoned because clogging could not be prevented (Marcy *et al.* 1980). A proposed 95 m^3/min system for a Washington Public Power Supply System nuclear plant was rejected due to operational and maintenance problems (Richards 1978). By comparison, the flow for Units 2 and 3 is 3144 m^3/min. The problem of clogging has not been solved; periodic backflushing seems to be the most promising solution, although it can cause excessive turbidity in the surrounding water.

SCE studied the possibility of using an infiltration bed at SONGS in 1978 (SCE 1981). They concluded that a natural sand filter system would require 160 acres of bottom and 288,000 ft of screened collector pipe per unit. A porous gravel system would require only 7 acres, but it could be covered with silt and sand during storms. It is possible that the gravel bed could be cleaned by reversing the flow of water and/or air, but this technology has not been tested (see above). Thus, the natural sand system would be required for reliable operation at SONGS. While this system would be excellent for reducing entrainment of all life stages and size classes of fish and invertebrates, the impacts on local benthic communities of constructing and maintaining this large system could be extensive.

Cost of constructing the infiltration bed investigated by SCE was estimated at about $283 million (± 50%), an order of magnitude above the cost of one offshore intake conduit (Lawler, Matusky and Skelly Engineers 1982).

3.2.3 Porous Dikes

The porous dike is a permeable stone breakwater that surrounds an intake. The most common design for porous dikes includes an inner core composed of small rock covered with successive layers of larger rock and an outer layer of large armor stone or cast shapes. The dike rises above the surface of the water so that all water entering the intake passes through the porous dike. The dike is designed to reduce the entrapment of organisms by: (1) lowering the velocity of the intake flow, (2) excluding organisms as water is filtered through the porous dike, and (3) the behavioral avoidance of the dike by some organisms.

Porous dikes have been used at a number of power plants, including Lakeside Generating Plant, Lake Nuclugen and Merced River, but this technique remains largely untested (Schrader and Ketschke 1978, Marcy *et al*. 1980).

Porous dikes are designed to exclude fish by filtering them from the intake water or causing a behavioral (avoidance) response (Edwards *et al*. 1981b, Ketschke 1981a). One potential problem with the filtering process is that fish will have already penetrated the coarse outer layers of the dike before they are filtered out by the finer inner layers. To survive, the fish must be able to return through the outer layers to open water. The material used for the core of a dike is too coarse to filter out very small organisms like larvae. Thus, while a porous dike can potentially exclude adults of most fish species, tests suggest that it will not effectively exclude larval fish. Other biological factors that require further evaluation include the potential attraction of fish to the dike and the impacts of construction on benthic communities.

A range of conceptual designs for SONGS has been studied (Lawler, Matusky and Skelly Engineers 1979). One dike was designed to provide an intake flow of 56.7 m^3/sec, which would be sufficient for one unit. The dike had a circumference of approximately 370 m and rose above the ocean surface. The velocity of the current approaching the dike was about 0.015 m/sec and the head loss across the dike was about 0.6 m.

The additional head loss associated with a retrofit dike installation could require modification or replacement of components of the existing intake system. The structural integrity of the dike in the open ocean environment may be at risk. The effect of long-term sediment transport must be studied. Finally, there is currently no method for cleaning a dike so the effect of long-term biofouling must also be considered. Both biofouling and sedimentation could cause severe clogging of the dike structure (Ketschke 1981b).

The cost of construction was estimated at $16-48 million, depending on the final design criteria and the material used for construction. The time and cost of studying sediment transport at the site would have to be added to this.

3.2.4 Barrier systems

Barrier systems consist of mesh net or rigid screen material placed around or in front of the intake opening. The barrier is placed at a location around the intake where the intake current velocity is very low, so that fish are not impinged on the screens or nets. If the mesh size of the barrier is small enough, it could reduce the entrainment of larvae as well as larger fish.

Barriers have been tested in freshwater and estuary environments at low flow rates, but have not been extensively tested in the open ocean. A simple barrier placed around the existing intake openings at SONGS would probably have little effect on larval mortality because the flow rate would be so high that larvae would be impinged on the mesh. Alternative intake arrangements (such as a manifold arrangement of multiple intakes) are possible, but present serious engineering challenges and additional costs.

A laboratory study sponsored by SCE examined the performance of fine mesh cylindrical screens when exposed to the types of debris and fouling common to Southern California coastal waters (McGroddy *et al.* 1981). The study concluded that an offshore screen system could become clogged by macrophytic algae in less than a day, depending on ambient conditions. No reliable method has been developed for cleaning screens at intakes with high flow rates in an open ocean environment. Air bursts have been proposed as a method of cleaning, which could be effective if currents removed the debris as it is blasted from the screens. Flow reversal has also been proposed for cleaning. This might result in clogging on the inside of the screens, and again, currents are needed to remove the debris. Clogging is not the only problem; there are additional difficulties associated with anchoring the screens in the open ocean.

3.2.5 Moving intakes

The organisms that are taken into SONGS are removed from the area immediately around the intakes. Therefore, the types and quantities of species entrained and entrapped by SONGS would likely be different if the intakes were located in a different depth or were upcoast or downcoast of SONGS. If fewer organisms would be taken into SONGS if the intakes were relocated, moving the intakes would be an effective means of reducing the losses due to SONGS.

The MRC has collected data on many different midwater taxa (which are at risk of entrainment or entrapment) at different locations around San Onofre, and these data can be used to indicate whether losses are likely to be reduced by moving the intakes. The major losses we are concerned with here are ichthyoplankton and midwater fishes.

In order to evaluate how the entrainment of fish larvae would change if the intakes were moved to deeper water, I have compared the densities of ichthyoplankton in shallow water, where the intakes are currently located, to the densities in deeper water. Using ichthyoplankton densities sampled near SONGS during the operational period, I have compared the densities nearshore (A&B Blocks) with the densities offshore (C&D Blocks)(Table 3-2). (See Appendix B for more details on the ichthyoplankton sampling design.) Fifteen species had greater midwater densities offshore than nearshore; these species would probably experience higher entrainment rates if the intakes were moved to deeper water. In contrast, six species would probably experience lower entrainment rates with deep-water intakes. Eight species with relatively high estimated adult equivalent losses (AEL) would experience higher entrainment rates with deeper intakes, while five high-AEL species would experience lower entrainment rates. It appears that moving the intakes to deeper water would not reduce the impacts of SONGS on fish larvae.

Larval entrainment rates might conceivably be different if the intakes were moved up- or downcoast, depending on whether there are differences in ichthyoplankton abundances at different locations along the coast. The MRC sampled ichthyoplankton at two locations along the coast, an Impact site 1-3 km

Table 3-2

Consequences of deep-water intakes for entrainment of fish larvae

Data presented are midwater ichthyoplankton densities nearshore (in A & B Blocks) and offshore (C & D Blocks) near SONGS during the operational period; see Interim Technical Report 5. In their present location, the intakes entrain water from A & B Blocks; if moved offshore, they would entrain more water from C & D Blocks. Species with the ratio AB:CD<1 would experience greater entrainment if the intakes are moved to deeper water.

SPECIES	LARVAL DENSITY (NO./100 M^3) A & B BLOCKS	C & D BLOCKS	RATIO AB:CD
California corbina	914	41114	0.02
Black croaker	1380	40025	0.03
Sanddab	3479	126908	0.03
Fringehead sp.	257	7727	0.03
Yellowchin sculpin	507	14271	0.04
Bay goby	7724	194227	0.04
Unid. blenny	64289	843498	0.08
Northern lampfish	16954	212180	0.08
Northern anchovy	773085	7651245	0.10
Queenfish	75987	695609	0.11
White croaker	98725	633013	0.16
Diamond turbot	1153	1923	0.60
Cheekspot goby	24620	34665	0.71
Arrow goby	2509	2938	0.85
Shadow goby	3090	3450	0.90
Jacksmelt	8754	8219	1.07
California grunion	4578	1781	2.57
California clingfish	8366	3028	2.76
Reef finspot	11019	3595	3.07
Unid. kelpfish	14541	3755	3.87
Giant kelpfish	3621	517	7.00

downcoast from SONGS and a Control site 18.5 km downcoast from SONGS. Parker and DeMartini (Technical Report D) reviewed MEC's data for A- & B-block densities at the two sites, and concluded that there were no consistent differences between them. Ichthyoplankton densities at the Impact and Control sites are presented in Appendix B. There were differences between the two sites; for example, white croaker, arrow goby and shadow goby were more common at the Control site, while jacksmelt were more common at the Impact site. However, there were no consistent differences, and total abundances were not different between the two sites. Therefore, it is unlikely that moving the intakes up- or downcoast would reduce the entrainment of fish larvae.

Finally, it is possible that moving the intakes would reduce the entrapment of older lifestages of fish. To examine this possibility, I have compared the densities of midwater fish in shallow and deep water near SONGS during the operational period (Table 3-3). Ten species had higher densities at offshore (deep water) stations, while 14 species had lower densities offshore. Although more species would appear to benefit from deep-water intakes, the number of species that would benefit is small and it seems unlikely that this slight improvement would not warrant moving the intakes (particularly in light of the higher ichthyoplankton losses that would result).

In conclusion, it does not appear that moving the intakes could reduce the entrainment or entrapment of fish by SONGS.

Table 3-3

Consequences of deep-water intakes for entrapment of midwater fish

Data presented are midwater fish abundances (as catch per unit effort, CPUE) nearshore ("shallow") and offshore ("deep") near SONGS during the operational period; see Interim Technical Report 3. In their present location, the intakes entrain shallow water; if moved offshore, they would entrain more deep water. Species with the ratio shallow:deep<1 would experience greater entrapment if the intakes are moved to deeper water.

SPECIES	FISH ABUNDANCE (CPUE) SHALLOW	FISH ABUNDANCE (CPUE) DEEP	RATIO SHALLOW:DEEP
Barred sand bass	0.00	0.48	0.00
Pacific sardine	1.03	25.86	0.04
Pacific mackerel	4.93	39.42	0.13
Bat ray	0.23	1.10	0.21
Jack mackerel	6.67	29.59	0.23
Round herring	1.17	2.79	0.42
Kelp bass	0.03	0.07	0.43
Salema	3.80	8.00	0.50
White seaperch	0.13	0.24	0.54
White sea bass	0.07	0.10	0.70
Pacific barracuda	3.20	2.34	1.37
White croaker	1.87	1.34	1.40
Sharpchin flying fish	0.30	0.17	1.76
Queenfish	56.93	29.55	1.93
Pacific butterfish	3.37	1.62	2.08
Deepbody anchovy	0.20	0.07	2.86
California halibut	0.10	0.03	3.33
California scorpionfish	0.10	0.03	3.33
Sargo	0.10	0.03	3.33
Northern anchovy	1618.87	361.97	4.47
Silversides spp.	12.00	2.34	5.13
Walleye surfperch	0.60	0.10	6.00
California corbina	0.27	0.03	9.00
Yellowfin croaker	0.20	0.00	-

3.3 Behavioral Barriers

In addition to physical barriers to entrapment, various techniques have been proposed or implemented that take advantage of fish behavior to reduce entrapment rates. Fish behavior varies greatly among different species and lifestages of fish and is influenced by environmental and physiological conditions, making it difficult both to find a behavioral barrier that will work for all species at all times and to predict how effective a technique will be under particular circumstances. However, behavioral barriers tend to be less expensive to test and implement than structural barriers, and so can be valuable mitigation techniques. Behavioral barriers that have been proposed to reduce entrapment of fish include light, sound, velocity gradients (which are used at SONGS), bubble screens, and electric barriers (Hanson *et al.* 1977).

3.3.1 Sonic devices

Overall, 5.6 million juvenile and adult fish (36.9 MT) have been entrapped each year in Units 2 and 3 (Final Technical Report C). Although the Fish Return System (FRS) diverted about 85% of the entrapped fish, nearly 800,000 (7.2 MT) fish were impinged on the traveling screens, 66,000 (3 MT) killed during heat treatments, and 411,000 (4.8 MT) did not survive diversion through the FRS. Sonic devices might reduce these losses. Placed near the intakes, sonic devices might reduce the number of fish entrapped at SONGS; inside the plant, sonic devices might direct more fish into the FRS, reducing the number of fish impinged on traveling screens (especially during heat treatments).

Sonic devices provide a high-energy acoustic output that can startle fish and alter their behavior near the device. Several different types of sonic devices have been proposed for reducing fish entrapment. The most common device is the pneumatic gun, or "popper", which stores high-pressure air in a firing chamber and then explosively releases it through portholes to create a sound pressure wave in the range of 200 to 2000 psi. Other sonic devices include underwater speakers, an arc-gun, an impact device called a "hammer", and a "fishdrone" (McKinley *et al.* 1987). Since most work has been conducted on pneumatic guns, I have focused on them; however, the hammer has the potential for being as effective as pneumatic guns with better reliability (McKinley *et al.* 1987, Patrick *et al.* 1988, McKinley and Patrick 1988). Broadcast underwater sound generally is not effective (Smith and Anderson 1984).

Sonic devices rely on fish avoidance behavior to keep fish away from an area. Their effectiveness depends on how a species responds to the characteristics of a particular device; for example, some species may respond to certain frequencies and not others. Because the fish must actively swim away from the source of the sound in order to avoid entrapment, sonic devices have little effect on the entrainment of larvae.

Fish have been shown to avoid areas with pneumatic guns; they do not become habituated to the sound over the short-term (EPRI 1984). Long-term habituation is a potential problem but has not been tested. If habituation occurs, it would most likely be restricted to fish that reside in the vicinity of the intakes. Results of a study on white croaker and northern anchovy indicate that white croaker habituated fairly quickly, but the anchovy were still responding to the gun after five hours of testing (Norris *et al.* 1988). Pneumatic guns might be most effective in redirecting transient schools of fish (such as northern anchovies) away from the intakes. They have been successfully used to exclude schools of alewives from the intakes at the Pickering Diversion System (Haymes and Patrick 1985). Pneumatic guns could be very effective at SONGS, since schooling species make up a large proportion of the fish entrapped in the plant (see Final Technical Report C).

Pneumatic guns were tested by Central Hudson Gas & Electric at Danskammer Point (Lawler, Matusky and Skelly Engineers 1984). Dynamite was used initially to break up frazil ice that accumulated on the intake trash racks. Subsequently, powerful pneumatic guns were found to be effective for breaking up the ice without killing nearby fish. The effectiveness of pneumatic guns as a method of reducing entrapment of fish at the plant was evaluated by comparing impingement rates with pneumatic guns in use to impingement rates from previous years when dynamite was used. Impingement rates were slightly lower when pneumatic guns were in use. However, the results of this study are inconclusive because there was no control for changes in the local abundance of fish between years. Also, impingement rates could be higher during the dynamite years because fish that were stunned or killed by the dynamite blasts could not escape from the intake current.

In the mid-1970's, SCE supported a pilot test of pneumatic guns (Schuler and Larson 1975). A pneumatic gun was deployed in the Long Beach Generating Station forebay; there was no flow through the forebay at the time because the Station was not operating. When the pneumatic gun was cycled continuously, fish avoided the area within 3 m of the gun; fish in open areas reacted more dramatically than those in more protected areas. Schuler and Larson also report two sets of observations of the pneumatic gun at the offshore intake of the Redondo Beach Generating Station. Upon operation of the gun, the dense concentration of fish within 3.7 m of the device vacated the area. After three hours of continuous operation, the density of fish remained low near the pneumatic gun. Schuler and Larson concluded that the pneumatic gun produced "sufficient stimulus to reduce fish concentrations within a 10-ft (3 m) radius of the device."

The Electric Power Research Institute (EPRI) requested that SCE perform a more extensive test of pneumatic guns at SCE's Redondo Beach station in 1985. Preliminary plans were developed, but the testing never took place. This testing is critical to the final evaluation of this concept.

Several studies have compared the effectiveness of sonic devices and other behavioral barriers. Patrick *et al.* (1988) found pneumatic guns to be more effective than bubble curtains or strobe lights. McKinley and Patrick (1988) found hammers and pneumatic guns to be more effective than strobe lights for sockeye salmon smolts. On the other hand, Matousek *et al.* (1988) found that strobes, especially when combined with bubble curtains or pneumatic guns, were most effective; pneumatic guns alone were only effective under certain conditions, such as at dusk, and especially for blueback herring and alewife.

3.3.1.1 Potential reductions in losses

Sonic devices might be effective at two locations: at the intakes and in the screenwells inside the plant. The types of fish saved and the amount of savings would differ at the two locations.

At the intakes, sonic devices would probably be most effective at reducing the entrapment of transient schooling species, since there would be no possibility of habituation with these species. Schooling species that are entrapped by SONGS include northern anchovy, queenfish, jacksmelt, white croaker, salema, spotfin croaker (aggregates for spawning), walleye surfperch, topsmelt and grunion. Some of these schooling species are more strongly schooling or more transient than others and some would undoubtedly be more susceptible to sonic devices. For example, northern anchovy, with 4.2 million (4.8 MT) fish entrapped per year, might be a prime candidate for sonic devices because large anchovy schools periodically move into the area of SONGS' intakes. The entrapment data indicate that much of the anchovy entrapment occurs when very large numbers of anchovies are entrapped over a short period of time, apparently when a school of anchovies happens to pass too close to an intake. Sonic devices might be able to reduce this entrapment substantially.

There are few data on the actual effectiveness of sonic devices. McKinley and Patrick (1988) report a diversion rate of 75% for a hammer and 66% for a pneumatic gun when used to guide downstream migrating salmon smolt at a hydroelectric plant, even at current velocities of 1 m/sec. No studies have estimated the effectiveness of sonic devices in the marine environment, which is likely to be quite different. Since there are no relevant quantitative data on the efficiency or effectiveness of sonic devices, it is difficult to estimate how many losses they might be able to prevent. I have based my estimates of possible reductions in losses on the nine schooling species listed above, but it is important to keep in mind how little information these estimates are based on.

The schooling species were entrapped at a rate of 5,486,142 (24.8 MT) fish per year (Final Technical Report C). If sonic devices had an effectiveness of 10%, they would reduce entrapment by about 550,000 (2.5 MT) fish per year. At 10% effectiveness, 420,000 (0.5 MT) of the fish that would not be entrapped would be anchovies and 110,000 (1.4 MT) would be queenfish. At 50% effectiveness, entrapment would be reduced by 2.7 million fish weighing 12.4 MT, a substantial reduction. 2.1 million (2.4 MT) of the fish that would not be entrapped would be anchovies and 560,000 (7.1 MT) would be queenfish. In terms of the fish killed by SONGS Units 2 and 3, a 50% effectiveness against entrapment of schooling fish would reduce the fish killed by 608,000 individuals weighing 5.4 MT. The total entrapment losses would be reduced from 1.27 million (15 MT) to 662,000 (9.7 MT), a 48% reduction in number and a 36% reduction in biomass lost. These savings would be substantially larger if, over the long term, SONGS kills more fish than we have measured; for example, Technical Report C reports that the long-term average fish kill from SONGS Units 1, 2 and 3 could be 52 MT/year rather than the 19 MT/year we have measured.

Fifty-percent effectiveness may be overly optimistic, although the few short-term tests indicated high effectiveness and appropriate testing could reveal an even higher effectiveness. For example, pneumatic guns achieved a 76% effectiveness in excluding alewives at the Pickering Nuclear Generating Station (EPRI 1989). However, for this evaluation 50% is taken as the upper limit of effectiveness upon which to base possible loss reductions.

Sonic devices could also be used inside the intake screenwells as an additional technique to reduce fish losses. If these sonic devices were not operated continuously, they might increase the efficiency of the FRS by directing more fish into the FRS. As with mercury lights (see section 3.2.2.3.1), sonic devices might be most effective during heat treatments. The fish that are killed during heat treatments apparently do not move to the Fish Return System before the water temperature in the screenwells becomes fatal. Sonic devices might be used to frighten fish into the FRS, where they could be removed safely. Sonic devices have never been proposed for this purpose before, so their effectiveness for this use has not been tested. However, the potential benefits are important, since heat treatments comprise a sizable portion of the entrapment losses caused by SONGS (5% by number and 20% by weight at Units 2 and 3) and larger, more valuable fish are killed during the heat treatments. A rough estimate of the possible reductions in heat-treatment losses, given in Section 3.3.3.1.1, is 1.5 MT.

3.3.1.2 Technical feasibility

Pneumatic guns are commercially available, and test systems have been established at Pickering Nuclear Generating Station (EPRI 1989). Pneumatic guns would require routine maintenance consisting of recharging the air cylinders which drive the pneumatic guns and periodically replacing pneumatic guns as they wear out. During the test at Pickering Nuclear Generating Station the pneumatic gun had some operational problems, primarily with leakage due to worn seals, and required frequent maintenance (EPRI 1989). Similar problems were encountered during tests at the Roseton Generating Station in 1986, with gun failure being caused by wearing of the O-ring seals, and weekly maintenance being required to minimize this problem. Maintenance problems remain one of the major concerns regarding the implementation of pneumatic guns (K. Herbinson, SCE, *personal communication*).

The hammer is a potential alternative to pneumatic guns. The hammer is a spring mass device that produces a sound that is somewhat similar to that of a pneumatic gun, but the sound can easily be altered by changing the end plate of the device and the maintenance requirements should be substantially lower than for the gun. However, there is some concern that the hammer may experience premature failure because the end plate cannot withstand the constant hammering.

3.3.1.3 Costs

Costs could best be estimated after field testing. The cost estimate for testing pneumatic guns for one year at Redondo Beach (also an open ocean environment) was estimated at $245,000 (EPRI 1984). It is likely that the actual cost at SONGS would be even greater (perhaps $500,000); this was one reason that the testing never took place (W. Micheletti, EPRI, *personal communication*).

3.3.2 Electric fields

Electric fields are designed to momentarily stun fish, which then drift away from the area of risk and recover safely downstream of the hazard. This will not work for power plant intakes because the prevailing current would draw stunned fish into the hazardous area. Electrical screening systems are limited in the ocean because of high electrical losses (Hocutt 1980). In addition, electric barriers are hazardous to humans and other animals.

3.3.3 Light systems

Depending on the type of light, fish can be either attracted to or repelled from a light system. Two types of lights systems could be useful for reducing losses at SONGS: mercury lights, which attract fish, and strobe lights, which repel them.

3.3.3.1 Mercury lights

Various types of light have been proposed to attract fish, with mercury light frequently being mentioned as effective. One of the first studies to demonstrate the potential effectiveness of mercury light was conducted by Patrick and Vascotto (1981), who found an increase of 237% in the number of alewife in an experimental chamber compared with a control chamber. In addition, alewife were continuously attracted to mercury light over a 48-hr period. Several recent studies have also indicated that mercury lights could be used to guide fish (Puckett and Anderson 1988, Taft *et al.* 1988, Williams *et al.* 1988), but all of these studies have emphasized the preliminary or restricted nature of their findings. Mercury light effectiveness certainly depends on the species involved, but may also depend on the season

(Williams *et al.* 1988), whether it is day or night (Taft *et al.* 1988), or even the rate of change of light levels (Puckett and Anderson 1988). For example, in evaluating the status of existing fish protection technologies, Taft *et al.* (1988) state:

> Mercury lights also modified the behavior of some species and lifestages in the lab and field evaluation confirmed this behavior can be exploited to alter fish passage rates. The field attraction to mercury lights did not always produce the desired or expected results in all species or under all test conditions. Therefore, test results should be applied with caution and possibly only with additional field verification.

It seems likely that a mercury light system could be used to guide entrapped fish out of the screenwells at SONGS and into the FRS collection area. Improved guidance of fish into the FRS would be advantageous at all times, but it would be particularly important during heat treatments. Losses due to heat treatments are important (20% of the biomass lost at Units 2 & 3) and involve larger and more valuable fish. It seems likely that considerable savings could be realized by using mercury lights to guide fish into the collection areas.

To my knowledge, mercury lights have never been used in a situation similar to the one at SONGS, so it is impossible to predict their effectiveness. Two previous studies provide some indication of the potential effectiveness of the lights, however. Patrick and Vascotto (1981) found twice as many alewife in chambers lighted with mercury lights as in control chambers. Taft *et al.* (1988) report that nearly twice as many salmon were bypassed at Wapatox Canal when mercury lights were on as when the light were off.

Potential reductions in losses

A very rough estimate of the savings that might be expected at SONGS can be calculated by arbitrarily reducing the present impingement and heat treatment mortality rates. For example, the annual estimate of biomass impinged by Units 2 and 3 is 7.2 MT. Most of these fish (at least 4.5 MT) are quite small, and may be unable to swim against the intake flow even if they are attracted to mercury lights in the collection bay. If half of the remaining fish could be saved by mercury lights, the savings would amount to about 1.4 MT. At least 0.3 MT of the 3.0 MT of fish killed during heat treatments each year consist of small species. If half of the remaining fish could be saved by mercury lights, the savings would amount to about 1.5 MT. The total savings from installing mercury lights might be **roughly** on the order of 3 MT. This estimate would be higher or lower depending on the actual increase in diversion efficiency due to the mercury lights, and how this diversion efficiency changes from species to species.

Because some studies have indicated greater attractiveness of mercury lights when they are cycled on and off, this pattern might provide the highest effectiveness at SONGS. In particular, the lights might be turned off most of the time, and then turned on immediately before operating the Fish Return System.

Technical feasibility

There seem to be no particular technical problems with implementing mercury lights at SONGS; in fact, this technique has some distinct advantages. The most likely location for the lights would be in the collection bay of the FRS. The collection bay is one of the most accessible areas of the intake system, so maintenance of the lights would be relatively easy.

Costs

Although I have not seen any published estimates of the cost of installing a mercury light system, the costs would be relatively small.

It seems likely that considerable savings could be realized by using mercury lights to guide fish into the collection areas. Mercury lights should be tested at SONGS in order to estimate the reduction in fish losses that are possible.

3.3.3.2 Strobe lights

A number of studies have indicated that strobe lights provide an effective behavioral barrier to entrapment. For example 56% of the gizzard shad tested in the laboratory avoided a simulated intake with an incurrent velocity up to 1.0 fps when the intake was illuminated with a strobe light (Patrick 1982a, Patrick and Vascotto 1981). However, strobe lights have not been tested extensively in the field, and no tests have been performed in Southern California. Strobe lights in the turbine intake of a dam apparently increased diversion of some salmonids during the day and steelhead at night, but decreased diversion for some salmonids at night (Hays 1988); furthermore, the strobes appeared to have no effect the following year. Sockeye salmon smolts avoided a dam intake when strobes were used, although the effectiveness of strobes (56%) was lower than sonic devices (66-75%) (McKinley and Patrick 1988). In another field study, strobe light diverted or repelled 65% to 98% of eels at risk (EPRI 1984). However, preliminary results at Hadley

Falls/Holyoke indicate that strobe lights had no effect on the behavior of shad under any condition during the test period (Taft *et al.* 1988).

The effectiveness of strobes undoubtedly depends on the time of day, turbidity, and species considered; it may also depend on the size of the fish, since larger eels were repelled more successfully than smaller eels (Patrick *et al.* 1982) and the intensity and duration of the flash. The effectiveness of strobe lights appears to be enhanced when they are used in conjunction with other devices such as pneumatic guns or air bubblers. Effectiveness at a Hudson River power plant increased from 23% for strobes alone to 56% with a pneumatic gun and 62% with an air curtain; however, all three devices together *decreased* effectiveness by 19% (Matousek *et al.* 1988). Fish apparently do not habituate to the strobe.

Because strobe light systems have not been tested under relevant conditions, it is impossible to predict how much they might reduce entrapment. The few tests conducted so far suggest that, at least for some species, entrapment of juvenile and adult fish might be reduced substantially. However, additional testing is needed, particularly in the Southern California area, before this technique could be considered effective. These tests should consider the effectiveness of strobe lights for different species and should employ the lights at night as well as during the day. Testing also needs to evaluate the possibility that fish would be attracted to the light form far away (although a demonstrably lower, overall entrapment rate might indicate that strobe lights could effectively mitigate entrapment losses in spite of the attractiveness).

There probably are no serious technical problems involved with installing a strobe system at the intakes, although power would need to be supplied to the intake area.

The cost of a strobe light system would be relatively low. No structural modifications to the existing system would be necessary. There would be some ongoing costs associated with maintaining the lights near the intakes.

3.3.4 Bubble curtains

Bubble curtains consist of a system for releasing air on the bottom of the water column to create a rising "screen" or curtain of bubbles near the intake opening. A wide variety of bubble patterns have been tried in controlled tests and in prototype installations. Bubble screens have been used at power plants located in freshwater or estuarine environments. In general, bubble screens usually result in less than a 50% reduction in the entrapment of fish (Andrew *et al.* 1955, Bibko *et al.* 1972, Zweiacker *et al.* 1977). In a study at Ontario Hydro (Patrick 1982b), there was a 70-98% reduction in entrapment when bubbles were used under low-level light conditions. When used in conjunction with a strobe light, the air bubble curtain could be an effective method of fish diversion under various turbidity conditions.

Bubble curtains have never been tried in the open ocean of Southern California, so it is impossible to predict their effectiveness. However, the high intake flows at SONGS Units 2 and 3, in conjunction with frequent high current- and wave-induced water motion, would undoubtedly put serious constraints on the effectiveness of this system. Bubble curtains seem unlikely to be effective at SONGS.

Bubble curtains do not present any serious technical problems, and their cost would be relatively low.

3.3.5 Water Jets

Water jet curtains have been used successfully to guide juvenile salmon in a test flume (Bates and VanDerWalder 1969). However, fish approaching an intake are often responding to the plant-induced intake flow. It is likely that a flow rate roughly equivalent to the intake flow would be required to influence the behavior of fish in such a situation. Water jets would seem appropriate only in relatively calm water with low intake flow rates; they would probably be ineffective at SONGS.

CHAPTER 4

DISCHARGE SYSTEM

4.1 Loss reduction techniques now in use

Units 2 and 3 were designed to discharge water through diffusers in order to comply with the thermal discharge requirements of the California State Thermal Plan. The diffusers are designed so that discharged water mixes rapidly with entrained water and reduces the maximum surface temperature to less than 4°F above ambient beyond 1000 ft from the discharge structure, even in the absence of currents. With the prevailing longshore currents, plume surface temperatures are generally 2°F or less above ambient temperatures. The cost of designing and installing each system was about $124 million, as compared to about $76 million for a simple single port discharge.

The primary consideration for the design of the discharge was the thermal standard; this standard was presumably established to minimize the environmental impacts of thermal discharges such as the discharge from SONGS. However, the diffuser system, which effectively meets the thermal standard, also produces a plume that is frequently more turbid than the ambient water, and this turbid plume has direct and indirect adverse effects on a variety of organisms, particularly those in the San Onofre Kelp bed (see Technical Reports B, F, J and K). The potential techniques for reducing losses due to SONGS' discharge have revolved around ways of reducing or eliminating the turbid plume near SOK.

The Final Environmental Statement for SONGS Units 2 & 3 (U.S. Atomic Energy Commission 1973c) evaluated four types of alternative cooling systems: (1) single-point discharge, once-through cooling; (2) multi-point discharge system (which was adopted); (3) once-through systems with lower temperature differentials; and (4) open- and closed-cycle seawater cooling towers. This chapter considers the first two of these alternatives; Chapter 6 considers the third alternative, while Chapter 5 considers the fourth alternative.

Several potential changes to the existing cooling system at SONGS might reduce the turbidity of the plume or avoid having a plume over SOK. Unfortunately, no one alternative stands out as clearly superior. The more expensive alternatives seem to have more certain results, while the least expensive alternatives might actually increase turbidity in the plume and affect transport of sand and sediment by affecting local currents and flow patterns. Also, most modifications to the existing diffuser system involve reducing the amount of water entrained; SONGS might exceed the current thermal standards if entrainment is reduced by 50%.

In order to evaluate fully their feasibility, design changes need to be studied in more detail than we can provide. Nevertheless, we present preliminary evaluations in this section.

4.2 Modify bottom topography

One possible technique for reducing the entrainment of turbid bottom water would be to place rocks around the diffusers so that the flow of entrained water is redirected. It is conceivable that entrainment flow could be redirected so that more water is drawn from the top and mid-depth regions of the water column and less from the bottom, turbid region.

Logistically, this would be the easiest solution to the problem of entraining turbid water because it would not require any plant downtime or underwater construction. The rocks to modify the bottom topography could be lowered from a barge, although care would have to be taken to prevent damage to the ports. The rocks would also act as an artificial reef, potentially enhancing the marine environment (see Chapter 8). Because there would be no plant downtime, this technique would be relatively inexpensive, although the cost of acquiring and placing the rocks would run into several million dollars.

There are two serious technical problems associated with this technique. First, the volume of the make-up flow may be so large that, in the absence of very strong density-stratification, bottom water would be entrained in spite of the modified topography. Hydraulic modelling would be needed to ensure that the structure would modify the flow as expected. Second, this technique would have unknown effects on the long-shore transport of sediment in the area. The line of rocks used to modify the topography might "catch" sand, increasing deposition near the rocks. Eventually, the accumulating sediments might spill over into the area near the diffuser ports. As the area filled with sediments, the height of the ports above the bottom would be reduced, which could actually lead to a worsening of the turbidity problem. Recent observations of the diffusers have indicated that sediment accumulation may even be a problem with the existing diffuser design, so any technique that might increase the accumulation of sediments needs to be viewed with caution.

This cannot be considered feasible unless accurate predictions of entrainment and sedimentation patterns indicate that these potential problems would not be serious. Given the current state of our knowledge, this technique does not seem to be worth considering further.

4.3 Modify diffuser ports

The original diffuser design presented in the 1973 SONGS Environmental Impact Statement included only 30 ports per diffuser, with each port extending 3 m above the bottom and discharging water vertically (SCE 1973a, 1973b). Although laboratory model studies indicated that this design would meet, by a small margin, the state thermal discharge standards (less than 4°F temperature rise at 1000 ft from discharge) in a current of 0.09 knots, the diffusers were redesigned with 63 ports, each raised 2 m off the bottom and discharging water at a 20° angle in order to increase the rate of thermal diffusion and meet the thermal requirement with no current. Although it was not a design criterion at the time, the original design, with its vertically oriented discharge at about 1 m higher than the current design, would have entrained less water, and in particular, less of the turbid bottom water. It would not be easy to reduce the number of ports on the existing diffusers, but modifications could be made to the ports themselves that would reduce the turbidity in the plume.

The most effective modification to reduce turbidity would probably be to increase the height of the ports. This could be accomplished by replacing the ports, as discussed in this section, or by lowering prefabricated structures over the ports (see next section, Section 4.4). Raising the ports off the bottom would increase the distance between the discharge opening and ocean bottom, thereby reducing the amount of turbid bottom water that would be entrained.

A second potential modification would be to alter the angle at which water is discharged. If ports were altered to direct the flow of discharged water upward (instead of upward and offshore), as in the original SCE design, the offshore component of the flow would be eliminated. This would reduce the entrainment of inshore water, which is more turbid because it is stirred up by wave action. It would also reduce the total amount of water the discharge entrains.

Finally, entrainment could be decreased by reducing the velocity at which the water was discharged. The exit velocity could be decreased by increasing the size of the port openings. The entrainment would be reduced in proportion to the decrease in exit velocity.

The reduction in entrainment of bottom water cannot be precisely calculated without scale models, but List and Koh (1989) provide the following qualitative analysis: When the diffusers are operating in a current, they entrain approaching fluid. For the original SCE design with vertical ports, almost 75% of the oncoming flow would have been mixed; the diffusers that were actually constructed achieve full (100%) mixing. Because the installed ports are almost 100% efficient in mixing the discharged water with the oncoming flow, turbid water near the bottom is almost certainly entrained with the discharged water. With the original SCE design, the 25% of the flow not mixed is probably the fraction nearest the sea floor. Thus, the tall vertical discharge ports of the original design would entrain less turbid bottom water than the original design.

Although List and Koh's analysis suggests that entrainment might be reduced by 25% with the original SCE design, and that much of this reduction would come from the most turbid bottom water, it cannot specify how much the turbidity in the plume could be reduced. However, it seems that some type of modification of the discharge ports could be considered capable of substantially reducing the turbidity of the plume.

Any technique that reduces entrainment flow will increase the surface water temperatures. The actual change in temperature will depend on the amount that entrainment is reduced. With the present diffuser design, surface temperatures 1000 ft from the discharge structure are well within the thermal standards (4°F above ambient), so some increase in temperature can be tolerated within the existing standards. However, if entrainment is reduced substantially (which is, after all, the goal of modifying the diffuser ports), SONGS would exceed the thermal standard, and a waiver from the State Water Control Board and/or Regional Water Quality Control Board would be required. For this discussion of the *feasibility* of possible mitigation techniques, I have assumed that such a waiver could be obtained.

Cost of this option would include hydraulic scale modeling to confirm the effectiveness of any modification and fine-tune the design, fabrication of the units, and installation of the units. Scale modeling would run into hundreds of thousands of dollars. It is unlikely that a simple modification of the existing ports would meet necessary structural requirements, so each port unit would probably need to be replaced with a new unit. The original ports, with aluminum/bronze nozzles, cost $100,000 each (J. List, *personal communication*); assuming a similar cost for redesigned ports, fabrication alone would cost approximately $1.2 million for all ports on both diffusers. Installation would involve removing the existing ports (which have been cement-keyed to the diffuser conduit) and replacing them with modified units. The existing ports have a base consisting of a saddle that fits over openings in the main discharge pipe. Replacing the ports would involve excavating around the existing ports, removing the ports (an expensive and difficult procedure, with a risk of damaging the diffuser conduit; List and Koh 1989), placing the new ports over the pipe (using the method with which the ports were originally installed), and backfilling around the new ports. Construction costs would probably be in the range of millions of dollars. List and Koh (1989) estimate construction costs of more than $25-30 million per unit, but note that the potential damage to the diffuser conduit could cause construction complications. These operations could begin during a regularly scheduled plant outage, minimizing additional costs from plant downtime, but the entire operation might take longer than the plant is routinely offline, in which case additional costs from differential fuel costs would be incurred.

4.4 Place structures over diffuser ports

Covering the discharge ports with rocks or other structural units might reduce the turbidity of the discharge plume. This technique would modify the way that water is entrained, but would not require costly port fabrication and underwater construction.

4.4.1 Rocks

One way to alter entrainment would be to cover the diffuser ports with rocks. The rocks would reduce the entrainment of ambient seawater by reducing the momentum of the discharge before it mixes with the ambient water. The warm discharge water would rise directly to the surface from the reef due to buoyancy. All of the offshore component of the momentum would be blocked, and thus the plume would no longer tend to flow offshore, eliminating the inshore-to-offshore causes of the turbidity. Less water would be entrained because the velocity of the discharged water would be lower. The amount and source of entrained water is difficult to predict accurately without scale modeling, but it seems likely that there would be less of the turbid bottom water entrained. The temperature of surface water would also change with changes in entrainment flow, and the modified diffuser might not meet the requirements of the current Thermal Plan.

The implementation of this technique is conceptually simple: rocks would be carefully laid over the ports until they completely covered the ports. In practice, it is difficult to handle the large rocks that would be used, and their positioning might damage the discharge ports.

In addition to the difficulties of carefully placing the rocks, there are three technical obstacles to implementing this technique. The most serious obstacle stems from the increased backpressure that would result from piling rocks over the ports.

The present pumping system is tuned to the head required by the discharge system. Placing rocks over the ports would greatly increase the head needed. Larger pumps would be required to achieve a greater head, but the design of the discharge system limits the amount of increase that would be possible. Simply replacing the pumps, which in itself would be expensive (several million dollars per pump, plus the cost of downtime and the higher pumping costs), would not be enough. The design of the hydraulic system, including the elevations and dimensions of the condensers and seal well weir (see Appendix A), is geared specifically for the pressure (i.e., head) needed to move the water through the condensers and discharge it into the ocean, so the entire system would probably have to be re-engineered in order to accommodate the increased backpressure.

The second obstacle involves the potential recirculation of effluent water. Since the discharge plume would have no offshore momentum and less initial dilution, SONGS' effluent might accumulate locally and the discharged water might recirculate through the cooling system, with the discharge temperature increasing in proportion to the percentage of recirculating water. Koh *et al.* (1974) discuss this problem for the Unit 1 discharge.

Finally, it is possible that the reef area caused by the rocks over the diffusers would increase the deposition of sand near the diffusers. The outward flow of the discharges should keep lighter sediments from settling on the reef, but other mechanisms might lead to increased deposition. Since the reef would be perpendicular to the normal longshore sediment transport, it might intercept sand, which would then accumulate around the reef. If a low-pressure area develops behind the rocks, sand that settles into the low-pressure zone could form a sand bar reported to the CCC that a single-point discharge would probably cause less environmental damage than the diffuser system (MRC 1980). Therefore, changing the diffuser systems into single-point or triple-point discharges might reduce the resource losses caused by SONGS.

The diffusers could be changed into single-point discharges in two ways. First, the discharge system could be changed in place. Essentially, all of the cooling water could be allowed to escape from the end of the diffusers and the ports sealed off. Second, the discharge could be moved to a new location, either farther offshore or up- or downcoast; this alternative is considered in the next section, Section 4.6.

There are advantages and disadvantages to modifying the existing discharge system into a single-point discharge. This change would lessen the impact of SONGS' discharge because the plume from a single-point discharge would be less turbid (it would entrain less water) and would cover a smaller area than the plume from the diffuser. Unfortunately, the disadvantages are many, including the fact that the discharge will still be close to SOK and so there might be continuing impacts to the reef from the plume; seston flux (movements of particles through the area) might still be higher than normal; there might be a problem with recirculation of plume water into the intakes (Section A5 in Koh *et al.* 1974); changes in diameter of the existing diffuser piping would impose a very large pressure head loss if all the cooling water were to be pumped offshore; and reverse flow capabilities would be severely reduced, making heat treatment of the intake lines impossible (List and Koh 1989). Discharging water from the end of the diffusers would require at the minimum the replacement of both pump motors and pumps, and might not be possible without complete re-engineering of the cooling system because of design

In general, placing structural units over the diffusers would provide the same types of reductions as rocks, but with fewer disadvantages. The actual installation of the units would be fairly simple. Some preparation of the surface of the sea floor around the diffuser ports would be necessary, but the actual installation would basically involve carefully placing the units over the ports.

Although some of the problems associated with placing rocks over the diffuser ports would be ameliorated by using prefabricated structural units, severe problems would remain. As with rocks, the most serious problem is the increased backpressure that would be added to the diffuser system. (The structural units would cause backpressure because the discharged water would strike the inner sides of the units rather than being discharged freely into the ocean.) The added backpressure would probably be great enough that larger pumps would be required and/or the circulation system would need to be re-engineered. The recirculation of plume water would be about the same for structural units as for rocks. The possible problem of increased sedimentation near the diffusers would be much less severe than for rocks; even with the broad base needed for structural stability, a structural unit would have a smaller footprint than a pile of rocks covering a port.

4.5 Change to single-point or triple-point discharge

The initial design criteria for the discharge systems for Units 2 and 3 focused on meeting the thermal standards rather than the turbidity of the discharge plume. However, the MRC's studies have indicated that the environmental effects of the warm-water discharge are likely to have little adverse effect on the marine biota compared to the effects of turbidity in the plume. In fact, the MRC has already serious limitation; however, the ΔT would probably be too high to allow normal operation with reversed flow (List and Koh 1989).

Although replacing the diffuser ports with three discharge ports appears to be technically feasible, the offshore construction would be significant. It would be relatively simple to block off the unnecessary diffuser ports; however, installing new, large ports would require excavation of the existing diffuser conduit, constructing new discharge openings, and attaching the large ports--three times for each diffuser line. List and Koh (1989) estimate the cost of constructing three large ports on both diffusers to be $30-40 million, plus any costs for down time during construction.

4.6 Relocate discharge

Relocating SONGS' discharge would eliminate the adverse effect of the discharge on SOK because the plume would no longer impinge on the kelp bed. The discharge could be moved in four different ways: inshore, upcoast, downcoast, and offshore. In all cases, it is likely that the new discharge would incorporate a single-point discharge rather than a diffuser system, since a waiver of the thermal standards would be needed in most cases regardless of the discharge design, and a single-point system is simpler and less expensive.

Although moving the discharge would eliminate the turbid plume over the San Onofre Kelp Bed (SOK), and therefore any future impacts to the bed, SONGS has already impacted SOK. Residual effects, such as sediments covering the cobbles, might persist for some time even if the discharge was moved. It is not pressure limitations on the condensers (List and Koh 1989). This does not appear to be a viable alternative.

However, it would be feasible to replace the 63 diffuser ports with three large discharge ports (List and Koh 1989). If these large ports were similar in structural design to the Unit 1 discharge, they would be about 3 m in diameter and would discharge cooling water 5 to 6 m above the sea floor. List and Koh (1989) propose that they could be placed at the end of each of the three pipe sizes in the diffusers (see Appendix A). If these ports discharged water vertically, they would entrain a smaller total volume of water than the present diffuser system. (If the ports are angled up from the horizontal, they could entrain a similar volume as the present diffusers and meet the state thermal requirements.) As with other techniques for reducing entrainment, there is a trade-off between lower entrainment and thermal discharge standards.

Evaluating the triple-point discharge option requires a careful assessment of the cooling water system hydraulics in order to determine the hydraulic head available to drive the modification, evaluate the potential for recirculation of discharge water, and determine whether there is sufficient flow available to drive the system in reverse flow mode during heat treatments. List and Koh (1989) conducted a hydraulic analysis evaluating the possible consequences of modifying the diffuser geometry. This analysis indicated that (1) the total head required for normal operation would be slightly higher, but not enough to be of significant concern, and (2) the reverse flow capacity would be considerably lower than with the existing system, resulting in a higher ΔT across the condensers. Since the higher ΔT would only apply to periods of reverse flow, which occur rarely, this is not a

As mentioned above, there is a problem associated with locating the discharge close to the intakes because the plume could recirculate through the intakes. Koh *et al.* (1974) have discussed the problem of recirculation from the Unit 1 discharge. Because Units 2 and 3 discharge a much greater volume of water, the recirculation problem would be serious enough to eliminate this possibility from consideration.

Costs would probably be in the range of tens of millions of dollars. Costs would be minimized if construction was performed when the plant is scheduled for refueling and maintenance, although additional down time might be needed.

4.6.2 Move upcoast or downcoast

To avoid the recirculation problem, the discharge could be moved away from the intakes, either upcoast or downcoast. As with a discharge close to SONGS, the discharge could take place in shallow water or across the beach.

Moving the discharge upcoast or downcoast would cause some new environment impacts. The primary impact would probably stem from the construction of new pipeline to the discharge. This impact would be similar to the impact of the original construction of the diffusers. If the pipeline ran along the shore, the beach habitat would be disturbed; since this is already a highly disturbed habitat (all of the beach sediments can be eroded away or deposited over a very short period of time), construction would most likely be a temporary perturbation. (It would compromise public access to the beach during construction, however.) If the pipeline was subtidal, soft-bottom habitat would be destroyed and turbidity possible to estimate the intensity or duration of these residual effects, but until they disappeared a net loss of resources would persist that should be mitigated.

4.6.1 Move inshore

The problem with SONGS' plume is not so much how turbid it is as where it occurs. High turbidity is the norm close to shore and close to the bottom. SONGS, however, moves turbid water offshore and up into the water column over SOK. One solution to the turbidity problem would be to have SONGS discharge close to shore, near the surf zone, where the water is already turbid.

The discharge could have two configurations. The discharge could be a single-point underwater discharge, much like the discharge for Unit 1 but closer to shore. Alternatively, SONGS could discharge water across the beach, like the discharge at Diablo Canyon. In either case, the effluent would mix with water that was already turbid, so SONGS' discharge would have little influence on the spatial distribution of turbidity in the area; in particular, turbidity over SOK would not be higher than normal.

Moving the discharge closer to shore would cause some new environmental impacts. If the discharge was across the beach, there would likely be substantial erosion of the beach sediments. If the discharge was subtidal and utilized the existing pipeline, there would be some temporary construction impacts (from turbidity and construction barges), but the environmental impacts would be minimal. Although the water temperature would be elevated due to the discharge, it seems unlikely that it would have any important effects.

construction costs would be lower. If SONGS had to be offline during construction, costs would be higher.

4.6.3 Move offshore

Relocating the diffusers so that they extend beyond the San Onofre Kelp bed could eliminate the adverse effects of SONGS on the kelp bed. The discharge would need to be moved far enough that the plume no longer spread over the kelp bed, perhaps as far as 1.5 km farther offshore, where the water depth is 30 m. The discharge could then be fitted with either a diffuser or, more likely, a single-point discharge. This option would require significant underwater construction, since the discharge line is buried in sand and the extended line would also have to be buried for proper anchoring.

Extending the discharge would cause additional environmental impacts. Construction would destroy a limited area of soft-bottom habitat. Enrichment of the benthic biota (infaunal organisms and bottom fish) would be expected from the extended discharge, since this has occurred with the existing system; if a single-point discharge was used, the "enrichment" might be more concentrated than with the present diffuser system, possible causing a qualitatively different impact (for example, different species might invade the area around the discharge). These impacts would be expected to be restricted to the region around the discharge. Changes in the thermal characteristics of the discharge stemming from the use of a single-point discharge in deeper water seem unlikely to cause any substantial impacts.

would be increased during construction. If SONGS' cooling water was discharged across the beach, there would likely be substantial erosion of the beach sediments. If the discharge was subtidal, any increased turbidity from the discharge would probably have minimal effects. In the high-energy inshore area it seems unlikely that the discharge would cause increased sedimentation; in any case, based on the MRC's data on soft benthos and bottom fish, effects of the discharge are more likely to be positive than negative. Similarly, it seems likely that any increase in water temperature would have negligible effects. However, discharging the heated water close to shore would definitely require a waiver of the thermal standards.

There are no major technical problems associated with this technique. Moving the discharge away from the plant would require laying pipe to the new discharge area, which would be a fairly routine procedure. The distance that could be reached without changing the pumps depends on the head made available by not moving the water several km offshore and through the diffuser ports. With a single-point discharge, the discharge pipe could be approximately 750 m longer and still have the same head loss (J. List, *personal communication*). Thus, the discharge for SONGS could be located as far as 3.5 km upcoast or downcoast from the plant (present configuration of 1975 m to the beginning of Unit 2 discharge, 750 m-long diffuser, plus extra 750 m gained by using a single-point discharge) without significant modifications to the existing pumps; this would include the coastline from opposite the weigh station south of SONGS up to San Mateo Creek.

Cost of moving SONGS' discharge 3.5 km from plant would be at least $70 million (based on $2000/ft of pipeline; J. List, *personal communication*), and probably considerably more. Of course, if the discharge was closer to SONGS, the *communication*). If SONGS could not operate for six months while the new discharge was being tied into the existing system, as suggested by Ebert (1980), the replacement fuel costs would be at least $96 million. Thus, the overall cost of extending the diffusers 1 km might be roughly $200 million.

CHAPTER 5

REPLACEMENT OF EXISTING COOLING SYSTEM

The most radical approach to reducing the effects of SONGS' cooling system would be to replace the open-cycle cooling system with a closed-cycle system. Closed-cycle cooling systems are now required on inland power plants using river water for cooling because of the adverse effects of the thermal load on aquatic communities in rivers. Although thermal effects are far less important for power plants located on the open coast, closed-cycle cooling systems would still reduce the intake and discharge effects of an open-cycle system. Closed-cycle cooling systems include cooling ponds and canals and many different types of cooling towers.

5.1 Cooling Towers

The substantial environmental impacts resulting from the once-through cooling system used at SONGS could be greatly reduced or eliminated by reducing the quantity of water used for cooling. Cooling towers have been successfully employed in cases where abundant water is unavailable, or in situations where the environmental effects of once-through cooling systems are unacceptable. Because cooling towers at SONGS would use 10% or less of the volume of water used by the once-through cooling system(U.S. Nuclear Regulatory Commission 1979), there would be a proportionate decrease in the intake losses, and the discharge losses measured by the MRC would be eliminated since there would no longer be a turbid plume.

Cooling towers transfer the waste heat directly to the atmosphere. The hot water is pumped to the top of the tower and cools as it drops down the height of the tower; the cooled water is recirculated through the condensers. Cooling air enters the tower at the bottom and exits at the top. There are many types of cooling towers that use different methods to drop water down the tower and pump air up the tower. The basic types of cooling towers are discussed below, with their advantages and disadvantages summarized in Table 5-1.

In dry cooling towers, air and water never come into direct contact. The water is dropped through an array of thin tubes, and heat is transferred by conduction and convection only; no evaporation takes place. Since water is not lost to evaporation, dry towers require very little additional water once they begin operating and can, therefore, use fresh water. However, they are expensive and do not transfer heat as effectively as wet towers. Reduced heat transfer will increase the turbine back pressure, and plant capacity can be expected to decrease by 5 to 15%, even with an optimized turbine design (which would not be the case in a retrofit operation such as at SONGS). The energy cost for a planned (not retrofitted) dry tower cooling system is about 20% more than the cost of a once-through cooling system due to increased construction costs and decreased capacity. Dry towers are now used in Europe and Africa in only small (< 200 MW) fossil fuel plants in cool climates with peak loads in winter. They have never been used at a power station larger than 200 MW.

Wet cooling towers allow the cooling water to drip through the open air, transferring heat primarily by evaporation, but also by conduction. Some type of porous material such as gravel is used to slow the water droplets. Drift eliminators

Table 5-1

Summary of advantages and disadvantages of closed-cycle cooling options.

METHODS	ADVANTAGES	DISADVANTAGES	COST* (MILLION $)
Cooling Ponds/ Canals	inexpensive if land is available	requires ~2000 acres/unit	land unavailable
Spray Ponds/ Canals	inexpensive, requires less land than cooling ponds	requires ~100 acres/unit; salt drift	land unavailable
Dry towers	operate with little makeup water, so can use fresh water; no evaporation, so no fogging or drift	technology has not been demonstrated on this scale; expensive, operating cost up 20%; Noisy	500
Mechanical draft wet towers	relatively small, so less vis. impact; can control exit temperature; most efficient and least expensive tower	large volume of makeup water; requires fan power, noisy; salt drift and ground-level fogging problems	370
Natural draft wet towers	quiet (no fan power); reduced fogging and drift problems due to height	large volume of makeup water; very large (500' tall) and unsightly; salt drift	400
Wet/dry towers	reduced water requirements; efficiency same as wet towers; reduced fogging and drift	technology has not been demonstrated on this scale; still requires salt water; high cost	450

* Cost is for construction and tie-in only (1988 dollars). Does not include plant downtime and reduced plant capacity.

are added at the top of the tower to catch unevaporated water droplets being carried up with the exiting air. Two types of wet cooling towers are used: mechanical draft and natural draft. Mechanical draft towers use fans to force the air through the towers. The size of the tower can be reduced if additional power is used to drive the fans. Mechanical draft towers are the most commonly used type of cooling tower. The advantages of mechanical draft towers compared to natural draft towers include: lower capital costs; greater flexibility because there is more control over water temperature; and a smaller size, which reduces the visual impact. Their main disadvantage is an increased potential for ground level fogging and drift. Natural draft towers are large and hyperbolic in shape, which is the optimal shape for natural convection flow. The disadvantages of natural draft towers are that construction costs are a little higher and the large towers (~500 ft) and visible plume are unsightly. However, since fans are not used, they are quieter and cost less to operate. Also, the high towers reduce ground level fogging and salt drift (if seawater is used for cooling).

All wet cooling towers at SONGS would have to use seawater because the water requirements would exceed fresh water supplies (U.S. Atomic Energy Commission 1973c). Saltwater cooling towers have been used only rarely, and they have never been used at a plant as large as SONGS. Costs are estimated to be 10 to 20% higher than for an equivalent freshwater tower, but cost overruns seem likely given the unproven technology. A high salt concentration in the tower water would reduce the efficiency of a wet cooling tower, decreasing plant power by increasing turbine back pressure (J. Giambastiani, Ecodyne, Inc., *personal communication* 1988).

Wet/dry mechanical draft towers attempt to combine the best features of both wet and dry cooling towers (e.g., lower water use and more economical cooling in the summer). Heated water is first passed through tubes as in a dry tower and then allowed to drip through an open gravel bed as in a wet tower. This allows the water temperature to drop as low as it does in a wet tower, but evaporation is much lower than in a wet tower. Evaporation is still far too great to use freshwater in Southern California, however. Only a few power stations in the 200 MW range have used wet/dry towers. Thermal performance is expected to be equivalent to a wet tower, but the cost of the more complicated design is usually about 10% higher.

Cooling towers decrease the efficiency of the plant for a number of reasons, including (Reynolds 1980): (1) Extra power is required for pumping the water to the tower, which in the case of SONGS could be substantial because the water would have to travel 1 mile and uphill. (2) Energy is required for fans in the case of mechanical draft towers. And (3) Cooling towers cause higher turbine back pressures. This is caused by the greater temperature of recirculated cooling tower water compared to a once-through system. Stone and Webster Engineering Corp (1978) showed that energy loss for retrofitting a nuclear plant would be more than 4%, and capacity loss would be about 5%. The EIS for the Indian Point plant predicted a 4% decrease in annual plant capacity and a 9% reduction in peak generating capacity.

5.1.1 Potential Reduction of Losses

The degree of loss reduction would depend upon the type of tower employed. Dry cooling towers would use fresh water, thus eliminating the intake and discharge losses. Wet cooling towers would greatly reduce the amount of ocean water taken and returned to the ocean: Parkhurst and McLain (1978) report that a hypothetical 1000 MW nuclear power plant withdraws 2152 cubic feet per second for once-through cooling compared to 43 cubic feet per second, or 2% of the once-through flow, for closed-cycle with cooling towers. (Note: Each of SONGS units 2 and 3 actually withdraws 1840 cubic feet per second.)

The reduction in water utilized is about the same for retrofitted towers. The Palisades Nuclear Power Plant, originally operated with a once-through cooling system using water from Lake Michigan, was retrofitted with mechanical draft cooling towers in 1974. This change decreased the intake of water from Lake Michigan by 85%. A study of the impact on fish revealed that at least 95% fewer fish were impinged after the cooling towers were installed; there was also a reduction in the total weight and the number of fish species that were impinged (Benda *et al.* 1975). The Indian Point EIS (U.S. Nuclear Regulatory Commission 1979) predicted that the water used with cooling towers would be less than 4% of that used for once-through cooling, and entrainment and impingement would be reduced by a similar amount.

The EIS for SONGS Units 2 and 3 predicts that 97% fewer fish would be killed if cooling towers were used instead of a once-through system (U.S. Atomic Energy Commission 1973c); losses due to the turbid plume would probably be completely eliminated. Similarly, the EIS for SONGS Unit 1 predicted that intake volume would be reduced to 2-3% of present flow if mechanical draft cooling towers were used, essentially eliminating entrainment of marine life (U.S. Atomic Energy Commission 1973b).

5.1.2 Associated Impacts

Although the installation of cooling towers at SONGS would greatly reduce the losses measured by the MRC that are caused by the once-through cooling system, cooling towers would produce new impacts. These associated impacts will be discussed in six categories: Drift, blowdown disposal, possibility of cloud formation and fogging, air quality, noise, and aesthetics.

5.1.2.1 Drift

The water used in cooling towers contains a variety of solutes. Cooling towers at SONGS would circulate sea water, so the water would contain the salts present in sea water plus any additives used to control scale formation, corrosion, sedimentation, and fouling in the tower (Birchall 1979). Table 5-2 lists the elements commonly associated with cooling towers. As this water circulates through the wet cooling towers, evaporation concentrates salt and other solutes. During the cooling process, some of the water forms small droplets, termed drift or carryover. These droplets escape from the tower with the air stream and eventually fall to the ground. Because the drift contains salt and other solutes, there is potential for damage due to the deposition of these materials on vegetation, soils, and water.

The SONGS EIS (U.S. Atomic Energy Commission 1973c) predicted that 0.01% of the circulation of mechanical draft towers flow would escape as drift, and that 4500 lb/hr of salt would be deposited on land. 90% of the drift would be deposited within a 3-mile radius of the towers. The SONGS EIS predicted that the deposition rate would be between 181.5 lb/acre-mo. and 1,089 lb/acre-mo. (0.05 to 0.3 lb/ft^2-yr are the figures in the EIS). The predicted SONGS deposition rate is

Table 5-2

Toxicity and concentration factors of elements used in cooling tower operations

From Final Environmental Statement, Shoreham Nuclear Power Plant, U.S. Atomic Energy Commission, 1972 (After Eichholz 1985).

	Concentration Factor[a]			
Element	Plankton	Brown Algae	Functions	Environmental Toxicity[b] (not injected)
As[c]		2,500		Carcinogenic; moderately toxic to plants, highly to mammals—especially as AsH_3
B		6.6	Essential for green algae, angiosperms	Moderately toxic to plants, slightly to mammals
Br[c]		2.8	Essential for marine organisms; amino acids	Br_2 is very toxic; Br^- is relatively harmless to organisms
Cl[c]	1	0.062	Essential for mammals and angiosperms	Cl^- is relatively harmless; Cl_2, ClO^-, ClO_3^- are highly toxic
Cr[c]	17,000	6,500	May serve some physiological function	Cr(III) is moderately toxic; Cr(VI) is highly toxic to organisms and is probably carcinogenic (by inhalation)
Cu[c]	17,000	920	Essential to all organisms	Very toxic to algae, fungi, and seed plants; highly so to invertebrates; moderately so to mammals
Hg[c]		250		A cumulative poison in mammals; very toxic to fungi and green plants; highly to mammals in some forms
N	19,000	7,500	Essential as structural atom	Relatively harmless; concentrations higher in plankton and fish
P[c]	15,000	10,000	Vital in many ways	
Pb[c]	41,000	70,000	None	Very toxic to most plants, moderately so to mammals; cumulative poison
S[c]	1.7	3.4		S_2 highly toxic to bacteria and fungi, relatively harmless to green algae, seed plants, and mammals; H_2S is highly toxic to mammals, SO_2 moderately to highly; SO_4^{2-} is relatively harmless
Si[c]			Essential to some plants	Scarcely toxic, but large amounts in mammalian lung harmful, used by foraminifera, porifera, etc.
Sn[c]	2,900	92	None	Very toxic to plants and green algae
Zn[c]			Essential to all organisms	Moderately toxic to plants; slightly toxic to mammals; uptake by plant roots not linked to metabolic process

[a] ppm in fresh organism divided by ppm in seawater

[b] Toxicity terms: very, 1-10 ppm; highly, 10-100 ppm; moderately, 10-1000 ppm; slightly, over 1000 ppm (as 24-hr median tolerance limit in moderate-sized organisms—*e.g.*, fish).

[c] Accumulator species or genera known.

higher than natural deposition rates found several miles inland from the seashore: Talbot (1979) cites a study where background deposition values ranging from 2.6 lb/acre-mo to 31 lb/acre-mo were measured several km inland. However, the predicted SONGS rate is lower than the salt sedimentation rates near the surf zone: Moser (1975) measured deposition rates of about 900 lb/acre-mo falling near the surf zone, dropping to less that 250 lb/acre-mo 300 m inland.

For natural draft towers, the amount of drift would be reduced to 0.001% of the circulation flow, or 450 lb/hr deposited on land. The EIS indicates that the drift might impact an agricultural area two miles away in San Mateo Valley. If the towers were located near the State Park, they could have a detrimental impact on the vegetation there. The SONGS EIS does not comment on the spatial pattern of the deposition, or seasonal effects. It does not discuss the salt tolerances of the native plant species or the potential effects of salt deposition on native vegetation. Although the EIS mentions a truck farming business 2 miles from the plant, it does not mention likely impacts on the crops. The EIS does not comment on the ambient salt levels or how much the tower would add relative to the ambient level. The EIS states that 7 to 8 months without precipitation are common in the area, but it does not discuss the fact that the impact of salt might be greater where precipitation is not frequent enough to remove salt accumulation from vegetation. It does not comment on the relative humidity in the area, an important factor in assessing the degree of damage due to drift (Moser 1975, McCune *et al.* 1977).

Studies involving applications of saline aerosols similar to cooling tower drift onto foliage have demonstrated that solutes are absorbed (Mulchi and Armbruster 1975, 1981, 1983, Moser 1975, McCune *et al.* 1977, Francis and Curtis 1979, Taylor *et. al.* 1975, 1980, 1983, Armbruster and Mulchi 1984, Hofmann *et al.* 1987). Large enough quantities of salt can be injurious plants, causing necrosis, lesions, stunted growth, and/or decreased reproductive output. The extent of the damage depends on many factors, such as age and species of the plant and meteorological conditions. For example, simulations of salt drift have demonstrated that the salt is far more harmful at high humidities (>80% RH) than at low humidities (<60% RH) (Moser 1975, McCune *et al.* 1977) especially in times of low precipitation.

A literature review revealed that vegetation near cooling towers is often damaged by salt drift, but acute negative impacts are only found close to the towers; the chronic effects of long-term operation of cooling towers are not known (Talbot 1979). A field study at Chalk Point, Md., where cooling towers circulate brackish water, was conducted at sites 1.6, 4.8, and 9.6 km from the towers for two years prior to operation and 5 years following operation of the towers. No negative effects were determined on tobacco grown 1.6 km from the towers, the closest agricultural area, or at any of the more distant study sites (Mulchi and Armbruster 1982, 1983). In a short-term study at Turkey Point, FL the salt drift did not appear to harm native vegetation. Only the cultivated plants at the closest (215 m) site were injured; plants at the other sites (430 m to 3.2 km from the towers) were not affected (Hindawi *et al.* 1976).

Rochow (1978) observed high deposition rates of sulfate and calcium within 92 m of the Palisades Nuclear Plant mechanical draft cooling towers in Michigan (which uses water from Lake Michigan) with extensive damage to the vegetation, including complete defoliation of trees. There was no comment about vegetation farther from the towers. Hexavalent chromium is used in the Oak Ridge Gaseous

Diffusion Plant in Tennessee to inhibit corrosion. In a short-term experiment lasting 7 weeks, Parr *et al.* (1976) examined chromium damage in potted tobacco plants located 15, 200, 600, and 1400 m downwind from the cooling towers. They found that plants did accumulate the drift-born chromium, but by 1400 m the levels of chromium were indistinguishable from background. Chromium deposition damaged plants at the closest site, and leaf growth at the 15 and 200 m sites was less that at the 600 and 1400 m sites: on the basis of this short-term study, the authors concluded that there will not be significant accumulations of chromium beyond 500 m. At Oak Ridge Gaseous Diffusion Plant, the chromium and zinc levels in the vegetation decrease to near background levels at 1 mile from the towers; this has not harmed the native vegetation, but did harm the tobacco crop (Taylor *et al.* 1975). Another study was done to determine whether the deposition of chromium on fescue grass was seasonal at the Oak Ridge Gaseous Diffusion Plant. The highest chromium concentrations occurred in the winter, corresponding with maximum operational level (Taylor *et al.* 1983). As with previous studies, the highest chromium levels were found near the towers; the level of chromium was reported to be insignificant at the 1500 m site.

Another potential hazard of drift is the deposition of salts and other solutes into the soil. In a general discussion of the impacts of cooling towers, Edmonds *et al.* (1975) predicted that natural variability in soil salinity would exceed increases due to cooling towers, and did not think that buildup of salts from cooling towers would be significant. Simulations of salt drift and measurements of deposition at the Chalk Point Generating Station (Armbruster and Mulchi 1984, Mulchi and Armbruster 1983) showed that, although salts were deposited in soils, the rains returned the soil to normal. The soils in the Chalk Point area are very permeable with excellent drainage, and the regular precipitation (averaging 102 cm/yr) washes the solutes away. They predicted that towers at Chalk Point would have only minimal impact on the soils. The amount of salt deposition near the cooling towers in Galveston Bay, Texas was as much as 1,200 kg/ha-yr at a site 100 m from the towers, but was small at a site 434 m from the towers (Wiedenfield *et al.* 1978). Levels of salt in the soils were high around the salt water cooling towers, but were immeasurable beyond 434 m. The authors warn that as more salt is deposited the effects may be measurable at greater distances, and that because of the poor drainage, the potential for soil degradation exists. Based upon calculations, Roffman and Roffman (1973) predicted that cooling tower drift generally would not increase the salt content of soil significantly, but might in arid areas (like Southern California).

Finally, there is the danger that drift solutes could enter the ground water supply. The army draws 600 acre-feet/year from the San Onofre groundwater supply (U.S. Atomic Energy Commission 1973c). Whether the impact on the aquifer might be significant would need to be investigated. Other studies have addressed the problem of contamination of aquifers. At Indian Point, the EIS predicted that intrusion of salts into the groundwater would be highly unlikely. Roffman and Roffman (1973) calculated that the influence of salt drift on aquifers should not be significant, even over time periods of several hundred years.

Based upon the present analysis of the impact of cooling towers at SONGS, it is not possible to determine the state of the impact of drift on the local vegetation, soils, and ground water. However, it seems likely that drift would be detrimental, but that the damage would be restricted to an area near SONGS (perhaps within a radius of a few miles).

5.1.2.2 Blowdown disposal

Because of evaporation and drift losses, the solutes in the water in cooling towers become increasingly concentrated. A portion of this water, called blowdown, is periodically or continuously discharged; it is replaced by make-up water. The blowdown contains concentrated salts plus additives used to prevent corrosion, scaling, and biological growth. In the case of SONGS, the blowdown would be discharged into the ocean. Technology for removing some of the solutes exists (Edmonds *et al.* 1975, Anderson *et al.* 1984, Eichholz 1985) and certain toxic materials may degrade or evaporate (Holzwarth *et al.* 1984a, 1984b, Blanchard *et al.* 1987), but much would still be released into the ocean.

The consequences of blowdown solutes for marine water quality and marine life are not well studied. The Indian Point EIS (U.S. Nuclear Regulatory Commission 1979) predicted that the sulfuric acid added would increase the concentration of sulfate ion, but it would be within water quality standards. The chlorine concentrations would exceed water quality standards. The EIS predicted that if the blowdown was within water quality standards, it would not adversely impact organisms in the Hudson River.

The few studies that have addressed the toxicity of blowdown water on organisms have not measured relevant parameters and cannot be extrapolated to SONGS. For example, several species of fish were raised in a reservoir that received blowdown water that was high in chromium. These fish did not contain higher levels of chromium than fish grown in uncontaminated water, nor was any bioaccumulation of chromium detected (Elwood *et al.* 1980) but the study did not assess whether the elevated chromium had any effect on growth rates, longevity, health or reproductive rates of the fish. A study contrasting growth of eels raised in river water with eels raised in warm cooling tower pond water revealed that those raised in cooling tower pond water do not have abnormal levels of metals in their liver and muscle tissues, despite the higher concentrations of metals in those waters (Romeril and Davis 1976), apparently because the eels are growing at a greater rate (due to the elevated water temperature) than the rate at which they can accumulate metals. However, Romeril and Davis did not examine the rate at which eels would accumulate metals when held at normal temperatures in the cooling tower pond water, nor did they compare the mortality rates, fecundity or health of the animals in the cooling tower pond water with animals in the natural environment. It appears that rigorous testing of the influence of blowdown discharge has not been done, although reviews of the effects of chlorine and other solutes present in the blowdown document the deleterious effects of these solutes (EPRI 1979, Central Electric Research Laboratories 1975).

An indirect test of the toxicity of blowdown is the use of saline cooling tower water for irrigation. In Maryland crops of corn and alfalfa were not adversely affected by this water (Mulchi and Armbruster 1981, 1982). Engle *et al.* (1985) irrigated corn and alfalfa crops in Minnesota with saline cooling tower water and found that the crops were not adversely affected. On the other hand, Amjal and Khan (1986) found that although watering plants with cooling tower effluents in India did not reduce germination, it did reduce plant growth. Because the power plant is discharging chlorides, sulfates, solids and other pollutants, they suggest treatment of the water before it is discharged.

The SONGS EIS calculated that blowdown would contain 100 ppt of dissolved solids (which is three times the concentration of solutes in the ocean, 34.7 ppt) (U.S. Atomic Energy Commission 1973c). This water would be discharged into the ocean. Table 5-3 shows the composition of the discharge from the present once-through cooling system. The SONGS EIS mentions periodic use of sodium hypochlorite. "The concentration of total chlorine in the receiving water will be less than 0.1 mg/liter for no more than six 15-minute periods per day."

5.1.2.3 Air quality

If cooling towers were installed at SONGS, the resulting reduced efficiency would mean that the plant could not provide as much energy as it does presently. For example, the Indian Point plant predicted a 4% decrease in annual plant capacity and a 9% reduction in peak generating capacity. SCE would need to replace the energy lost due to reduced efficiency at SONGS. It would be necessary, therefore, for SCE to generate more energy at its fossil-fuel plants. Although SCE would first generate electricity at its most fuel-efficient plants (B. Mechalas, *personal communication*), any additional use of these plants would produce far more air pollutants than SONGS. Furthermore, these plants would release pollutants into the South Coast Basin. On balance, air quality would be degraded by constructing cooling towers.

Table 5-3

Chemical composition of water discharged from SONGS.

From Table 3.9 of SONGS Units 2 and 3 Final Environmental Statement (U.S. Atomic Energy Commission 1973c). Based on information supplied by Southern California Edison. Discharge from Unit 1 must be added to obtain total amounts, but concentrations cited will not change.

CHEMICAL	MAXIMUM RELEASE PER UNIT (LB/DAY) NATURALLY OCCURRING	ADDED BY EACH UNIT	MAXIMUM CONCENTRATION[a] NATURALLY OCCURRING (PPM)	ADDED BY EACH UNIT (PPM)	INCREASE (%)
Boron	46,000	10	4.6	0.002	0.05
Bromide	6.5×10^5	250[b]	65	0.05[b]	0.08
Calcium	4.0×10^6	1450[b]	400	0.29[b]	0.07
Cellulose sealant[c]		< 1000		< 0.1	
Chloride	2.0×10^8	71,500[b]	19,980	14.4[b]	0.07
Chlorine (free residual)[c]		< 60		< 0.1	
Copper[c]	10-100	70	0.001-0.01	0.007	70-700[d]
Fluoride	14,000	5.0	1.4	0.001[b]	0.07
(Hardness, total)	6.2×10^7	22,500[b]	6218	4.5[b]	0.07
Magnesium	1.26×10^7	4600[b]	1272	0.92[b]	0.07
Nickel[c]	1	7.0	0.0003	0.0007	233[d]
Nitrate	3400	11.5	0.34	0.00228	0.67
Nitrogen, organic	1000	3.3	0.10	0.000665	0.67
Phosphates, as ortho	1000	20	0.10	0.004	4.0
Potassium	3.80×10^6	1350[b]	380	0.27[b]	0.07
Sodium	1.05×10^8	38,000[b]	10,500	7.6	0.07
Sulfate	2.64×10^7	9500[b]	2655	1.92[b]	0.07
Sulfide	1000	0.60	0.10	0.000122	0.12

[a] Assumes that maximum concentrations would occur during periodic condenser maintenance when circulating water flow would be only half of normal flow.

[b] Brine discharge from flash evaporators only.

[c] Calculated from information supplied by the applicants.

[d] Based on assumed maximum corrosion rate.

5.1.2.4 Cloud Formation and Fogging

Cooling towers release huge quantities of water vapor into the atmosphere that can form clouds under appropriate meteorological conditions. A model developed by Neiwiadomshi and Haman (1984) predicted that large power plants (5000 MW) could increase rainfall within 5-7 km of the plant by up to 70%, given favorable conditions. They recommend that this possibility be closely examined during environmental impact studies before cooling towers are installed. Therefore, concern exists about their potential for modifying the weather. The degree and frequency of cloud formation depends on tower construction and meteorological factors. An extensive review for the Indian Point Unit showed that cloud formation due to cooling towers would occur, and the clouds might alter precipitation patterns in an area. The plume from the towers at Indian Point was predicted to reduce sunshine for a few minutes each day, but the increase in precipitation was predicted to be undetectable (U.S. Nuclear Regulatory Commission 1979). Observations by Kramer *et al.* (1976) in West Virginia showed that the cooling tower plumes can modify the local atmosphere, both by increasing cloud cover and by creating new cloud formations. Shadowing effect on the ground occurred. Campistron (1975) found a precipitation band extending 30 km downwind from a nuclear power plant in France, and an augmentation in the amount of snowfall there.

A further problem is the possibility of ground-level fog: This is a potential hazard because it could make driving near cooling towers more hazardous (Hall *et al.* 1987). In the Indian Point EIS, a review of fogging revealed that fogging has not been a problem around natural draft cooling towers in the United States, England or Switzerland, and they predicted that the increase in ground fog would be small (4 hr per year) if natural draft towers were installed at Indian Point. Mechanical draft towers have a greater potential for producing fog than natural draft towers, since they release their water vapor at about 50 ft instead of 300-500 ft. One Indian Point EIS estimate predicted an increase of nearly 100 hours of fogging per year if mechanical draft towers were installed, .

The EIS for SONGS Units 2 and 3 predicted that a cooling tower would produce a plume and sometimes fog under some (unspecified) weather conditions, and that the plume could reduce visibility for drivers on Highway I-5. The SONGS EIS stated that this would only happen rarely, but did not estimate the frequency. The EIS does not mention how often a plume is expected to be visible, or whether any changes in precipitation patterns or in the amount of shading due to a plume are expected. The EIS for SONGS Unit 1 (U.S. Atomic Energy Commission 1973b) estimated an increase of 90 hours of fog per year if cooling towers were installed.

5.1.2.5 Noise

Sources of noise in cooling towers include the water pump, airflow-induced resonance, fan noise (in mechanical draft towers), and waterfall noise (Edmonds *et al.* 1975). The loudest of these is the waterfall noise. The amount of noise produced by towers depends on their size and type and the flow through the tower. Edmonds states that the noise level at towers is usually between 80 and 90 DB.

Noise pollution is a growing and serious problem in modern society, and excessive noise may cause progressive hearing loss and deafness. To put the magnitude of noise produced by cooling towers in perspective, the following table presents the noise levels for some common sounds:

100 db	90 db	80 db	70 db
power mowers farm tractor jackhammer motorcycle (8 m) jet (300 m)	diesel truck busy city street	garbage disposal average factory freight train (14 m) dishwasher	vacuum cleaner freeway traffic (15 m)

Noises above 80 dB cause hearing damage after long-term exposure.

The influence of the noise produced by cooling towers would depend upon where the towers were located. Edmonds *et al.* (1975) predict that the noise from cooling towers would probably not affect wildlife adversely, as the sound is similar to that of a waterfall, a sound found in nature (though not in the San Onofre area). Such steady and uniform broad-band random noises with no large pure tones peaks in mid-range are easy to adapt to. However, if the towers were on a recreational area or near a state beach, visitors might find that the noise detracts from the serenity of the area. Sound levels can be as high as 60 dB at 2,000 ft (Capano and Bradly 1974). If the towers are close to work areas, workers may find the noise annoying or objectionable. However, at a distance, the noise might not offend, or it might not be noticeable above the sound of traffic on I-5. The Indian Point study included an analysis of the augmentation of noise levels at sites used by people at various locations surrounding the towers. Such a study would be necessary at SONGS if cooling towers were built.

5.1.2.6 Aesthetics

SONGS is located along a very scenic portion of the Southern California coastline. The area is characterized by unobstructed views of gently rolling terrain with cliffs leading down to sandy beaches. Cooling towers would require more than 30 acres of land, and SCE has stated that there is not enough room beside SONGS to place them there (J.B. Palmer, *personal communication*). Southern California Edison (J.B. Palmer, *personal communication*) suggested two possibilities on the inland side of I-5, one of which is on State Park land. The aesthetic impact of cooling towers would be substantial. The towers would be highly visible; typical natural draft towers are 400 ft in diameter and 400 ft high. (However, it is possible that less-obtrusive towers could be constructed; B. Mechalas, *personal communication.*) On days when there is a visible plume, the visual impact would be much greater than the physical structure of the tower itself and would be visible from a greater distance. For example, it was predicted that the plume produced by the Rancho Seco natural draft cooling towers could extend as far as 20 to 30 miles before dissipating (U.S. Atomic Energy Commission 1973a). A large number of people would see the towers and plume daily, as this segment of Interstate 5 is traversed by thousands of motorists daily. Modeling would be necessary to tell how visible the towers would be from different locations, and to survey what types of use fall within the areas that the towers will be visible from.

The Indian Point EIS (U.S. Nuclear Regulatory Commission 1979) stated that the visual impacts of cooling towers could be the most significant social and economic impact. The California Coastal Act also recognizes the importance of aesthetics, stating that "the scenic and visual qualities of coastal areas shall be considered and protected as a resource of public importance" (Section 30251 of the California Coastal Act).

As one means of protecting the scenic qualities of the coast, the Coastal Act states that development should "minimize the alteration of natural land forms" (Section 30251). In keeping with this policy, the Permit was explicit about the need to minimize destruction of the coastal bluffs near SONGS. The construction associated with cooling towers would result in the destruction of additional bluff area. The extent of bluff destruction would depend on the specific location of the cooling towers. If the towers were located on the inland side of the freeway (about a mile from the plant), it would be necessary to tunnel underneath the freeway and into the hills, defacing at least some of the seacliffs. On the other hand, a more extensive bluff area would be destroyed if the cooling towers were constructed downcoast of Units 2 and 3.

5.1.2.7 Summary of Associated Impacts

If SONGS had been constructed with cooling towers instead of using a once-through cooling system, some of the substantial impacts on the marine environment would not have occurred. In their place, there would be terrestrial impacts and new marine impacts, the magnitude of which is difficult to estimate. Salt drift would be detrimental to plants, but probably only close to the towers. Noise levels would increase, and it is possible that fog might be slightly more frequent, but these impacts would probably not be substantial. Blowdown disposal in the ocean would add toxins to the marine environment. Perhaps most substantial would be the detraction from the aesthetic appeal of the area and the destruction of the coastal habitats, particularly the coastal bluffs.

In addition to the impacts mentioned above, the use of cooling towers would decrease the efficiency of SONGS because of lower condenser efficiency and the additional pumping requirements. This would translate into higher electricity costs for users and greater air pollution in the South Coast Basin.

5.1.3 Feasibility

Although retrofitting SONGS Units 2 and 3 is probably technically feasible, this project would present many difficulties because it would include technology that is untested and because the scale of the project is so large.

Although dry towers do not produce problems associated with drift and blowdown, they have presently been used only with small (<200 MW) fossil fuel plants in cool climates. Wet/dry mechanical draft towers are only used by a few power stations in the 200 MW range, and they cost about 10% more than wet towers. Saltwater wet cooling towers have never been used at a plant as large as SONGS, and cost overruns seem likely because of the unproven technology.

A retrofit of a plant is more difficult than if the plant were originally designed for cooling towers. For example, the intake pipes are currently pointing the wrong direction for use by cooling towers. To adapt the system, it would be necessary to build a curving pipeline from the plant out and back up the beach. A SCE engineer said a huge concrete anchor would be necessary to support the pipe against the force of the water. This plan would also require a tunnel below the freeway for the pipes to carry water up the hills; it is not known whether the Department of Transportation would give SCE permission to tunnel under the freeway. Because the towers will be 200 feet uphill, a large pumping capacity would be required.

Cooling towers require a great deal of space. Edison contends that there is not sufficient space next to the plant, and that they would therefore need to obtain land for the towers. The nearest potential locations, either land owned by the Marine Base, or land from the State Park, are about a mile away and across Interstate 5. It is not known whether SCE could acquire permission to build on these lands.

In summary, the scale of the construction needed to retrofit SONGS with cooling towers is enormous. Many technical aspects relating to the design of the towers would have to be overcome. Although it seems likely that these design problems could eventually be solved, the solutions are likely to be costly, both financially and in terms of delays as unproven technology is implemented. Furthermore, there are logistical obstacles relating to the use of land that does not belong to SCE that might not be solvable.

5.1.4 Costs

The cost for replacing open-cycle cooling with cooling towers is quite high, as was demonstrated at Indian Point Unit 3, a nuclear power plant operated by Consolidated Edison Co. of New York. Natural draft cooling towers were used at an estimated cost of $338 million, not including the cost of the reduction in the generating capacity of the plant (4% of average power and 9% of peak capacity, Consolidated Edison Co. 1979). Table 5-1 indicates that cooling towers could be expected to cost at least $400-500 million, depending on the type built.

In 1981, SCE estimated that the cost for converting to cooling towers at SONGS would be in the range of $800 million to $1 billion in 1980 dollars (Gardner 1981). This estimate is probably still valid. Recent estimates by SCE put the total cost of retrofitting cooling towers at between $500 million and $1 billion. In addition, they project an additional $1 billion cost over the remaining life of the plant due to reduced efficiency caused by the cooling towers (J. Palmer, SCE, *personal communication*).

In addition to the financial costs, there would be environmental costs if cooling towers were used at SONGS. Cooling towers can have significant environmental impacts, both on the terrestrial environment through the deposition of drift, and on water quality because of the addition of biocides and corrosion-inhibiting chemicals to the cooling water (Section 5.1.2).

5.2 Cooling ponds and canals

Cooling ponds are an economical and proven method of rejecting waste heat, but require about 1 to 3 acres of level land per MW (i.e., 2000 to 6000 acres at SONGS). Using spray ponds and canals would reduce the size of a cooling pond by a factor of 20, but at least 100 acres would still be needed to cool the water from

SONGS. A buffer zone of 300-500 m is required to confine the effects of steam fogs and drift effects to the site.

There are two major problems with cooling ponds and canals. First, the scarcity of fresh water would necessitate the use of salt water, and salt drift can damage the surrounding terrestrial environment (see Section 5.1.2.1). The drift from spray ponds is likely to be less extensive than from cooling towers, but nonetheless this alternative would result in shifting environmental effects from the marine environment to the terrestrial environment. Second, a relatively large amount of land is required. The land requirement is particularly difficult to solve. SONGS is situated along a relatively narrow strip of land on the Camp Pendleton Marine Corps base. The coastline near SONGS consists mostly of narrow beach bounded by high bluffs, with San Onofre State Beach just upcoast of the power plant; the San Diego Freeway parallels the coast about 300-500 m inland. Southern California Edison has an 84-acre easement for SONGS, 68 acres of which are used by the three units (SCE 1973a). Thus, only about 16 acres of the original tract have been left undisturbed, which is clearly not sufficient for even spray ponds or canals. It is not known whether additional land might be available, but even if additional land could be obtained, it would be difficult or impossible to find sufficient space for a cooling pond. There is little flat area on the ocean side of the freeway, even considering the top of the bluffs; sufficient area could be found directly north of SONGS, but it would be at least 500 m away on the other side of the freeway. Locating a cooling pond at this site would encounter the same logistical difficulties noted for cooling towers (Section 5.1.3).

The difficulties and uncertainties associated with finding sufficient land for cooling or spray ponds, along with the new environmental effects, mean that this alternative is not feasible at SONGS.

CHAPTER 6

MODIFICATION OF OPERATIONS

Three types of modifications to plant operations are considered: (1) scheduling operations to avoid critical periods, (2) reducing flow while the plant continues to operate, and (3) modifying the heat treatment procedures.

6.1 Scheduling operations to avoid critical periods

Curtailing plant operations at specific times might be a reasonable mitigation technique if it results in a disproportionate reduction in impacts (Marcy *et al.* 1980). This technique has been utilized on the Hudson River, where the utilities involved were willing to implement flow reductions and scheduled shutdowns to reduce entrainment in order to avoid constructing cooling towers (Barnthouse *et al.* 1984). While the plant is not operating (i.e., producing power) the entrapment of fish and entrainment of fish larvae are greatly reduced. Losses are not always completely eliminated when the plant is off-line because some flow (often 50% during part of the scheduled outage) occurs even when the plant is not producing power, but fish mortality are reduced because the flow rate would be substantially lower. Scheduling SONGS to avoid operation during periods of kelp recruitment could alleviate the problem of water turbidity and allow normal kelp recruitment events to occur near San Onofre.

6.1.1 Potential reductions in losses

Shutting down SONGS would be most effective if there were seasonal variation in the risk to a species. The abundance of fish larvae was very seasonal (Figure 6-1). Most species were most abundant in late winter/early spring. The abundance of all species combined peaked sharply in March; in fact, March alone accounted for 31% of the total ichthyoplankton abundance, while April accounted for an additional 25%. Details about the monthly patterns of ichthyoplankton abundance near SONGS are presented in Appendix B.

The ichthyoplankton abundance data can be used to evaluate the savings that could be achieved by rescheduling the operation of SONGS. This analysis is presented in detail in Appendix B.

A substantial reduction in the loss of ichthyoplankton could be achieved by restricting plant operations during early spring. This technique appears to be the one most likely to be effective for reducing losses of ichthyoplankton. By ceasing operations completely during March and April, roughly 2.5 billion fewer larvae would be killed than under the present operating schedule, cutting the current losses in half (Table 6-1). Considering only the 13 species with estimated adult equivalent losses >1%, 827 million fewer larvae would be killed by not operating SONGS in March and April (again, cutting the losses in half); this savings could be increased to more than 1 billion larvae by also not operating SONGS in August.

If the plant does not produce power in March and April but one or more pumps circulates water while the plant is off-line, the savings in fish larvae would be

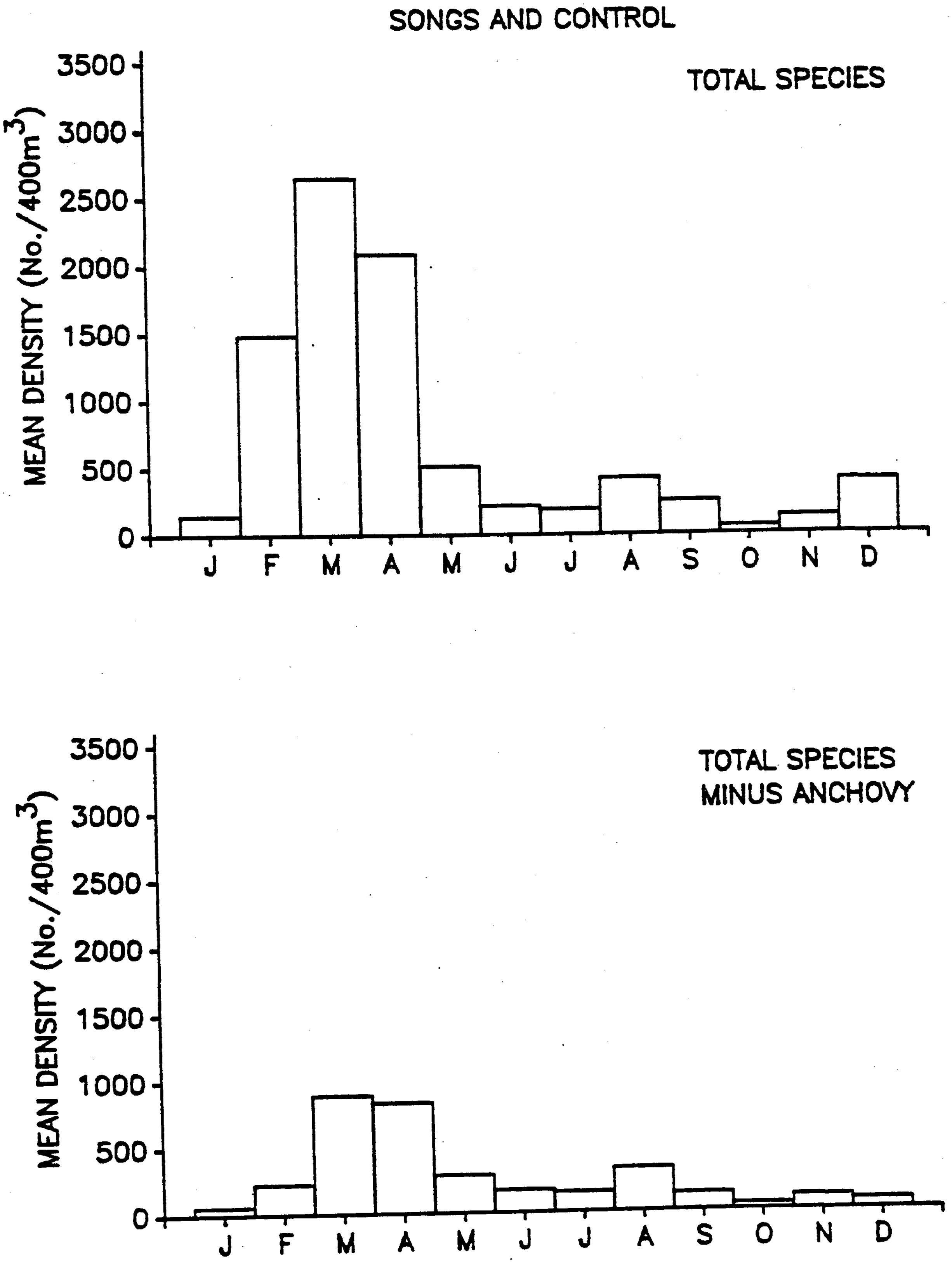


Figure 6-1: Seasonal pattern of larval fish abundances near SONGS. Shown are the estimated density of total fish larvae and total larvae minus northern anchovy for each month. Actual entrapment at SONGS will be a function of larval abundance and flow rate through the plant.

Table 6-1

Possible reduction in entrainment of fish larvae from eliminating flow during certain months.

Data are presented for total species, northern anchovy (the most abundant species), total species minus anchovy, and 13 species with estimated adult equivalent losses >1% (AEL species). Loss prevented was calculated as the number of larvae that would be entrained in the months noted (see Table B2) minus the number that would not be entrained under the present operating schedule (see Table B5).

Species/ Group	Loss Prevented by Eliminating Flow During:					
	March & April		February, March & April		March, April & August	
	x 10^9	%	x 10^9	%	x 10^9	%
Total	2.5432	49	3.4832	68	2.8322	55
Northern anchovy	1.6444	52	2.4444	77	1.7414	54
Total minus anchovy	0.9088	46	1.0488	53	1.1388	58
Queenfish	0.0879	18	0.0922	19	0.2479	52
Giant kelpfish	0.0008	13	0.0029	48	0.0011	18
White croaker	0.6650	76	0.7560	86	0.6670	76
California grunion	0.0017	10	0.0017	10	0.0024	13
Black croaker	0.000002	0.06	0.000002	0.06	0.0015	43
California corbina	-0.0011	-14	-0.0011	-14	0.0049	63
Cheekspot goby	0.0070	5	0.0136	9	0.0180	12
Reef finspot	-0.00106	-14	-0.00106	-14	0.0019	24
Arrow goby	0.0172	32	0.0202	37	0.0195	36
Jacksmelt	0.0423	52	0.0493	60	0.0423	52
Shadow goby	0.0020	9	0.0052	23	0.0047	21
Diamond turbot	0.0033	30	0.0053	48	0.0035	32
California clingfish	0.0019	19	0.0019	19	0.0035	34
Total AEL species	0.826942	48	0.946142	55	1.018242	59

less than indicated in Table 6-1. The general operating procedure at SONGS is to have no flow through the pumps during half of the scheduled refueling and maintenance period, then have two of the four pumps operating during the other half of the period (A. Dykes and D. Pilmer, *personal communication*). In recent years this has not always been the case (see Appendix B), but it might be expected to occur in the future.

The savings would be only half as great as indicated in Table 6-1 if only one Unit was offline each year, as would be the case if SONGS operated on a 24-month fuel cycle; even in this case, however, the loss of fish larvae would be reduced by 25%.

From a Bight-wide perspective, the savings might be further reduced depending on which fossil fuel plant SCE operates to provide replacement power. The impacts will be quite different, depending on whether the replacement power is produced at a plant with **offshore** intakes or **harbor or canal** intakes. If SCE operates a plant with an **offshore** intake, where larval abundance is similar to that near SONGS, more larvae will be killed when they are entrained into that plant than would be the case if SONGS was operating. The actual number will depend on the volume of water passed through the plant per MW of electricity generated. For example, SONGS Units 2 and 3 circulate 755 gpm/MW generated, while Ormond Beach circulates 317 gpm/MW; even if larval abundances were identical off of San Onofre and Ormond Beach, Ormond Beach would kill only half as many larvae as SONGS to generate the same amount of electricity. Nonetheless, operating Ormond Beach in March and April would reduce the savings of fish larvae shown in Table 6-1 by about half. The situation would be quite different if SCE operates a plant with a **harbor or canal** intake. At these stations, fish larvae are not abundant in March and April (Appendix B); these stations would kill few larvae if they were operated in place of SONGS in March and April.

Various combinations of pump operations could further reduce the entrainment of fish larvae while minimizing the costs involved (see Section 6.3). For example, reducing the flow of water throughout the winter (Section 6.2), in conjunction with no flow in March and April, would greatly increase the savings that could be achieved.

Unlike the case for fish larvae, the older lifestages of fish did not have a narrow period of high abundance. The risk for juvenile and adult fish can be assessed using mean monthly entrapment rates at SONGS. Figures 6-2 and 6-3 present these rates for the older lifestages of the most commonly entrapped species at SONGS, queenfish and northern anchovy, as well as all species combined. The entrapment of northern anchovy was highly seasonal, for both number (Figure 6-2) and biomass (Figure 6-3). Restricting operations during summer months would be likely to reduce the entrapment of northern anchovies. However, SONGS' effect on anchovies is negligible since most anchovies are found offshore; summer months are also the months when the demand for power is highest, so restricting operations during these months could cause severe logistical problems for SCE with regards to providing replacement power. Queenfish entrapment was somewhat lower during the winter months than at other times of the year (especially biomass, Figure 6-3), but there is no limited period of time during which plant operations could be restricted in order to reduce queenfish entrapment. Similarly, there is no period during which the total weight of fish entrapped could be substantially reduced by

Figure 6-2: Seasonal pattern of entrapment of juvenile and adult fish at SONGS: Numbers. Shown are the estimated number of queenfish, northern anchovy and total fish entrapped at Units 2 and 3 each month. Note the change in scale for queenfish.

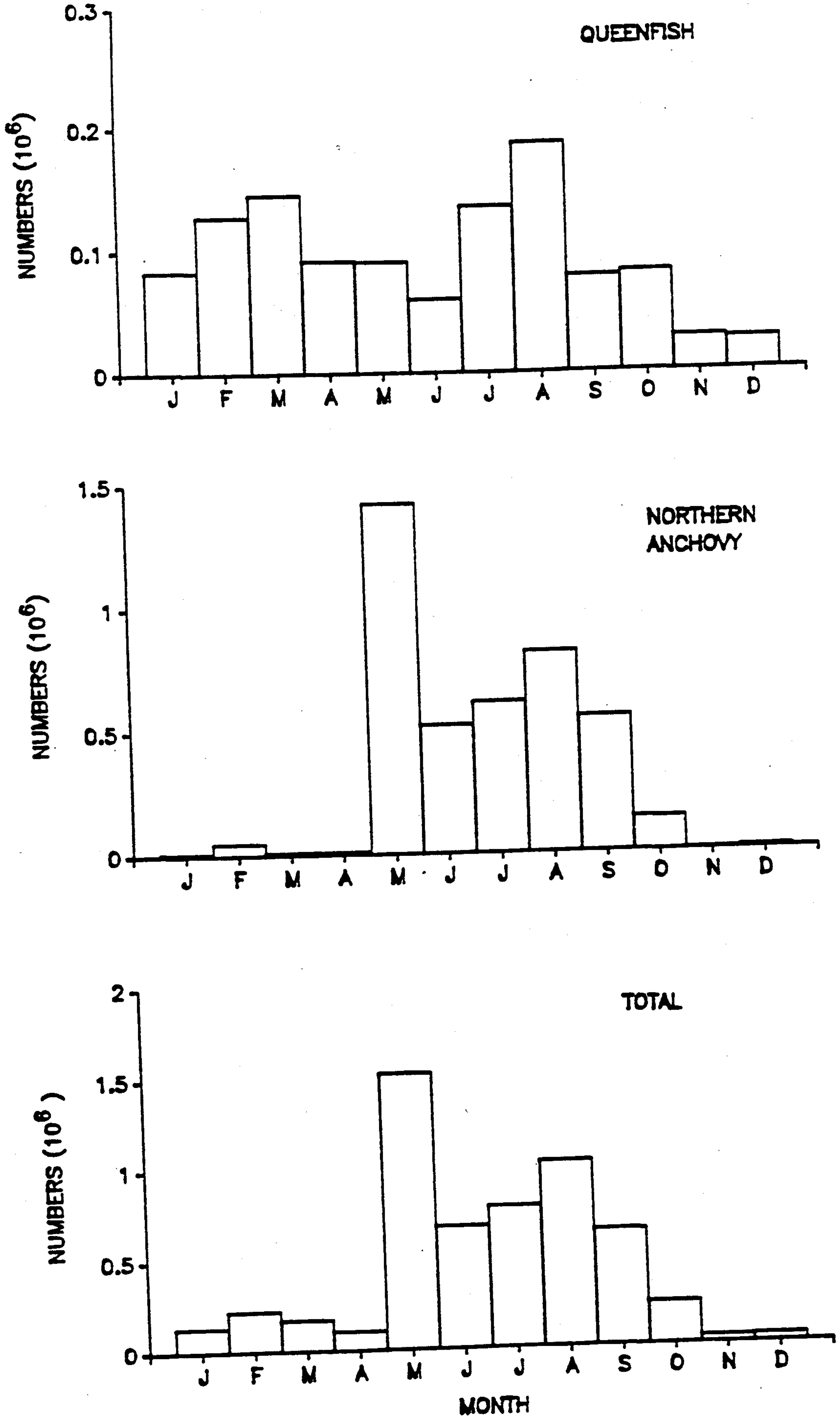
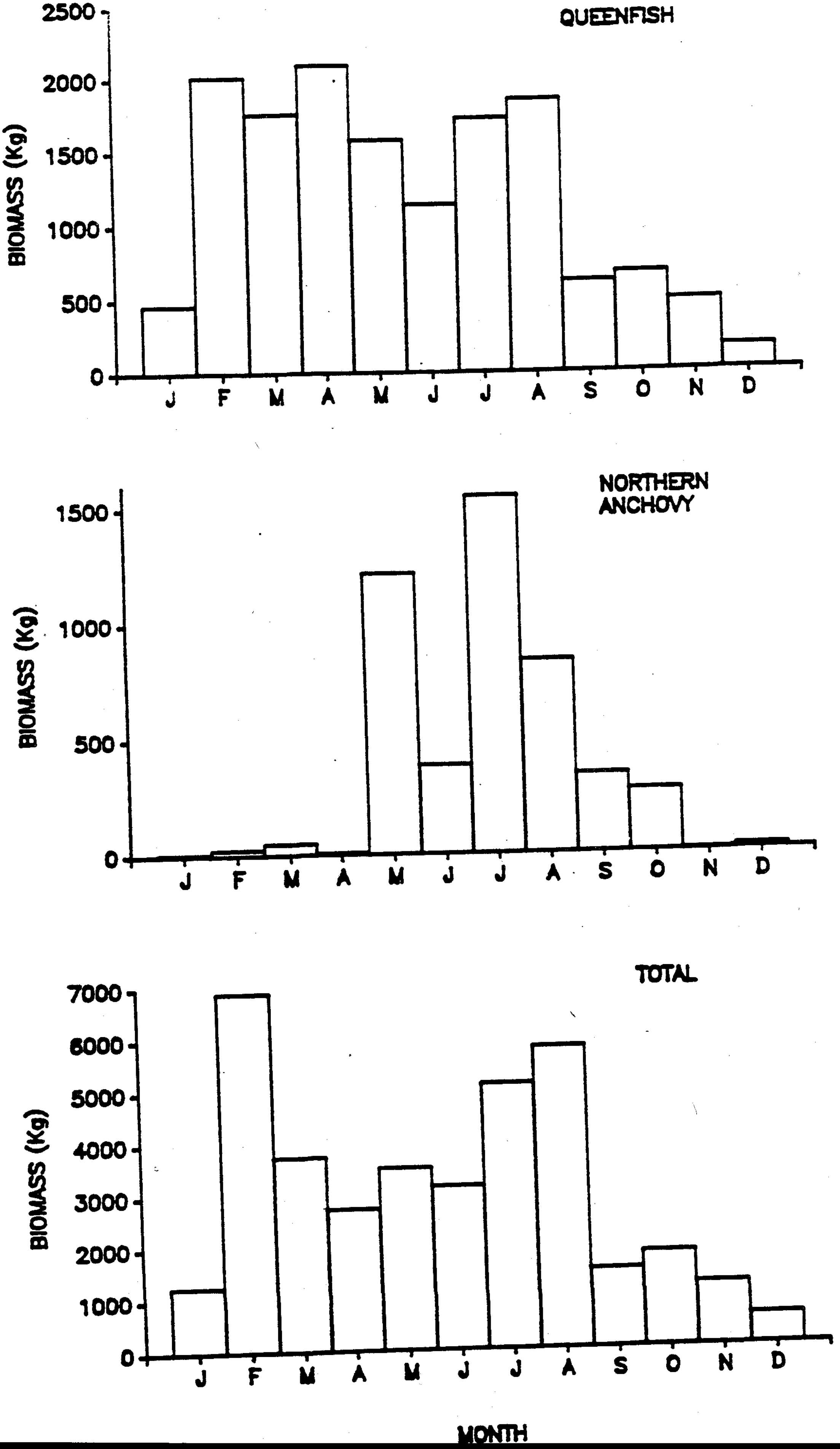


Figure 6-3: Seasonal pattern of entrapment of juvenile and adult fish at SONGS: Biomass. Shown are the estimated biomass of queenfish, northern anchovy and total fish entrapped at Units 2 and 3 each month. Note the changes in scale for biomass.



restricting plant operations (Figure 6-3). The absence of a very limited period of peak abundance means that reducing plant operations would not be a very effective technique for reducing the loss of juvenile and adult fish.

At the San Onofre and San Mateo kelp beds the highest kelp recruitment occurs in the winter and spring (Technical Report K). Rescheduling SONGS to avoid operation during recruitment periods could alleviate the problem of water turbidity and allow normal recruitment events to occur near San Onofre. The conditions necessary for kelp recruitment typically occur only 3 to 4 weeks per year, but the timing of the recruitment window is unpredictable, making it very difficult to schedule periods of restricted operations specifically for kelp. However, restricting flow any time between February and June, including March and April (the time proposed for reducing larval fish losses), would increase - to some unknown extent - the chances for successful kelp recruitment at the San Onofre Kelp bed.

6.1.2 Technical feasibility

It certainly is possible to cease producing power at SONGS. Currently, SONGS occasionally does not produce power at various times for various reasons, as noted in Table 6-2 and Appendix B. From 1984 to 1988, Units 2 and 3 did not produce power about 116 days/year, and had no flow on about 46 of these days. The problem is not how to cease producing power at SONGS, but rather how to have the plant offline during the specific periods of critically high abundances of fish larvae.

Table 6-2

Operating History of SONGS Units 2 and 3.

– indicates no outage. * indicates scheduled refueling outages.

MONTH/YEAR	UNIT 2		UNIT 3	
	FORCED OUTAGES (DAYS)	SCHEDULED OUTAGES (DAYS)	FORCED OUTAGES (DAYS)	SCHEDULED OUTAGES (DAYS)
9/86	1.1	–	1.1	0.9
10/86	no	data	no	data
11/86	–	–	–	–
12/86	3.5	–	–	–
1/87	–	–	–	29*
2/87	2	–	–	28*
3/87	1.5	1.6	–	11.3*
4/87	–	–	–	–
5/87	–	–	–	–
6/87	–	–	4.1	–
7/87	–	–	–	–
8/87	–	3*	–	–
9/87	–	30*	–	–
10/87	–	31*	1.5	–
11/87	–	30*	–	–
12/87	1.5	11.6*	–	–
1/88	–	0.06	9.8	–
2/88	–	–	2.7	–
3/88	–	14.9	–	–
4/88	–	4.8	–	0.9*
5/88	–	–	–	31*
6/88	–	–	–	30*
7/88	–	–	–	31*
8/88	no	data	no	data
9/88	–	–	–	–
10/88	–	–	–	–
11/88	–	–	–	–
12/88	–	–	–	–
1/89	19.4	–	2.4	–
2/89	10.9	–	–	–
3/89	–	–	–	–
4/89	–	–	10	–
5/89	18.7	–	–	–

Two alternative strategies could be used to avoid operating during critical periods. In the first alternative, all of SONGS' refueling and maintenance would take place during the period of highest ichthyoplankton abundances. SONGS would operate for about the same number of days each year, the principal difference being that its offline periods, during which refueling and scheduled maintenance are performed, would coincide with the period of highest ichthyoplankton abundances.

In the second alternative, SONGS would be offline when ichthyoplankton abundances are highest **in addition to** its normally scheduled period for refueling and maintenance. If SONGS could not coordinate refueling and maintenance with the period of highest ichthyoplankton abundances, it would have more days offline each year in order to avoid operating during these critical periods. Operating fewer days each year would cause two environmental consequences: greater emissions of air pollutants at other SCE plants, and lower savings of fish larvae. Greater emissions would occur because SCE would need to replace the electricity not produced at SONGS by generating electricity at fossil fuel plants. Lower savings of fish larvae would occur because more larvae would be entrained at other power stations than would otherwise be the case, since these stations would be required to operate for more days. This latter consequence can be minimized by operating plants with protected or harbor intakes (such as Mandalay, Long Beach, Alamitos, and Units 1-6 of Redondo Beach), where the seasonal pattern of ichthyoplankton abundances is quite different (see Appendix B). Also, there would be a savings in larvae in any case because SONGS (and nuclear power plants in general) circulates more m^3 of water per KW of electricity generated than do fossil fuel plants.

There are technical difficulties with insuring that SONGS refuels at exactly the same time each year. Managing the timing of refueling in a nuclear plant is very complex, many variables need to be considered; the issue is much too complicated to be discussed in detail here. The simplified analysis that follows discusses the technical difficulties in two categories: problems with adjusting the length of the fuel cycle to match the critical periods (particularly March and April), and the uncertainty associated with scheduling refueling and maintenance at a nuclear power plant.

6.1.2.1 Adjusting the length of the fuel cycle

SONGS could in principle avoid operating during the period of highest larval abundance if both units refueled on a 12-month cycle and both units did not operate during March and April each year, or if both units refueled on a 24-month cycle and Units 2 and 3 alternated years of not operating during March and April. A 12-month cycle would be shorter, and a 24-month cycle longer, than the current fuel cycle used at SONGS.

Adjusting the length of the fuel cycle used at SONGS would involve redesigning the fuel and how it is placed in the reactor. Core design is extremely complex. The variables that must normally be considered for a fuel loading plan are the fuel enrichment (fissile content of the fuel), the number of fresh fuel assemblies to be loaded (reload batch size), the arrangement of the fresh and partially spent fuel assemblies in the reactor, and the techniques used to control the excess reactivity of the reactor during the cycle (Graves 1979). SONGS' core utilizes a 16 x 16 array; with 20 positions reserved for guide posts, there are 236 pin positions at which fuel rods or burnable poison rods (boron assemblies that are used to control the reactivity) can be placed. Although SONGS started with 100 poison rods, the core design has become more complex and thousands are now used (D. Pilmer, SCE, *personal communication*). In addition, a neutron absorber (also boron) is dissolved in the reactor coolant as an additional means of controlling reactivity, and the concentration of this fluid can be varied. The design of each new load of fuel at SONGS, which involves fine-tuning rather than dramatic departures in core design, typically involves a $250,000 engineering task (D. Pilmer, SCE, *personal communication*). Obviously, large changes in the core design would involve substantially greater efforts.

There are both technical and regulatory/safety constraints on core design. The technical constraints include the enrichment of the fuel (with ^{235}U), the distribution of power in the core, and the worthiness of the fuel rods (which currently are used for two cycles at SONGS). The regulatory/safety constraints insures that the fuel behaves properly under different scenarios, such as loss of coolant accidents and transient events (e.g., trip at full power).

Because a portion of the old fuel remains in the core after refueling, a fuel cycle of a particular length cannot be achieved quickly. It takes a number of cycles after the startup of a new reactor to achieve the desired cycle (and even then the cycle undergoes constant perturbations due to unexpected events, as described in the next section). Similarly, any large change in the length of the fuel cycle would need to be achieved over several cycles; at 18 to 24 months per cycle, it could take many years to implement substantial changes.

At SONGS, half of the fuel rods are currently replaced at each refueling, and the fuel cycle is 525 Effective Full Power Days (EFPDs). (Because unexpected events frequently force shutdowns between scheduled outages, there will usually be more than 525 calendar days between refuelings.) The fuel used at SONGS is enriched to 4.1% ^{235}U.

Longer fuel cycle

To achieve a longer fuel cycle, the fuel would need to be enriched to a greater extent or a higher proportion of the core would need to be replaced during each refueling. In fact, there are few nuclear power plants with longer fuel cycles than SONGS. A 4.9% enrichment of ^{235}U, which might allow SONGS to move to a 600 day cycle, is currently being used for the first time at the Calvert Cliffs nuclear power plant, but there are no operational data available yet (D. Pilmer, *personal communication*). Although a longer fuel cycle is theoretically possible, Southern California Edison feels that the current design represents the state-of-the-art (D. Pilmer, SCE, *personal communication*).

Shorter fuel cycle

There are no technical difficulties with achieving a shorter fuel cycle at SONGS, and in fact a 12-month cycle was originally planned for the units (SONGS Final Environmental Statement, 1973). However, SCE considers the longer fuel cycles to have considerable advantages over the 12-month cycle. A longer fuel cycle increases the amount of electricity generated at SONGS (thereby reducing the amount of fossil fuel burned), decreases operating and maintenance costs, reduces the quantities of liquid and solid radioactive waste (some of which are discharged into the ocean), and reduces the amount of spent fuel produced and stored at the site (Nunn 1989).

Most importantly, it is not possible to schedule both units for refueling and maintenance at the same time due to safety and logistical considerations. Thus, at most one unit could be offline during the March/April period, and because of the possibility of unexpected extensions of the refueling period it is unlikely that the other unit could be scheduled to immediately follow.

Overall, there are financial, environmental, and logistical advantages to longer fuel cycles. As a consequence, SCE has moved away from a 12-month cycle to the present cycle of 18 months or so.

Flexibility in fuel cycle

Finally, it is worth noting that there is some flexibility in the length of the fuel cycle. Although the fuel might be designed for, say, 525 EFPD, there is a window of 25 days on either side of the 525 EFPD during which the unit could be shut down. Shutting down earlier or later than the fuel load was designed for has ramifications for the following cycle: if the unit is shut down early, the fuel assemblies that are used again in the next cycle have more reactivity than expected, whereas if the unit is shut down late these assemblies have less reactivity. The changes in reactivity would necessitate changes in the design for the next cycle (which requires some lead time), and might alter the length of the next fuel cycle.

6.1.2.2 Uncertainty associated with rescheduling

Fuel cycles are designed in terms of Effective Full Power Days (EFPDs) rather than calendar days. Various unexpected events can occur between refuelings that alter the schedule. For example, Table 6-3 summarizes the outages that occurred between refuelings at SONGS Units 2 and 3 for the time period January 1987 and May 1989; on average, unexpected events caused SONGS to be offline for 28 days between refuelings. In addition, the actual refueling period varies in length from cycle to cycle, depending primarily on the maintenance that needs to be performed, but also on whether unexpected work is required. These unexpected events affect the total length of the fuel cycle.

Table 6-3

Summary of outages at SONGS Units 2 and 3 between January 1987 and May 1989.

	DAYS			
OUTAGE	MEAN	SD	RANGE	N
Scheduled refueling periods	88.9	18.96	68.3-105.6	3
Outages between refuelings:[1]				
Scheduled maintenance	5.5	9.91	0-20.3	4
Equipment failure	19.9	21.04	2.6-50.5	4
Administrative	1.0	2.05	0-4.1	4
Operator error	1.4	2.75	0-5.5	4
Subtotal	27.7	28.92	9.7-70.8	4

[1] Note that data for 3 of the 4 fuel cycles were not complete, so this represents a minimum estimate.

Clearly, with a rigidly fixed fuel cycle length and unpredictable and varied outage periods, it would be impossible to schedule SONGS to refuel during all of March and April in every year. Southern California Edison has developed a Monte Carlo simulation to illustrate this point (A. Dykes, *personal communication*). Their model uses the probabilities of unscheduled outages (log-normally distributed with a median of 45 days) and refueling outages (ranging from 60 to 270 days, although the longest observed outage has only been 106 days) to demonstrate the increasing uncertainty about the startup and shutdown dates of each fuel cycle with time. This consideration indicates that, regardless of the length of the fuel cycle, it would not be possible to schedule a fixed cycle period to coincide with March and April every year.

However, there some flexibility in the length of the fuel cycle, as mentioned in the previous section, that has not been incorporated into the Monte Carlo model. This flexibility could be used to extend or contract the operating period in order to be offline during March or April. Furthermore, substantial savings of fish could be achieved even if a unit operated during a portion of March and April. Finally, it probably is not realistic to expect a particular level of larval savings every year (unless the plant is forced to shutdown during a particular period regardless of it fuel cycle). A target reduction, averaged over three or five years, might be achievable by maximal use of the available flexibility in the fuel cycle (perhaps combined with a somewhat longer fuel cycle).

6.1.3 Costs

Restricting plant operations would not require any structural changes or additions to the plant, but would result in additional costs if less power were generated.

The additional cost to SCE would be minimized if scheduled downtime (for refueling and maintenance) occurred during March and April. Since SONGS must be down at some time for refueling and maintenance, scheduling refueling during the period of greatest ichthyoplankton abundance would reduce resource losses with minimal additional costs to SCE. However, as discussed in the previous section, there are technical obstacles to this alternative, both in terms of lengthening the fuel cycle and in the uncertainty of being able to schedule refueling for any particular calendar period.

There would be both economic and environmental costs if SONGS were to be offline more days each year in order to avoid operating during critical periods. Because SONGS is a baseload plant, it operates at full capacity whenever possible; other SCE plants are brought online as additional electricity is needed. Therefore, whenever SONGS does not operate, power plants that would otherwise be offline must be operated. If SONGS operations stopped during a period of maximal power demand, the reduced capacity of the entire SCE system might also be a problem; however, the time periods proposed here do not encompass periods of highest power demands.

Downtime at SONGS would result in additional fuel costs because more expensive alternative fuels would be needed to generate power at other (fossil-fuel) SCE plants. Estimates of these additional costs range from roughly $4 million per week (B. Mechalas, *personal communication*, 1989) to $7 million per week (Ebert 1980), depending on the cost of gas; SCE has recently estimated the replacement power fuel differential to be $1.1 million per Effective Full Power Day (EFPD). Preliminary estimates of the costs of forcing SONGS to be offline during all of March and April suggest an annual cost of $30-40 million (A. Dykes, *personal communication*).

There would also be additional *environmental* costs if SCE had to generate power at other power plants in order to make up for SONGS being offline. These plants have higher emissions of air pollutants and are located in more populous areas than SONGS, so air quality will be degraded. In addition, these plants have open cooling systems like those at SONGS, so additional organisms will be killed if the plants must be operated at higher-than-normal capacities in response to lower power production at SONGS. As noted above, the actual additional losses at other plants, and the overall net loss, depend on the specific plant operated. Plants with harbor or canal intakes would kill very few additional larvae because the seasonal abundance of larvae at these locations is very different from that at SONGS (Appendix B). Plants with offshore intakes would kill more larvae. Regardless of which plant operated to replace electricity that would be generated at SONGS, there would still be a net savings in larvae because ther flow rate per MW_e generated at other plants is only one-half to two-thirds that of SONGS.

SONGS could be operated at reduced flow throughout the year. However, the condenser temperature is already around 91°F during summer with a turbine back pressure of 2.3" Hg (Table 6-4). Increasing the ΔT from 20°F to 30°F would raise the condenser temperature to 101°F, which would lead to a turbine back pressure of about 2.7" Hg and reduced plant capacity. Furthermore, most fish larvae are less abundant during most of summer (except August; see Appendix B). The most cost-effective schedule for protecting fish larvae might be to operate at reduced flow only during the periods of highest larval abundances (see next section).

6.2.1 Potential reduction in losses

Since fish eggs and larvae are killed when they are brought passively into the plant with the cooling water, reducing the volume of water flowing through SONGS would result in lower entrainment of fish eggs and larvae (Marcy *et al.* 1980). The savings that could be achieved are related to the reduction in water flow. As with rescheduling plant operations, reducing the flow rate during periods of highest larval abundances would result in the greatest savings. For example, reducing the flow by one-third during March would save 541 million fish larvae, of which 161 million belong to species with estimated adult equivalent losses >1% ("AEL species")(Table 6-5A), which is about a 19% reduction in larval fish losses (Table 6-5B).

March and April are the months with highest larval abundances, but reducing the flow in February and May could also save more than a million larvae each month. The 19% reduction that could be achieved by reducing flow by one-third in

Table 6-5

Potential savings of fish larvae from reducing flow at SONGS

A. Data are the total number of fish larvae killed each year under the present operating schedule at SONGS, and the number that could be saved by reducing flow through SONGS by one-third. Total AEL species is the total of the 13 species with estimated adult equivalent losses >1%.

SPECIES/ GROUP	TOTAL ENTRAINED WITH PRESENT SCHEDULE (x10^8)	LARVAE SAVED WITH ONE-THIRD LESS FLOW (x10^8)											
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Total	50.42	0.30	3.12	5.41	4.11	1.05	0.43	0.39	0.81	0.48	0.11	0.25	0.82
Northern Anchovy	31.11	0.18	2.29	3.59	2.47	0.47	0.10	0.09	0.20	0.24	0.03	0.06	0.67
Total minus anchovy	19.50	0.12	0.41	1.81	1.64	0.58	0.33	0.30	0.66	0.25	0.08	0.20	0.15
Total AEL species	17.00	0.08	0.34	1.61	1.51	0.48	0.27	0.26	0.55	0.20	0.06	0.19	0.13

B. Percent reduction in larval fish losses from reducing flow by one-third for specified periods of time. Total AEL species is the total of the 13 species with estimated adult equivalent losses >1%.

SPECIES/ GROUP	MAR & APR (2 MOS)	MARCH TO MAY (3 MOS)	FEB TO MAY (4 MOS)	FEB TO MAY & AUG (5 MOS)	MAR TO MAY & AUG (4 MOS)
Total	18.9%	21.0%	27.2%	28.6%	22.6%
Northern Anchovy	19.5%	21.0%	28.4%	29.2%	21.6%
Total minus anchovy	17.7%	20.7%	22.8%	26.2%	24.1%
Total AEL species	18.4%	21.2%	23.2%	26.4%	24.4%

March and April could be improved to 27% by reducing flow between February and May, and to almost 29% by reducing flow February to May and in August. Reducing flow in February would mostly affect northern anchovy larvae, which dominate the ichthyoplankton during that month; although the absolute number of northern anchovy larvae saved would be substantial (230 million), this species is not substantially impacted by SONGS. In contrast, reducing the flow during August would add considerable savings for the species most impacted by SONGS, since species with high adult equivalent losses have their third highest abundance (after March and April) in that month. Reducing the flow of water through SONGS by one-third during the four months with the highest abundances of these species, March to May and August, would save more than 400 million larvae of the species with high adult equivalent losses and reduce the impacts to these species by nearly 25% (Table 6-5, Figure 6-4).

Reducing the flow of water through SONGS is a very flexible technique for preventing losses because, once variable-speed motors and controls have been installed, flow can be reduced in virtually any month or combination of months. (In contrast, refueling can only occur in a single block of time, and any additional periods offline would be extremely expensive.) Obviously, the greater the number of months operated at two-thirds flow the greater the savings in fish larvae; however, more months also mean greater costs to SCE. There is no obvious breakpoint in the savings that could be achieved (which might help determine the most cost-effective number of months with reduced flow), but there are diminishing returns as more months are added (Figure 6-4).

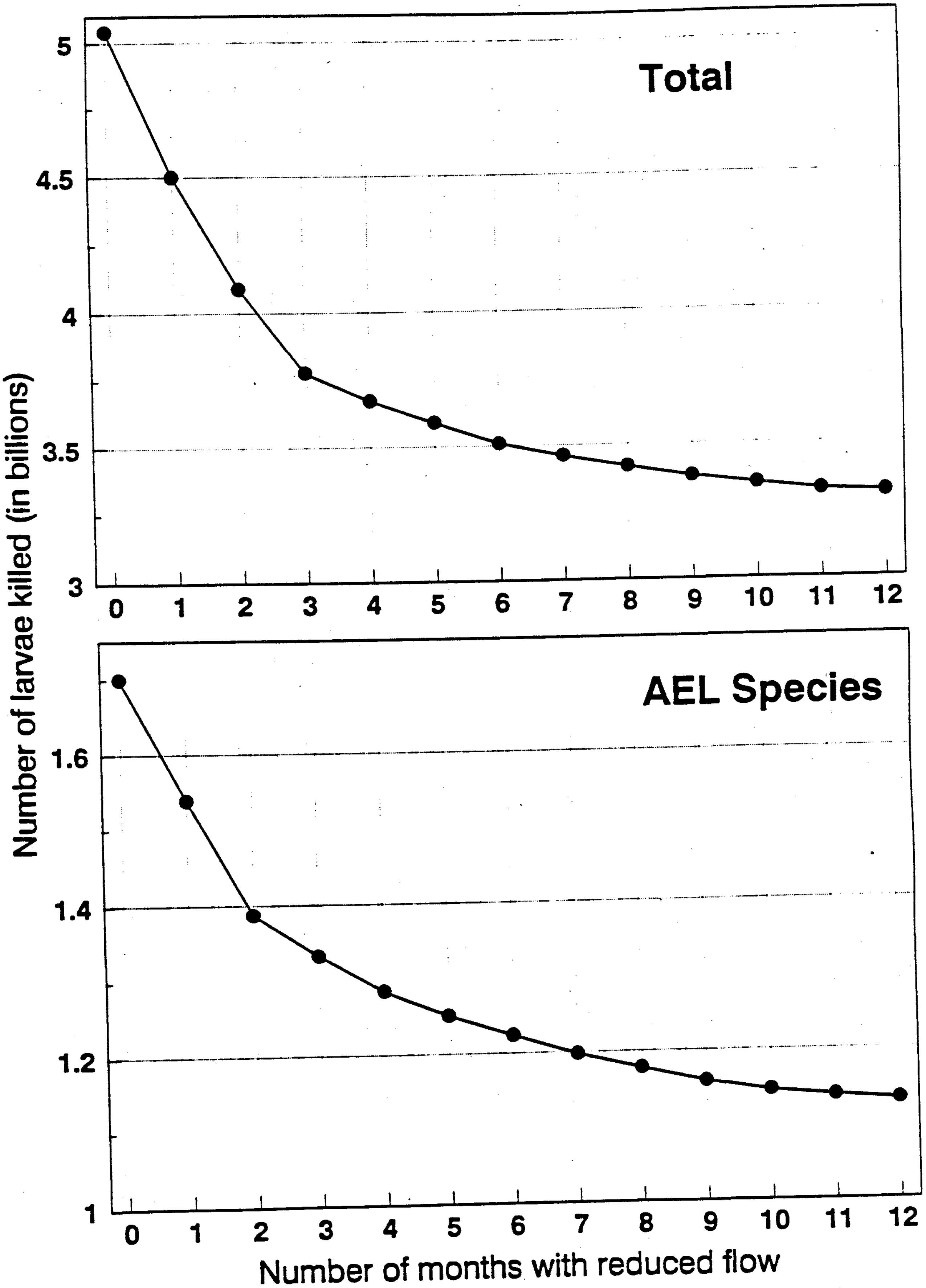


Figure 6-4: Number of fish larvae killed with different numbers of months operated a two-thirds flow. The number of months was incremented by adding in the next-mos abundant month. "AEL species" is the sum of species with estimated adult equivaler losses > 1%.

Studies by Thomas *et al.* (1980) and Marcy *et al.* (1980) have indicated that reduced flow lowered the vulnerability of the older lifestages of fish to entrapment. However, there are not enough data to estimate how many fish might be saved at SONGS. Ebert (1980) suggests that the velocity cap and Fish Return System might not be as effective at lower flow velocities, so that more fish might actually be killed at lower flow rates. However, analyses of entrapment data during different flow regimes at SONGS indicates that lower flow rates did not result in higher entrapment rates (Appendix A of Technical Report C).

As with fish larvae, entrapment of older life stages could potentially be disproportionately reduced by reducing flow during the times of highest fish densities; in reality, only anchovies have a limited period of peak abundances (Figure 6-3), so reduced flow could not be timed to coincide with peak abundances of older lifestages of fish.

In theory, reducing the flow rate through SONGS should reduce turbidity, thereby reducing impacts on kelp and the San Onofre Kelp Forest community. Reducing flow rate by a third would reduce the diffuser jet velocity by a similar amount, and therefore the entrainment near the diffuser ports would also be reduced slightly. Moreover, less turbid bottom water in particular would be entrained because the discharged water would become plumelike more quickly due to its reduced momentum and higher buoyancy flux (List and Koh 1989). However, since the present diffuser gives essentially 100% mixing with the natural cross flow, List and Koh (1989) believe it is unlikely that the decreased entrainment would be significant.

6.2.2 Technical feasibility

Reducing the flow rate during normal operations could be achieved in two possible ways. The simpler method would be to open the recirculation bypass gate used during heat treatments (see Appendix A) to allow partial recirculation of the cooling water. Alternatively, the pump motors and controls could be modified to allow operation at variable speeds. (Unfortunately, the condenser design does not allow simply shutting down one of the four pumps, which would be the simplest way to reduce the flow rate, because each pump serves a section of the condenser shell; shutting down one pump would leave a section of the shell without cooling water.)

Both of these methods would reduce the plant efficiency by increasing the condenser temperature above the 20°F for which it was designed, thereby increasing the turbine back pressure. Under normal operations power production is currently limited to 75% when the cooling system has only three circulating pumps operating (Miller 1989); power is limited in order to prevent excessive steam velocities inside the condenser and subsequent tube damage (Miller 1989). The plant was designed for the particular steam velocities inside the condenser that are associated with a $\Delta T = 20°F$, and it is possible that a higher ΔT could result in structural damage to the plant. However, it now appears that this would not be a problem (List, *personal communication*).

A major drawback to the higher turbine pressure is the fact that it reduces plant efficiency. For example, increasing the condenser temperature to 30°F from 20°F would increase the turbine back pressure by approximately 0.38" Hg, resulting in a loss of 10 to 12 MW (about 1%) of generating capacity (List and Koh 1989).

Southern California Edison engineers contend that List and Koh did not consider that the water-side film coefficient of heat transfer is dependent of water velocity, that at reduced velocity there would be a much greater effect on the overall ΔT, and that the increase in back pressure would be 0.99" Hg rather than 0.38" Hg (D. Pilmer, SCE, *personal communication*). A plant-specific model predicts a reduction of 22 MW/unit (Wharton 1989) or 27.4 MW/unit (D. Pilmer, *personal communication*), or about 2.5%, rather than 10-12 MW/unit.

In addition, the higher turbine pressure could have an undesirable effect on one of the safety features for the turbine, the high exhaust pressure trip. This trip is currently set at 4.5" Hg, with a pretrip alarm at 3.5" Hg (Wharton 1989). Normal pressure in the low-pressure section of the condenser varies between 1.7" to 2.3" Hg. Although List and Koh predict an increase of 0.38" Hg, Wharton reports that the plant thermal model predicts an increase close to 0.8" Hg, and Pilmer (*personal communication*) reports an increase of 0.99" Hg. Wharton states that this is "a significant reduction in margin to trip which increases the likelihood of a plant trip with possible challenge to plant safety system."

SCE has expressed concern about the potential hydraulic limitations of this technique (D. Pilmer, *personal communication*). As currently operated, the circulation pumps provide 45 ft of head needed to move the cooling water through the system; the condensers (water boxes) are at 35 ft. SCE estimates that reducing the flow by one-third would allow the pumps to produce only a 20 ft head, so the water boxes would be at -15 ft head. Under these conditions, the system would operate under a vacuum (like a siphon); SCE's concern is that the -15 ft head might be too large a vacuum for the system to operate properly. If this is the case, a lesser reduction in flow might be necessary; for example, a 20% reduction would produce a 30 ft head, which is likely to be adequate. It is also possible that modifications to the cooling system or operations, such as adding an evacuation system or periodically running the system at full flow, would allow the system to be operated at one-third reduction.

Finally, SCE has indicated that there might be unanticipated problems with running the pumps at different speeds. These pumps previously have experienced problems from torsional vibrations; although solved for current speeds, such problems might resurface if the pumps are used at a different speed. It is apparently not possible to anticipate these problem; rather, resonant vibrations would need to be investigated at different speeds. If vibrations (or some other problem) become apparent, various modifications or, at worse, replacement of the pumps may be necessary.

In conclusion, it appears to be technically feasible to operate the plant at reduced flow. Reducing flow through SONGS by installing variable speed motors on the circulating cooling water pumps would reduce the energy demands of the circulating pumps, but also reduce the efficiency of the turbines due to higher turbine pressures, for an overall net cost of 5 to 7 MW per unit (List and Koh 1989) or 27 MW per unit (D. Pilmer, *personal communication*).

In addition to these technical considerations, operating SONGS at reduced flow but full power would require a waiver of current thermal standards. SONGS' operating license currently limits the ΔT across the condensers to 20°F (Section 3.b.3 of the Thermal Plan). In addition, the thermal standard requires that the plume not be warmer than 4°F above ambient at a distance of 1000 feet from the discharge (Section 3.b.4 of the Thermal Plan). If the flow rate at SONGS is decreased but the power level stays the same, water will be discharged at a higher temperature. Assuming that water flow was reduced by 33%, List and Koh (1989) calculated that the offshore regulation (4°F at 1000 feet) would not be violated, but that the condenser discharge temperature would increase by 10°F, and a inplant variance would be required. At any rate, for this evaluation I have assumed that the thermal standards are not a consideration. It is also worth noting that the MRC has concluded that the higher discharge temperature would be unlikely to affect the marine environment adversely (Final Report to the California Coastal Commission).

6.2.3 Costs

The two alternatives to reducing flow while operating at full power, using the recirculation bypass gate versus installing variable speed motors, differ in their costs. Opening the bypass gate would not reduce the costs of pumping water through SONGS, which is proportional to the cube of the flow rate. The recirculation gates would erode considerably if used in this manner, so would have to be replaced more frequently (at additional costs). Finally, warm water would be discharged into the intake embayment (as in a heat treatment), which might increase the mortality of older life stages of fish.

In contrast, pumping costs would be lower if the motors were operating at a lower speed. Reducing the flow rate through SONGS by one-third would reduce pumping power demand by a factor of 3.4, for an electric power saving of 4.7 MW

(List and Koh 1989). Retrofitting the pump motors would involve a considerable capital cost because the existing constant speed motors for the circulating water pumps would have to be replaced with variable speed motors and controls. List and Koh (1989) estimate this cost to be more than $3 million per unit, based on their recent experience with similar horsepower variable speed motors and controls for San Diego METRO. SCE has indicated that the costs could be higher, possibly by an order of magnitude (Wharton 1989). Wharton (1989) also points out that there are numerous uncertainties involved with modifying the circulating system (e.g., possible vibration problems in the pumps at these reduced conditions that would require pump replacement) that could become significant operational concerns and/or increases in the proposed capital costs.

Beyond the capital costs of retrofitting the pump motors, there would be an ongoing cost from the reduced power output of the plant due to the higher turbine back pressures. List and Koh (1989) estimate that, with the water flow rate reduced by 33% and the condenser discharge temperature increased by 10°F, the operating capacity of each unit would be reduced by 10-12 MW; the electrical demand for each set of pumps would be 4-5 MW lower than at present, for a net loss of generating capacity of about 5 to 7 MW per unit (List and Koh 1989). List and Koh (1989) estimated that the cost of the lost energy, computed using the current averaged purchased energy cost of $0.045/KWH and an estimated load factor of 80%, would be $1.6-2.2 million per year per unit. [Wharton (1989) suggests that the actual replacement power cost will likely be higher by a factor of 2 on a levelized basis, and that the actual projected capacity for SONGS Units 2 and 3 is 90% based upon a two-year fuel cycle.]

SCE's preliminary analysis indicated that the net power reduction would be considerably greater than List and Koh's estimate, about 54.8 MW_e for the two units combined. Using SCE's 1991 projection of the cost of replacement power ($0.048/KWH annualized cost of burning gas), the net annual cost of reducing flow for the four months (February to May) has been estimated to be $5 million for both units combined (D. Pilmer, *personal communication*). This annual cost has a present value of $25-30 million.

In addition to financial costs, the reduced efficiency of SONGS would result in some environmental costs. It is likely that SCE would compensate for the lower output of Units 2 and 3 by increased operation of fossil fuel plants. As noted in Section 6.1.3, SCE's fossil fuel plants have higher emissions of air pollutants and are located in more populous areas than SONGS, so air quality in the South Coast Basin will be degraded; however, the amount of electricity that would need to be generated is quite small, so the environmental impacts would also be small. Some larvae might be killed at power plants with offshore intakes if they are operated to replace SONGS' energy; however, this would be trivial relative to the savings at SONGS, since a 33% reduction in flow rate would yield only a 1-2.5% reduction in power output.

6.3 Combined Approach: Rescheduling and Reducing Flow

A compromise between the maximum protection of fish larvae and minimal disruption of plant operations would be to combine rescheduling plant operations with reducing flow rates. For example, reducing the flow rate by 33% in February, May and August would reduce the total number of fish larvae killed by nearly 500 million individuals, or 10%. If Units 2 and 3 did not operate during March and April, 2.5 billion (50%) fewer fish larvae would be killed. Using these two techniques together would save a total of 3 billion fish larvae, reducing the overall impact of the Units 2 and 3 by 60%. This combination would substantially reduce the impact of SONGS on species with high adult equivalent losses, reducing larval losses by 57% (827 million [48.6%] from being offline and 137 million [8.1%] from reducing the flow). (Note that the savings achieved by having SONGS offline in March and April would be considerably lower if SCE operates power plants with offshore intakes to produce the replacement power.)

Combining these techniques would also be beneficial if Unit 2 alternated being offline during March and April with Unit 3, as could occur if they operated on a 24-month fuel cycle. For example, each year the larval fish losses could be reduced by 25% in the unit that was offline in March and April, with an additional 9.5% savings achieved by reducing flow rate in the other plant during this time, and a 9.9% savings from reducing flow in both plants in February, May and August, for a total savings of 44% (Tables 6-5 and 6-6).

Finally, combining these two techniques would add some certainty to the uncertainty of scheduling refueling periods for SONGS. If SONGS cannot be offline for normal refueling and maintenance every March and April, reduced flow could be used to insure that a minimum number of larvae are saved, since the flow could be reduced at will.

Table 6-6

Reduction in ichthyoplankton entrainment under different flow schedules and flow reduction.

A. Total ichthyoplankton

	MONTHS WITH NO FLOW				
MONTHS WITH 67% FLOW	NONE	MAR	MAR & APR	FEB, MAR, & APR	MAR, APR, & AUG
None	0%	32%	49%	68%	55%
Feb to May	26%	47%	58%	71%	64%

B. Species with estimated Adult Equivalent Losses > 1%.

	MONTHS WITH NO FLOW				
MONTHS WITH 67% FLOW	NONE	MAR	MAR & APR	FEB, MAR, & APR	MAR, APR, & AUG
None	0%	28%	48%	55%	59%
Feb to May	23%	42%	54%	59%	65%

6.4 Modification of Heat Treatment Procedures

Biofouling in the cooling system is controlled by heat treatments. Heat treatments are done when flow through the system becomes restricted (about every 6 to 8 weeks). The power production of the plant is reduced to 80% during heat treatments (Miller 1989), and this is costly. However, the use of heat treatments to eliminate biofoulers greatly reduces the need for chlorine treatments and thus reduces the amount of chlorine discharged into the ocean. The current operational procedure at SONGS during heat treatments is to recirculate approximately two-thirds of the normal discharge flow back through the condenser to allow the water to heat up to 150°F (41°C). The temperature is maintained for about an hour. When the water is heated, the flow is reversed to clean out the intake system.

The heat treatment procedure kills a substantial number of fish that were entrapped but residing in the screenwells. These fish are generally the largest individuals entrapped, include many economically important species, and comprise 20% of the biomass of all fish killed by SONGS. The fish are killed because, for some reason, they do not move into the Fish Return System before the rise in temperature kills them. Initially, many more fish were killed during heat treatments because the temperature was increased too quickly; however, the heat treatment procedures have been modified so that the temperature is now increased slowly, and all of the fish should have sufficient warning to move into the FRS.

Several modifications of the current operating procedures might reduce the loss of fish during heat treatments; however, it should be noted that SCE's procedures have already been designed to minimize the mortality of fish during heat treatments; it is unlikely that any further modifications to the procedures would have much effect on losses. The temperature is already raised gradually during heat treatments, but it is possible that an even more gradual temperature build-up might be more effective at driving fish out of screenwells and into the collection area; the effectiveness of this procedure could easily be tested. In addition, fish losses might be reduced if the collection area of the Fish Return System were emptied for a longer period of time during the warm-up phase of the heat treatments, since some fish tolerate fairly high temperatures; the effectiveness of this potential procedural change could also be tested easily. Finally, survivorship of diverted fish might be enhanced by insuring that water is run through the return sluice for a long enough period of time.

Although these possible modifications of the current heat treatment procedure should be tested, the primary problem seems to be *guiding* the fish into the FRS. These procedural changes would have little effect on fish guidance. Potentially feasible mechanisms for driving and/or attracting fish into the collection area, sonic devices and light systems, have been discussed in Sections 3.3.1 and 3.3.3.

SECTION I

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SECTION II

REPLACEMENT TECHNIQUES

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CHAPTER 7

INTRODUCTION TO REPLACEMENT TECHNIQUES

Although it is generally best to avoid an impact if possible (see Chapter 1), under some circumstances mitigating an impact by replacing lost resources with similar resources (*in-kind mitigation*) or by substituting dissimilar resources for lost resources (*out-of-kind mitigation*) is acceptable. The Fish and Wildlife Service mitigation policy, which is generally followed by resource agencies in California, establishes in-kind compensation as the preferred replacement method, especially for highly valued resources (USFWS 1981).

The most promising techniques for mitigating SONGS impacts **in-kind** are constructing an artificial reef to replace fish and other reef-associated resources (Chapter 8) and creating a kelp bed to replace kelp (Chapter 9); these techniques can be combined into constructing an artificial reef that supports a kelp bed. In addition, the restoration of degraded coastal wetlands (Chapter 10) would provide in-kind mitigation for some of the fish species impacted by SONGS; at least 15 fish species at risk at SONGS occur in coastal wetlands.

The **out-of-kind** techniques that seem most feasible and generally acceptable are artificial reef construction and wetland restoration. Constructing an artificial reef would produce reef resources that could be substituted for resources impacted by SONGS. On the basis of existing information, it is reasonable to conclude that *some* fish are produced on artificial reefs, but it is not possible to predict with confidence *how much* production occurs. In addition, there is the problem of equating the resources produced on the reef with the dissimilar resources impacted by SONGS, such as water-column fish; yet these dissimilar resources need to be compared in order to determine the size of reef needed. In spite of the difficulties in determining the size of reef needed, an artificial reef would be an appropriate technique for mitigating impacts of SONGS because it would enhance the productivity of the marine environment.

Most of the species of invertebrates, algae and fish that are impacted by SONGS do not occur in wetlands. However, wetlands have such exceptional resource value that wetland restoration would be an appropriate technique for mitigating losses that cannot be prevented or for which no feasible in-kind technique exists. As with constructing an artificial reef, it would be very difficult to compare the resources impacted by SONGS with the value of restoring a wetland.

There are other alternatives for out-of-kind compensation. Virtually any technique that produces natural resources could be an appropriate out-of-kind mitigation technique. Other techniques that are discussed in this section include fish hatcheries, coastal preservation, research and water quality improvement. Fish hatcheries are not considered feasible for mitigating the effects of SONGS, and the other three techniques do not conform to generally accepted mitigation guidelines.

This second section of the Mitigation Technical Report evaluates the feasibility of replacement techniques that could be used to mitigate the impacts of SONGS. Both in-kind and out-of-kind techniques are considered. The techniques considered here have been discussed in other reports to the MRC (e.g., Sheehy 1981a, Thum *et al.* 1983, Ambrose 1986a, 1986b, 1987a) and elsewhere; this report updates and summarizes these discussions.

This section is comprised of five chapters besides this one. Chapter 8 evaluates artificial reefs, including the evidence for fish production on artificial reefs; artificial reefs could be used for either in-kind or out-of-kind mitigation. Chapter 9 evaluates kelp bed creation as a means of mitigating kelp bed losses in-kind. Chapter 10 discusses the restoration of coastal wetlands; although wetland restoration would produce some in-kind value, it would most likely be primarily out-of-kind. Chapter 11 evaluates the feasibility of using fish hatcheries as mitigation. Finally, Chapter 12 evaluates other mitigation techniques, such as coastal preservation, research and water quality improvement.

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CHAPTER 8

ARTIFICIAL REEFS

Summary

The main conclusions from this chapter are: Properly designed artificial reefs can support communities of fish, invertebrates and algae that are similar to those found on natural reefs. The production of sessile and sedentary organisms (such as invertebrates and algae) is increased by artificial reefs, but the amount of fish produced by (as opposed to attracted to) artificial reefs has not been determined. There is clear evidence that some aspects of production, such as recruitment, are enhanced by artificial reefs, but there may also be negative effects from increased fishing mortality. Most concern about fish production on artificial reefs has focused on small artificial reefs and artificial reefs constructed from scrap materials; a large artificial reef constructed from quarry rock would likely circumvent the limitations of these small reefs. A large artificial reef could furnish many different types of habitats and an increased variety of food resources for fish. Fish that are transients on a small reef might remain as residents on a large one. Fishing mortality might be reduced on a large reef since it would not be as attractive to fishermen if fish densities are lower and fish are not concentrated in a small area. Thus, in spite of the unresolved question of fish production, it seems likely that an artificial reef that mimics the size, configuration and location of a natural reef would provide suitable in-kind mitigation for impacts to the natural reef. There is more uncertainty associated with using an artificial reef as out-of-kind mitigation because there are no quantitative data on the amount of fish produced. Nonetheless, properly designed artificial reefs (either with or without kelp) that are sufficiently large certainly produce resources, and so represent, along with wetland restoration, one of the two best available techniques for enhancing marine resources.

Introduction

Artificial reefs have been constructed for centuries, although their widespread use has only occurred in the last 20-30 years. The recent popularity of artificial reefs is linked to the perception of their usefulness as a fisheries management tool and the desire by various government and private organizations to increase fishing success. Because fish are found around them and benthic organisms (algae and invertebrates) grow on them, artificial reefs have been considered as a potential mitigation technique for at least 10 years (Swanson *et al.* 1978, Stephens and Palmer 1979, Sheehy 1981a, Grove 1982, Grove *et al.* 1983, Spanier and Pisanti 1983, Thum *et al.* 1983, Alevras and Edwards 1985, Davis 1985). Several "mitigation reefs" have been constructed in California and other states (see Table 1-1). For example, in 1981 a small artificial reef was constructed from concrete pipe in San Diego Bay to mitigate a fill project, and THUMS' reef in Long Beach Harbor was built in 1982 to mitigate dredging and filling in the harbor. Recently, a 7-acre artificial reef (with rock covering 3.5 acres) was constructed in Washington to mitigate for the loss of 7 acres of breakwater (Hueckel *et al.* 1987). In spite of these applications, some resource agencies question the actual contribution of artificial reefs to fish production (J. Fancher, U.S. Fish and Wildlife Service, *personal communication*), and their implementation in mitigation remains controversial.

The MRC has made two recommendations about artificial reefs. First, the MRC has recommended that a high-relief artificial reef be one possible means of mitigating midwater fish losses caused by SONGS; this reef would serve as out-of-kind mitigation. Second, the MRC has recommended that a low-relief artificial reef with kelp be built to mitigate SONGS' impacts on the San Onofre Kelp forest community. This chapter considers issues that concern both of these applications. Most of the discussion is relevant to both applications, but where appropriate I distinguish between using reefs for in-kind versus out-of-kind mitigation. Also note that the MRC's recommendation for in-kind mitigation requires that the artificial reef support a kelp bed; the general evaluation of using an artificial reef for in-kind mitigation is given in this chapter, but the technical feasibility of creating a kelp bed on an artificial reef is discussed in Chapter 9.

To be suitable for use as in-kind mitigation, artificial reefs must replace lost resources with new, similar resources. Two aspects of this requirement, the similarity of artificial reef communities to communities on natural reefs and the production of resources (especially fish) on an artificial reef, are discussed in the first two sections of this chapter. The production of reef resources (Section 8.2) is also a major concern for using an artificial reef as out-of-kind mitigation. The third section of this chapter discusses aspects of the design and location of artificial reefs (including cost), the fourth section reviews information about the impacts of artificial reefs on soft-bottom communities, and the last section provides an overall evaluation.

Previous MRC studies

The MRC has commissioned several studies to evaluate artificial reefs as a potential technique for mitigating the effects of SONGS (Sheehy 1981a, Thum *et al.*

1983, Ambrose 1986a). In addition, the MRC sponsored several field programs that collected data on artificial reefs. Lockheed Ocean Science Laboratories (LOSL 1983 a, b and c) and DeMartini (1985, 1987) have conducted detailed studies of Pendleton Artificial Reef (PAR). Ambrose conducted a survey of artificial and natural reefs throughout Southern California in Fall 1986. Results from the survey are summarized in this report and presented in more detail in Ambrose (1987a, Ambrose and Swarbrick 1989); the methods used are summarized in Appendix C.

8.1 Similarity of artificial and natural reef communities

Many studies of artificial reefs have compared communities on artificial and natural reefs (for a general review of fish studies, see Bohnsack and Sutherland 1985). Most of these studies focused on reefs made from man-made materials (including tires and concrete). There have been very few comparisons of artificial and natural reefs in Southern California. In this section, we discuss (1) the community structure (i.e., species diversity and composition) of assemblages on artificial and natural reefs, and (2) the densities of fish on the two reef types.

8.1.1 Community structure

The similarity of fish communities on artificial and natural reefs can be assessed by comparing the composition and species diversities of assemblages on the two types of reefs. The survey by Ambrose (1987a) in Fall 1986 represents one of the most detailed comparisons of community structure on artificial and natural reefs, and these data are presented in this section.

Forty-one species of fish were sampled on the reefs during the Fall 1986 survey, with more species found on artificial reefs (Mean=18.7) than on natural reefs (Mean=14.2; Table 8-1). The difference in total species richness was a result of significantly higher species richness near the bottom on artificial reefs (Mean=15.3 vs. 10.9 species on natural reefs). Although higher species richness on artificial reefs has been reported previously (Stephens *et al.* 1984), most studies have reported equal or higher species richness on natural reefs (Randall 1963, Fast and Pagan 1974, Smith *et al.* 1979, Alevizon *et al.* 1985, Burchmore *et al.* 1985, Matthews 1985).

Most fish species were found on both artificial and natural reefs, although a few species were found on a higher proportion of one type of reef than on the other (Table 8-2; Ambrose 1987a). Most common species were found equally often on both reef types. For example, kelp bass, black surfperch, blacksmith, California sheephead, senorita and rock wrasse were found on virtually all reefs. Opaleye and pile surfperch were the only relatively common species that occurred on a higher proportion of artificial reefs than natural reefs.

Cluster analysis was used to indicate the similarity of the fish assemblages on different reefs (Figure 8-1). Some pairs of artificial reefs clustered closely together (e.g., Torrey Pines and Pendleton, and Marina del Rey and Hermosa Beach), indicating they were quite similar. However, artificial reefs as a whole did not segregate into their own cluster at higher levels, as would be expected if the fish assemblages on them were not similar to those on natural reefs. In fact, most of the clusters containing natural reefs also contained some artificial reefs.

Table 8-1
Species richness and density of fish on artificial and natural reefs.

Benthic and water column species richness was determined from benthic and water-column transects (Ambrose 1987a). Total richness on reef includes all species recorded in benthic transects, water-column transects, and fish-length samples. Total species richness and benthic species richness were significantly different between artificial and natural reefs (Total: t = 4.28, 24 df, P = 0.0003; Benthic: t = 4.15, 24 df, P = 0.0004). For densities, standard errors could not be calculated for water column samples due to methods used to sample different lifestages (see Ambrose 1987a). Density near the benthos was significantly different between artificial and natural reefs (t = 3.64, 24 df, P = 0.0013).

	Species Richness			Density (No./1000 m^3)		
	Benthic	Water Column	Total on Reef	Benthic Mean	Benthic SE	Water Column Mean
			Artificial Reefs			
Torrey Pines AR	12	0	13	732.6	(138.1)	0
Pendleton AR	16	2	21	940.0	(256.9)	0.66
Newport Beach AR	20	0	22	501.6	(96.6)	0
L.A. Harbor Breakwater - inside	15	8	18	319.7	(62.8)	581.68
L.A. Harbor Breakwater - outside	12	13	20	235.0	(34.9)	296.22
King Harbor Breakwater	16	3	18	562.7	(90.5)	184.10
Hermosa Beach AR	19	0	21	260.2	(91.2)	0
Marina Del Rey AR	16	0	17	269.8	(46.0)	0
Pitas Point AR	13	5	16	208.3	(57.2)	156.86
Rincon Oil Island	14	9	21	222.7	(54.3)	399.48
MEAN (SE)	15.3 (0.86)	4.0 (1.46)	18.7 (0.90)	425.3	(79.66)	162.1 (65.23)
			Natural Reefs			
Marine Street Reef	9	6	14	51.2	(11.3)	362.57
La Jolla Cove Reef	13	2	16	191.7	(42.5)	75.0
Del Mar Reef	11	5	17	87.5	(23.7)	116.92
Barn Kelp	11	2	12	198.6	(79.2)	0.02
Las Pulgas Reef	7	0	11	124.8	(44.3)	0
Box Canyon	6	0	10	86.1	(44.5)	0
San Onofre Kelp - Main	10	5	12	316.4	(99.6)	109.13
San Onofre Kelp - North	10	5	14	94.7	(35.9)	27.28
San Mateo Kelp	9	6	14	176.2	(94.3)	100.16
Two Man Rock	12	2	13	303.5	(133.1)	4.16
Laguna Beach North	12	5	17	153.3	(39.3)	869.09
Pelican Point	14	1	15	165.0	(29.5)	189.58
Point Vicente	16	1	17	571.3	(158.7)	0.20
Don't Dive There	14	9	19	280.3	(17.7)	81.46
Flat Rock	10	4	13	68.8	(15.2)	25.04
Rincon Kelp	10	3	11	87.5	(22.7)	2.28
MEAN (SE)	10.9 (0.65)	3.5 (0.63)	14.2 (0.62)	184.9	(33.12)	122.7 (55.20)

Table 8-2

Occurrence of species of fish on artificial and natural reefs.

The proportions of artificial or natural reefs on which a species occurred, including all lifestages of fish seen in benthic and water column transects and fish length samples (Ambrose 1987a). Species that are fished either commercially or for sport are indicated by ^{S}.

SPECIES	COMMON NAMES	REEF TYPE	
		ARTIFICIAL	NATURAL
Scorpaena guttata	Spotted scorpionfish^S	0.40	0.06
Sebastes atrovirens	Kelp rockfish^S	0.20	0.19
Sebastes serriceps	Treefish^S	0	0.06
Sebastes serranoides	Olive rockfish^S	0.70	0.19
Sebastes carnatus	Gopher rockfish^S	0	0.06
Sebastes miniatus	Vermilion rockfish^S	0.10	0
Sebastes rastrelliger	Grass rockfish^S	0.10	0
Sebastes caurinus	Copper rockfish^S	0.10	0
Oxylebius pictus	Painted greenling	0.60	0.50
Scorpaenichthys marmoratus	Cabezon^S	0.20	0.06
Paralabrax clathratus	Kelp bass^S	1.00	1.00
Paralabrax nebulifer	Barred sand bass^S	0.80	0.88
Trachurus symmetricus	Jack mackerel^S	0.20	0.38
Anisotremus davidsonii	Sargo^S	0.70	0.38
Cheilotrema saturnum	Black croaker^S	0.60	0.06
Girella nigricans	Opaleye^S	1.00	0.56
Medialuna californiensis	Halfmoon^S	0.90	0.81
Embiotoca jacksoni	Black surfperch^S	1.00	1.00
Phanerodon furcatus	White surfperch	0.50	0.13
Damalichthys vacca	Pile surfperch^S	1.00	0.69
Hypsurus caryi	Rainbow surfperch^S	0.80	0.63
Rhacochilus toxotes	Rubberlip surfperch	0.60	0.25
Brachyistius frenatus	Kelp surfperch	0.50	0.63
Hypsypops rubicundus	Garibaldi	0.70	0.69
Chromis punctipinnis	Blacksmith	1.00	0.75
Semicossyphus pulcher	California sheephead^S	0.80	1.00
Oxyjulis californica	Senorita	0.90	0.88
Halichoeres semicinctus	Rock wrasse	1.00	1.00
Lythrypnus dalli	Blue-banded goby	0.40	0.25
Coryphopterus nicholsii	Blackeye goby	0.40	0.31
Pleuronichthys coenosus	Turbot^S	0.10	0.06
Microstomus pacificus	Dover sole^S	0.10	0
Paralichthys californicus	California halibut^S	0	0.06
Heterostichus rostratus	Giant kelpfish	0.30	0.25
Gibbonsia spp.	Kelpfish spp.	0.20	0
Alloclinus holderi	Island kelpfish	0	0.13
Atherinids	Jacksmelt, Topsmelt^S	0.30	0.13
Hermosilla azurea	Zebraperch^S	0.20	0.13
Rathbunella spp.	Ronquil	0.10	0
Sarda chiliensis	Pacific bonito^S	0	0.06
Triakis semifasciata	Leopard shark^S	0.20	0

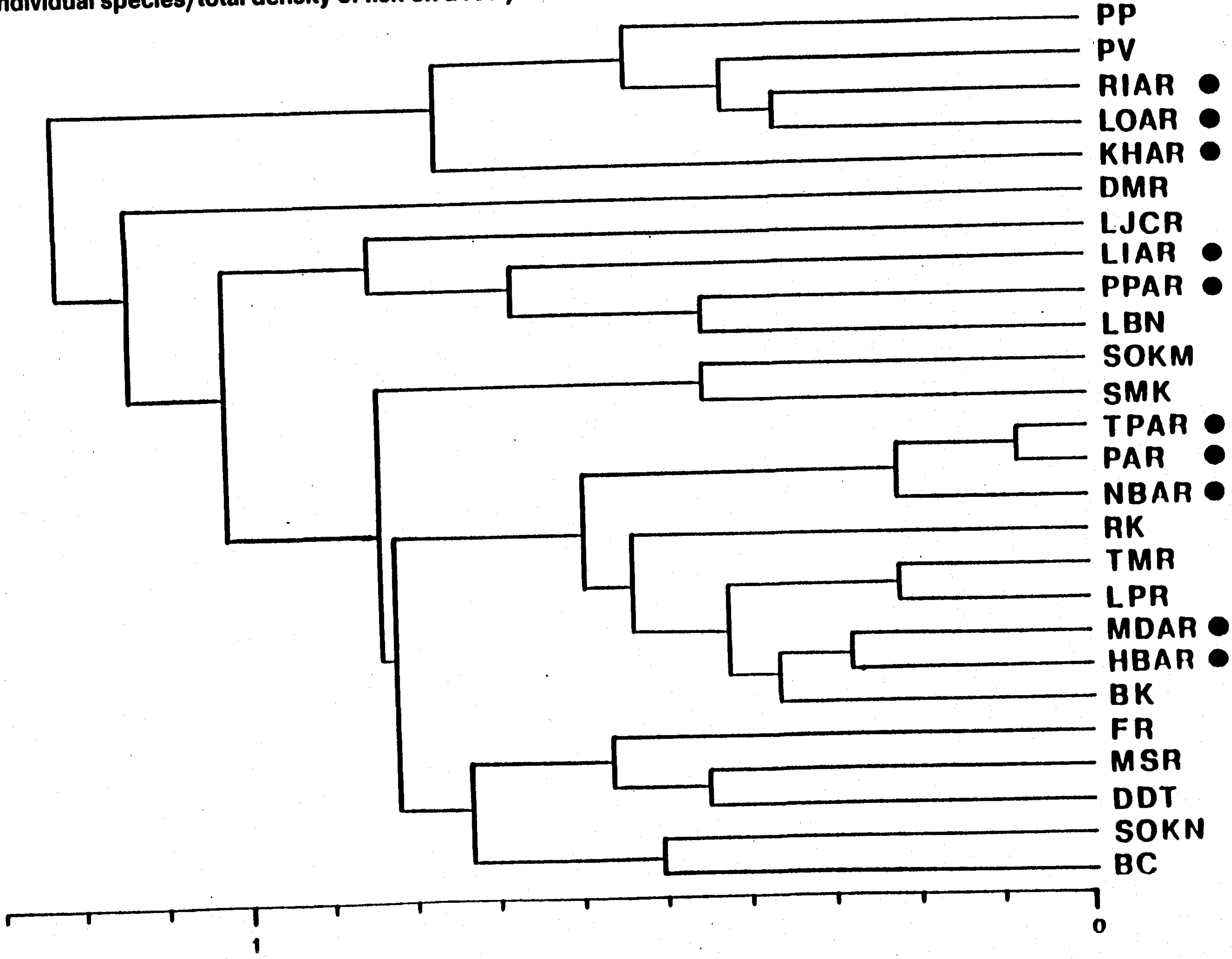


Figure 8-1 Cluster analysis of fish assemblages on reefs sampled during Fall 1986 survey of artificial and natural reefs (Ambrose 1987a). Codes for reef names are given in Table C-1 in Appendix C. Artificial reefs are indicated by bullets. Analysis was based on relative densities of fish (i.e., density of individual species/total density of fish on a reef).

The data from Ambrose (1987a) indicate that, overall, the composition and diversity of fish assemblages on artificial and natural reefs in Southern California were similar. These results agree with numerous other studies comparing artificial and natural reefs that have found a general similarity in the fish assemblages (Russell 1975, Jones and Thompson 1978, Molles 1978, Bohnsack 1979, 1983a, 1983b, Walton 1979, Smith *et al.* 1979, Stone *et al.* 1979, Gascon and Miller 1981, Stephens *et al.* 1984, Alevizon *et al.* 1985, Matthews 1985).

Although most attention has been focused on fish, there are also some data on algal and invertebrate assemblages on artificial and natural reefs. The similarities of artificial and natural reefs are summarized here, with a detailed evaluation given in Ambrose (1987a) and Ambrose *et al.* (1987).

The algal communities found on artificial and natural reefs were quantitatively different. Percent cover or density of most groups of algae was higher on natural reefs than on artificial ones. Giant kelp (*Macrocystis pyrifera*) occurred more frequently on natural reefs (70% of natural reefs compared to 40% of the artificial reefs), and the density and size of giant kelp plants also tended to be greater on natural reefs (although the differences were not significant). Mean algal height was greater on natural reefs because of the high cover of foliose red algae and kelps. Algal assemblages seemed particularly sensitive to location and placement of artificial reefs. For example, much of the differences between artificial and natural reefs can be explained by the depths of the reefs, with the shallowest reefs (the breakwaters, Pitas Point Artificial Reef and Torrey Pines

Artificial Reef) supporting relatively high densities of algae. Water turbidity may also have influenced the algal assemblages.

Overall, the invertebrate assemblages on artificial and natural reefs were quite similar. The cover of sessile invertebrates, particularly bryozoans, and the density of the gorgonian *Lophogorgia* tended to be higher on artificial reefs, while anemones, bivalves, the snail *Kelletia kelletii* and the red urchin *Strongylocentrotus franciscanus* had higher densities on natural reefs. Total invertebrate density was not significantly different between the two reef types.

8.1.2 Fish density

Many studies have found that densities of fish are higher on artificial reefs than on natural reefs (Fast and Pagan 1974, Russell 1975, Smith *et al.* 1979, Walton 1979, Stephens *et al.* 1984, Laufle and Pauley 1985, Matthews 1985). In California, Pendleton Artificial Reef (PAR) has been the subject of several investigations. Jessee *et al.* (1985) reported a higher density of fish on PAR than on two nearby natural reefs, Las Pulgas Reef (LPR) and San Onofre Kelp Bed (SOK). The California Department of Fish and Game (CDF&G) also compared PAR and LPR, and found a higher density of fish on PAR (Togstad *et al.* 1986). DeMartini (1987) found that PAR had higher density and biomass density of fish than SOK, but noted that the standing stock (total number or biomass) on PAR was much lower because the artificial reef was much smaller.

In the survey of reefs in Southern California by Ambrose (1987a), benthic fish generally had higher densities on artificial reefs than on natural reefs (Table 8-

1). Much of the difference in density was due to blacksmith (*Chromis punctipinnis*). Blacksmith densities on three artificial reefs were particularly high (697, 529 and 297 fish/1000 m^3 on Pendleton, Torrey Pines, and Newport Beach artificial reefs, respectively). In contrast, density was this high on only one natural reef (300 fish/1000 m^3 on Palos Verdes). However, the observed pattern in fish densities is not entirely due to blacksmith; the density of sport fish (which does not include blacksmith) was also significantly higher on artificial reefs (mean=145/1000 m^3 vs. 80/1000 m^3 on natural reefs, $t=3.946$, $df=22.1$, $P=0.0007$; fractional df result from Satterthwaite's correction for unequal variances).

The densities of fish in the water column were highly variable on both artificial and natural reefs, and there was no significant difference between the two reef types.

Previous studies have often shown that fish density is much higher on artificial reefs than natural reefs (for review, see Bohnsack and Sutherland 1985; for an exception, see Burchmore *et al.* 1985). The consistency of this pattern is somewhat surprising given the wide variety of reef types that have been studied (including reefs constructed from tires, boats, quarry rock, and concrete blocks, rubble and pipes), suggesting that placement features (i.e., piles of material that are isolated from natural rocky areas) rather than specific construction materials may be contributing to the general pattern of high fish richness and density.

Randall (1963) and Russell (1975) suggested that the position of an artificial reef in the surrounding habitat was an important determinant of fish density on the reef. Artificial reefs are usually placed on sand plains, isolated from natural rocky areas; they are also usually fairly small, with a high perimeter-to-area ratio. Both of these factors might influence the size of the area surrounding a reef from which fish are attracted to the reef. Assuming fish are attracted to a reef from a set distance (such as 300 m, as reported by Shimizu [1981]), small reefs will attract fish from a larger area, relative to reef size, than large reefs. For example, if the radius of an artificial reef is 10 m and it attracts fish from 300 m away, then the ratio of area of attraction to reef area is 960:1. If the radius of the reef is increased to 100 m, the absolute area of attraction increases, but the ratio of attraction area to reef area decreases to 15:1. If the radius of the reef is increased to 1000 m, the ratio decreases to 0.69:1. Small reefs will attract fish from a *proportionately* larger area than large reefs, so the fish attracted to the reef will occur at a higher density on the reef.

This putative relationship between reef size and area of attraction may explain why the artificial reefs that have been studied (which are small) generally have higher fish densities than most natural reefs (which are large): the artificial reefs might be attracting fish from an area that is large relative to their size. The density of fish on a large artificial reef might be lower than on a small reef (and similar to densities on large natural reefs) because of the relationship between reef size and the area of attraction.

In addition to placement features, the design of artificial reefs, especially their greater structural complexity (Smith *et al.* 1979), may contribute to higher fish densities. Jessee *et al.* (1985) attributed higher fish densities on Pendleton Artificial Reef to the relief and height of the reef, but also noted that the ratio of reef surface area to reef perimeter and the distance to neighboring reefs and hard bottom areas could be important. At present, we know too little about the behavior and population biology of most Southern California reef fish to identify critical aspects of reef design. However, two species that were abundant on artificial reefs, blacksmith and barred sand bass (*Paralabrax nebulifer*), deserve particular mention. Blacksmith rely on holes and crevices for shelter (Ebeling and Bray 1976, Bray 1981, Anderson *et al.* 1989); artificial reefs have abundant shelter sites in the interstices of their rocks that seem to be ideal for blacksmith. Barred sand bass were found predominantly along the perimeter of all reefs, at the sand/rock interface. Because of their design, artificial reefs have a relatively longer perimeter per unit area than natural reefs, and this may explain the higher densities of sand bass on artificial reefs.

One final aspect of artificial reefs that may influence fish densities is the biological community growing on the reefs. One of the most conspicuous characteristics of many reefs in Southern California is the presence of giant kelp (*Macrocystis pyrifera*), a large brown alga that forms a surface canopy. The presence of giant kelp did not influence our comparison of artificial and natural reefs because giant kelp density on the reefs we sampled was not significantly different on the two reef types (Ambrose 1987a). However, our data (Ambrose 1987a), along with a number of other studies (Miller and Geibel 1973, Coyer 1979, Larson and DeMartini 1984, Bodkin 1986, 1988), indicate that *Macrocystis* strongly influences the assemblage of fish in the water column, and thus is a key factor in determining the overall fish community on a reef. Therefore, the ability of an artificial reef to support giant kelp should be an important consideration in the design and planning of the reef.

Although giant kelp is clearly an important influence, fish assemblages can be surprisingly insensitive to the biological characteristics of artificial reefs. For example, fishes appeared at PAR within days after reef placement (Grant *et al.* 1982), long before there was any biological structure on the reef. Moreover, the number of fish species at PAR increased quickly during a time in which the invertebrate and algal community was dominated by the encrusting bryozoan *Cryptoarachnidium* and algal turf (Ambrose and Anderson 1989). It seems that the fish assemblage was not dependent on the cover of particular "habitat-forming" species. Instead, physical structure appears to be at least as important in attracting fishes as the developing invertebrate and algal communities (see Helvey and Dorn 1981; Helvey and Smith 1985).

The general lack of relationship between fish abundance and the biota occurring on PAR and other reefs (e.g., Holbrook *et al. in press*) presents a dilemma with regards to evaluating the amount of fish produced on the reef. It seems logical that, as an artificial reef such as PAR developed more and more food resources for fish, it would be contributing to greater and greater fish production. However, fish were abundant on PAR *before* it provided much food; these high densities must have stemmed from the attraction of fish to the reef. The present high fish densities on PAR may also result (to some unknown degree) from its attractiveness to fish, so the existence of food resources does not guarantee that the reef has increased net productivity of fish, nor that all of the fish on the reef were produced on the reef.

The invertebrate and algal species on PAR may be more important as food and shelter for young-of-year fishes than for older life stages. Fish did not recruit to PAR until it was two and a half years old; it is possible that the recruitment habitat at PAR was not suitable before this time (DeMartini 1987, Ambrose and Anderson 1989).

8.1.3 Discussion

The values of artificial reef enhancement efforts have been based primarily on the abundances of fishes and economically important invertebrates such as abalone and lobster (see Bohnsack and Sutherland 1985). Numerous studies have indicated that artificial reefs support higher fish densities than some natural reefs. The comparatively higher densities at artificial reefs have been used to suggest that they are beneficial to fishery management. Whether this is the case depends on the factors that cause the higher densities on artificial reefs.

The ability of artificial structures to attract fish, and hence increase fishing success, is well established. Large numbers of fish aggregate around Fish Attracting Devices (FADs)(Klima and Wickham 1971, Brock 1985), which are simply rafts or underwater "kites" that have no resources for fish, and many studies have reported significant abundances of adult fish shortly after a reef has been constructed (Turner *et al.* 1969, Fein and Morganstein 1974, Russell *et al.* 1974, Russell 1975, Molles 1978, Bohnsack and Talbot 1980, Ranasinghe 1981, Tubb *et al.* 1981, Wilson *et al.* 1981, Walsh 1985). However, FADs are so structurally simple that they could not be increasing recruitment, growth or survival, and the fish found on artificial reefs soon after construction, particularly large individuals, are clearly not produced there.

It is generally acknowledged that the high density of fish on new artificial reefs is due primarily to aggregation; the implication is that older reefs, with more mature biota, have produced the high densities of fish. However,, high densities of fish on older reefs could also be due to aggregation. Some older artificial reefs, such as the Newport Beach Artificial Reef, have virtually no algal or invertebrate populations that could provide food for fish, yet still have high densities of fish. Other reefs, such as the Hermosa Beach Artificial Reef, not only have few food resources but also have an open structure that provides little shelter, yet fish occur at high densities. The behavioral responses of fish that result in high densities around FADs may also be responsible for high densities on artificial reefs. Therefore, the presence of high densities of fish, even on reefs that have abundant resources, does not guarantee that the reef has increased net productivity of fish, nor that *all* of the fish on the reef were produced on the reef. The evidence for fish production on artificial reefs is discussed in the next section.

A distinction between density and abundance needs to be made. *Density* is the number of fish in a defined area (e.g., no./1000 m^3) regardless of the total area of habitat, whereas *abundance* is the *total* number of fish in a prescribed area (usually the areal extent of the reef or habitat examined). This distinction in terminology is important, especially with respect to mitigation. For mitigative purposes, there is no substitute for realistic estimates of production, but when such estimates do not exist, abundance would be better than density for indicating mitigative value in comparisons of habitats of unequal area (DeMartini 1987, DeMartini *et al.* 1989; Ambrose and Swarbrick 1989).

Density-abundance relationships at Pendleton Artificial Reef (PAR) illustrate a conceptually simple but nonetheless important consideration for using artificial reefs as mitigation for impacted natural-reef habitats. Both density and abundance estimates were determined at PAR and San Onofre Kelp Bed (SOK) in 1986 (DeMartini 1987, DeMartini *et al.* 1989). Overall, the density at PAR was 2.5 times greater than that at SOK. However, abundance at SOK was 21-26 times higher than at PAR due to its much greater size (approximately 88 ha at SOK versus 1.2 ha at PAR). As with numbers, the total biomass at SOK and PAR gives a clearer picture of mitigative value than biomass densities (the weight of fish per unit area). There was a much higher proportion of juveniles at PAR (70%) than at SOK (10%). The combination of higher densities but smaller fish at PAR resulted in comparable biomass densities between PAR and SOK. However, the total biomass of fish was about 75 times greater at SOK because of its greater area.

8.1.3.1 Comparison of fish assemblages at San Onofre Kelp Bed and Pendleton Artificial Reef

Pendleton Artificial Reef, conceived as a means of evaluating the potential of using artificial reefs to mitigate coastal impacts, has been evaluated in Ambrose and Anderson (1989). Although PAR was not intended to serve as mitigation for SONGS' impacts, it is instructive to consider how well it would serve such a purpose. An evaluation of PAR's potential to provide in-kind replacement of impacted SOK resources must include a comparison of similar resources between PAR and SOK. However, the necessary degree of similarity is subject to different interpretations, resulting in divergent views of PAR's worth. For example, similarity in a fish assemblage could be assessed in terms of overall species composition, total fish numbers or biomass, or one-to-one replacement at the species level.

At what level of similarity should PAR be evaluated? At a general level, the fish species composition at PAR was similar to that at SOK (DeMartini 1987). A cluster analysis (Fig. 8-1) based on fish assemblages indicated that PAR was basically similar to other Southern California artificial and natural reefs (Ambrose 1987a). In this analysis, the fish assemblage at PAR was most similar to two other artificial reefs (Torrey Pines and Newport Beach), but it was also similar to a number of natural reefs, including Two Man Rock, Las Pulgas Reef and Barn Kelp in the San Onofre region.

However, there are considerable differences in the relative densities of species between PAR and SOK (Table 8-3). The density of blacksmith was extremely high at PAR. This fish represented a major portion of total fish numbers at PAR, and also accounted for 95% of the total estimated production of young-of-year fishes (DeMartini 1987), yet was virtually absent from SOK. Garibaldi were also common at PAR but absent at SOK. Conversely, SOK had much higher densities of senorita and kelp bass than PAR. These differences in the relative densities of species are reflected in the cluster analysis, which indicates a relatively low degree of similarity between SOK (SOKM in Figure 8-1) and PAR.

Why do these marked differences in densities exist between the two reefs? A likely explanation is that they result from the interaction between the physical characteristics of SOK and PAR, and the microhabitat associations and habitat requirements of particular fish species. PAR is composed of high-relief rock piles with numerous crevices between boulders. The crest, slope, perimeter (ecotone), and sand are clearly defined microhabitats that were sampled at PAR. The fish on

Table 8-3

Densities (no./100 m^2) of select fish species at Pendleton Artificial Reef (PAR) and at two locations (SOK out, SOK in) within the San Onofre Kelp Forest (SOK). Data from DeMartini (1987).

SPECIES	PAR	SOK OUT	SOK IN
Blacksmith	963.9	2.1	<0.1
Garibaldi	11.3	0	0
Kelp bass	4.6	60.8	79.1
Senorita	30.0	746.7	280.8

Table 8-4

Densities (no./1000 m^3) of select fish species over microhabitats at Pendleton Artificial Reef (PAR) and at the San Onofre Kelp Forest (SOK). The crest, slope, and perimeter (= ecotone) microhabitats correspond to sampled strata at PAR. The canopy microhabitat represents the upper 3.1 m of water column within the kelp forest, and the bottom is defined as the sea floor and water column up to 1.5 m in height. Data for PAR and SOK are from DeMartini (1987) and Technical Report J.

SPECIES	PAR			SOK	
	CREST	SLOPE	PERIMETER	CANOPY	BOTTOM
Blacksmith	1364.6	200.7	34.9	0.1	1.1
Garibaldi	27.9	4.7	0.9	0	0
Kelp bass	9.1	2.1	1.1	5.02	15.4
Senorita	13.8	23.5	15.0	66.9	38.9

PAR use these microhabitats differently. For example, both blacksmith and garibaldi were most abundant on the crest regions of modules (Table 8-4).

In contrast to PAR, SOK is a cobble-bottom kelp forest that has virtually no vertical rock relief and few crevices and interstices, but it has *Macrocystis* canopy as well as bottom microhabitats. (The canopy includes the upper 3 m of water column, where *Macrocystis* fronds form a mat-like layer at the surface.) Blacksmith and garibaldi were essentially absent at SOK (Table 8-3), perhaps due to the lack of high-relief rock and crevices for shelter. Senorita were the most abundant species at SOK, perhaps because of their strong association with giant kelp (Feder *et al.* 1974; Bernstein and Jung 1979). Few senorita, other than young-of-year, were observed at PAR. Kelp bass were also more abundant at SOK (Table 8-3), and most were found on the bottom (Table 8-4). Two other species at SOK that are closely associated with *Macrocystis*, the kelp perch and the giant kelpfish, were present at SOK but absent at PAR, where there is no *Macrocystis*.

The dissimilarities between PAR and SOK suggest that PAR (or a reef like PAR) has only limited ability to serve as in-kind mitigation for impacts to fish at SOK. Most of the dissimilarities seem to result from the different microhabitat types occurring at PAR and SOK. PAR's limited ability to serve as in-kind mitigation does not mean that a different artificial reef would not be suitable. Since no artificial reef has yet been constructed with physical characteristics similar to those at SOK, it is not surprising that no artificial reef has a fish assemblage that is very similar to the assemblage at SOK (Fig. 8-1). Nonetheless, a low-relief artificial reef could be built; the assemblage on such a reef would likely be more similar to

SOK's (especially if it supported a kelp bed), and would be much more suitable for in-kind mitigation of SONGS' effects on SOK.

Mitigative value of Pendleton Artificial Reef

Pendleton Artificial Reef was conceived as a *test* of the mitigative potential of artificial reefs rather than to actually serve as mitigation. Nonetheless, it is of interest to assess the actual mitigative value that PAR might have. In this section, we briefly evaluate PAR's ability to serve as in-kind mitigation for the effects of SONGS on the San Onofre Kelp forest (SOK).

Two important resources that would be impacted at SOK, and the most amenable to in-kind replacement by artificial reefs, are giant kelp and the resident fish assemblage. Kelp provides habitat for many species of invertebrates and fishes, and fish abundance is nearly always central to mitigative considerations of artificial reefs, undoubtedly because of the economic importance of commercial and sport fisheries. Given that kelp and fishes are important resources, would PAR adequately compensate for their loss?

A persistent stand of kelp (*Macrocystis* or *Pterygophora*) was never established at PAR, despite transplant efforts (Ambrose and Anderson 1989). The lack of kelp probably affected the abundance of fishes such as senorita, kelp perch, giant kelpfish, and young-of-year kelp bass. Similarly, the abundance of certain invertebrates associated with kelp must also have been low. It is clear that PAR could not serve as in-kind mitigation for giant kelp and the organisms associated with it.

Although kelp could not be replaced, it is possible that the fish assemblage observed at PAR could serve to mitigate fish losses at SOK. However, the number of fish produced by the reef (as opposed to the number attracted to the reef) is very difficult to assess. A maximum estimate of production can be made by assuming that all of the individuals on PAR have been produced on PAR. It is likely that some fraction of the fish on PAR (perhaps a large fraction) is attracted to the reef, rather than produced on it, so this estimate is undoubtedly too high (DeMartini 1987). However, even under this assumption PAR falls well short of SOK in fish abundance: the standing stock of fish on PAR is 4% by number, and 1% by biomass, of the standing stock at SOK (DeMartini 1987, DeMartini *et al.* 1989, Ambrose and Anderson 1989).

8.2 Fish production

One of the most controversial aspects of artificial reefs revolves around the question of whether they actually increase the production of fish, or simply attract fish. This question is important because attraction alone is not acceptable for an artificial reef that is meant to offset a loss of resources. The simple redistribution of biomass that occurs when fish are attracted to an artificial reef would not compensate for the loss of resources, since no new resources would be provided. For this reason, determining the extent to which artificial reefs contribute to fish production is a critical step towards evaluating the usefulness of artificial reefs as mitigation.

The studies that have been cited most frequently as demonstrating that artificial reefs increase fish production in the marine environment have generally compared the density of fish on an artificial reef with density on a nearby natural reef (e.g., Stone *et al.* 1979). Although recent discussions about the necessary components of production (e.g., Bohnsack and Sutherland 1985) have clarified the point that local increases in density are not necessarily indications of increased production, some researchers are apparently still confused (e.g., Alevizon and Gorham 1987).

Fish production refers to the rate of change in fish biomass. Production includes the sum of growth increments for all population members alive at any time in a given period (Chapman 1978). Production can be increased by higher recruitment or growth, and decreased by greater mortality from natural causes or due to fishing. (Immigration and emigration do not alter fish production; although they change the spatial distribution of fish biomass, they do not change the total amount of fish biomass present.) Unfortunately, it is very difficult to measure these components of fish production, and no one has ever determined the actual amount of fish production resulting from the construction of an artificial reef. The evidence for fish production on artificial reefs has been reviewed in detail by Ambrose (1986a); the following sections summarize and update that information.

8.2.1 Recruitment

Artificial reefs could potentially increase fish production by making habitat or other resources available for new recruits. Since the number of fish strongly influences the amount of production (Backiel and Le Cren 1978), and young fish are both numerous and fast-growing, the youngest age-group is frequently very important to overall production (Chapman 1978). To estimate the contribution of recruitment to production, two factors must be evaluated: (1) Is there recruitment to an artificial reef and, if so, how much? (2) Would the recruits have been equally successful elsewhere if the artificial reef did not exist?

8.2.1.1 Recruitment to artificial reefs

The term "recruitment" has been used with different meanings in different studies; it is used here to mean the settlement of larval or post-larval fish (or the birth of fish without a larval stage), as opposed to the movement of fish to a reef, which is immigration.

Young-of-year have been observed on temperate artificial reefs by a number of researchers (including Parker *et al.* 1979 and Woodhead *et al.* 1982). In California, Turner *et al.* (1969) reported small juveniles or young-of-year for a number of fish species found on artificial reefs in Southern California, particularly senoritas (*Oxyjulis californica*) and sheephead (*Semicossyphus pulcher*). Young-of-year rockfish (*Sebastes* spp.) have been recorded from the San Luis Obispo County Artificial Reef (SLOCAR), an artificial reef in central California, from 1985 through 1987 (Krenn and Wilson 1986, *personal communication*). Recent information from SLOCAR indicates that young-of-year rockfish occur at higher densities on the artificial reef than on nearby natural reefs, possibly because of higher densities of the overstory kelp *Nereocystis leukteana* on the artificial reef (Krenn 1987).

One long-term study of fish recruitment was conducted on Pendleton Artificial Reef. The young-of-year of 11 fish species were observed in 1983, two and a half years after PAR was built (Table 8-5; LOSL 1983a). From 1984 through 1986, the young-of-year of 8 to 12 species were sampled on the reef each year (Table 8-5; DeMartini 1987). There were some differences in species composition of recruits in different years; for example, sand bass and rock wrasse recruited in 1983-84, but not in 1985-86. There were also tremendous differences in the relative abundances of different species. Blacksmith was by far the most abundant species on PAR, comprising 95-98% of all young-of-year fish on PAR in 1985-86.

The survey by Ambrose (1987a) provides a comparison of recruitment of fish to artificial and natural reefs. A variety of fish species recruited to artificial reefs. On average, more species of fish recruited to the benthos of artificial reefs than to natural reefs, and the mean density of young-of-year of all species combined was higher near the benthos on artificial reefs than on natural reefs (Table 8-6). On average, young-of-year were five times more dense on artificial reefs. No differences in the young-of-year in the water column of the two reef types were detected. As noted for PAR, blacksmith dominated the young-of-year density for a number of reefs, and much of the difference between artificial and natural reefs was due to young-of-year blacksmith. When blacksmith and gobies (which were very dense on one breakwater) were excluded, the difference in young-of-year densities between the two reef types was less, but young-of-year density on artificial reefs was still slightly higher than on natural reefs.

The survey results must be interpreted cautiously. Each reef was sampled only once, and even though no temporal bias was detected (Ambrose 1987a), detailed information over an entire recruitment period would have provided a better estimate of recruitment. In addition, the survey was conducted in only one

Table 8-5

Young-of-year fish at Pendleton Artificial Reef.

Data for 1983 (7 surveys; LOSL 1983a) and 1984 (1 survey; DeMartini 1985) were collected using different methods, so presence is indicated by X but densities are not presented. Identical methods were used in 1985 and 1986; data are estimated mean densities over the entire reef based on 3 surveys each year (DeMartini 1987). -- indicates young-of-year not present in any surveys for that year.

			DENSITY (NO./1000 M^2)			
	1983	1984	1985		1986	
SPECIES			MEAN	SE	MEAN	SE
Barred sand bass	X	X	--	--	--	--
Black perch	X	X	63	6.5	102	26.5
Blackeye goby	--	--	2	0.5	8	1.5
Blacksmith	X	X	8082	2162	3361	542.5
Bluebanded goby	X	X	10	8	2	1
California sheephead	X	X	32	2.5	4	2
California scorpionfish	--	--	0.1	0.03	0.1	0.1
Garibaldi	X	--	16	4.5	2	1
Kelp bass	X	X	--	--	1	1
Painted greenling	X	--	--	--	--	--
Pile perch	--	--	0.3	0.15	--	--
Rainbow perch	X	--	--	--	--	--
Rock wrasse	X	X	0.1	0.03	--	--
Sargo	--	--	2	2	--	--
Senorita	X	X	82	44.5	50	23.5
Zebra goby	-	--	0.2	0.04	--	--
Total Individuals			8289	2213	3529	583.5
Total Individuals minus blacksmith			207	56	168	46.5
Number of species	11	8	12		9	

Table 8-6
Species richness and density of young-of-year on artificial and natural reefs.

Benthic and water column species richness was determined from benthic and water-column transects (Ambrose 1987a). Benthic species richness was significantly different between artificial and natural reefs (t = 2.79, 24 df, P = 0.01). Density of all species combined near the benthos was significantly different between artificial and natural reefs (t = 3.06, 24 df, P = 0.005).

	Species Richness		Density (No./1000 m^3)	
	BENTHIC	WATER COLUMN	BENTHIC MEAN SE	WATER COLUMN MEAN SE
		ARTIFICIAL REEFS		
Torrey Pines AR	4	0	260.4 (92.8)	0
Pendleton AR	6	0	464.6 (157.7)	0
Newport Beach AR	3	0	58.3 (47.9)	0
L.A. Harbor Breakwater - inside	7	20	85.4 (17.7)	41.67 (11.79)
L.A. Harbor Breakwater - outside	4	18	47.9 (11.5)	14.8 (14.8)
King Harbor Breakwater	7	18	420.8 (95.5)	181.25 (132.19)
Hermosa Beach AR	3	0	50.0 (22.7)	0
Marina Del Rey AR	3	0	30.6 (15.8)	0
Pitas Point AR	2	1	12.5 (8.2)	83.33 (62.99)
Rincon Oil Island	2	1	12.5 (5.2)	6.25 (6.25)
MEAN (SE)	**4.1 (0.60)**	**1.2 (0.61)**	**144.3 (54.70)**	**32.7 (18.58)**
		NATURAL REEFS		
Marine Street Reef	3	3	8.3 (4.5)	264.58 (148.95)
La Jolla Cove Reef	2	0	27.1 (20.2)	0
Del Mar Reef	3	1	6.3 (4.4)	114.58 (103.09)
Barn Kelp	3	0	50.0 (34.8)	0
Las Pulgas Reef	2	0	47.9 (41.0)	0
Box Canyon	2	0	18.8 (16.5)	0
San Onofre Kelp - Main	1	12	2.1 (2.1)	0
San Onofre Kelp - North	2	14	16.7 (14.4)	10.42 (5.40)
San Mateo Kelp	1	3	2.1 (2.1)	10.42 (8.30)
Two Man Rock	3	0	125.0 (73.7)	0
Laguna Beach North	4	2	18.8 (10.2)	10.42 (5.42)
Pelican Point	3	0	18.8 (5.8)	0
Point Vicente	5	0	87.5 (28.7)	0
Don't Dive There	3	2	8.3 (6.3)	25.00 (13.36)
Flat Rock	1	1	6.3 (3.0)	8.33 (8.33)
Rincon Kelp	0	0	0	0
MEAN (SE)	**2.4 (0.31)**	**0.9 (0.31)**	**27.7 (8.68)**	**27.7 (17.30)**

year; since there is yearly variation in recruitment success for many species (Stephens *et al.* 1986), the 1986 survey will not be representative of all years. Nonetheless, the survey demonstrates clearly that fish recruit to artificial reefs; in fact, artificial reefs might provide particularly suitable settlement sites.

8.2.1.2 Consequences of recruitment to artificial reefs

Marine fish populations are sometimes regarded as either habitat/resource-limited or recruitment-limited. Habitat- or resource-limited populations occur in a "saturated" environment in which existing individuals utilize nearly all of the essential resources. Under these conditions, additional individuals can only survive and reproduce if more resources become available. In recruitment-limited populations, in contrast, the size of the population is determined by the number of individuals that survive the planktonic stage. Thus, when conditions are more favorable (e.g., more food and/or fewer predators), more individuals will survive to settle on reefs, and the population will increase.

We do not know if habitat limits the populations of most temperate reef fish, but proponents of artificial reefs often implicitly assume that it does. For example, it is sometimes argued that it does not matter if fish are simply attracted to an artificial reef, because a fish leaving a natural reef to move to an artificial reef will leave a "space" or "opportunity" behind on the natural reef into which another individual will recruit and grow; by this reasoning, even attraction to artificial reefs will result in higher fish production. However, this scenario is only valid if the fish population is habitat-limited. In a recruitment-limited population, emigration to a new habitat would have little effect on the total number of fish on a reef because no recruits would be available to fill the "space" left behind.

There is evidence that habitat may be limiting for a few (usually small) temperate reef fish. For example, shelter availability influenced the recruitment of the blue-banded goby (*Lythrypnus dalli*)(Behrents 1987), and nest sites influenced the number of breeding male blackeye gobies (*Coryphopterus nicholsi*) on a Southern California reef (Breitburg 1987). Other species, such as blacksmith and garibaldi (*Hypsypops rubicunda*), may also be limited by the availability of nesting or shelter sites (see Bray 1981, Clarke 1970).

However, there have been no studies on habitat limitation for the vast majority of temperate reef species, and therefore there is no evidence that habitat limits temperate reef fish populations in general. There are numerous studies indicating that coral reef fish populations are recruitment-limited rather than habitat-limited (e.g., Williams 1980, Doherty 1983, Victor 1986), which suggests that the same might be true of temperate reef fish. In fact, Doherty and Williams (*in press*) have argued that the dynamics of reef fish populations, including those in temperate coastal regions, will be strongly influenced by fluctuations in recruitment.

If resources (but not habitat) are sometimes limiting, the higher densities of young-of-year on artificial reefs could actually be detrimental. By concentrating a large number of young-of-year that might otherwise disperse to less crowded habitats, post-settlement growth and survivorship of a cohort of recruits might be lower on an artificial reef than it would be if the reef was not there.

We need to know much more about the population dynamics and community interactions of temperate rocky-reef fish than we presently know before we will be able to determine the relative importance of these different factors. The uncertainty about the factors that are limiting fish populations leads to uncertainty about the consequences of recruitment to artificial reefs. Even if fish recruit to artificial reefs in substantial numbers, constructing an artificial reef will not result in higher fish production if the recruits would have been equally successful elsewhere.

8.2.2 Growth

Some information on the growth of fish on an artificial reef has been collected by Dewees (1970, Dewees and Gotshall 1974) on a 30 m x 8 m reef constructed from tires. Thirteen tagged copper rockfish grew an average of 27.3 mm over 191 days. Diet information suggests that some fish, especially the younger ones, fed on organisms that grew on the artificial reef.

Most of the evidence on the contribution of artificial reefs to growth of fish is indirect. Several studies have shown that organisms that occur on artificial reefs were important items in the diets of some species (Pearce and Chess 1968, Turner *et al.* 1969, Lindquist *et al.* 1985). The work by Hueckel and his colleagues (Hueckel 1980, Hueckel and Stayton 1982, Buckley and Hueckel 1985) provides some of the best evidence to date for the contribution of an artificial reef to fish growth. It demonstrates that, while fish are in the vicinity of an artificial reef, at least some of them receive substantial portions of their diet from the reef. However, it is not clear what proportion of the overall diet of the fish, averaged over weeks or months, can be attributed to the artificial reefs, since fish might forage on an artificial reef for only a few days before moving to other areas; even fish captured on an artificial reef could have obtained food from natural rocky substrates (Hueckel 1980).

Although some fish on artificial reefs appear to feed on the reef, others do not. Eleven species of fish collected from artificial reefs off New York and South Carolina were not highly dependent on reef-associated fauna for food (Steimle and Ogren 1982). Diet information for fish associated with Torrey Pines Artificial Reef (=Bureaucrat Reef) in Southern California also indicated that some fish were eating large numbers of animals from the surrounding sand area (Davis *et al.* 1982). Mottet (1981) has suggested that artificial reefs will attract fish as long as there is adequate food nearby; the presence of food on the reef itself is not essential.

Much more detail about the feeding behavior of fish on artificial reefs is needed to determine how much artificial reefs contribute to growth. Even Hueckel's studies, which indicate that artificial reefs furnish some food for some fish, does not provide the information needed to make a quantitative estimate of the increase in fish biomass due to an artificial reef. The necessary information could be gathered from time/energy budgets, tagging studies to measure fish movements, gut-content and foraging behavior studies, etc.

8.2.3 Natural mortality

Survival of fish on artificial reefs has often been assumed to be higher than on natural reefs because the former offer a complex refuge from predation. However, the densities of predators are also higher on artificial reefs, and these predators probably increase the risk of predation on the reefs. Depending on the relative strengths of these two opposing factors, mortality of small fish could be either increased or decreased. Unfortunately, there has never been an attempt to measure survivorship on artificial reefs.

8.2.4 Fishing mortality

Many fish species experience mortality due to fishing. Fishing mortality may be particularly important for fish on artificial reefs because artificial reefs attract anglers, so fishing pressure is often much heavier over an artificial reef compared to a natural reef (Turner *et al.* 1969, Matthews 1985). If artificial reefs simply concentrated fishing effort, they would have no net effect on the fish stocks in a region. However, angler success (CPUE) is frequently higher on artificial reefs, and this may lead to an increase in both the total fishing effort expended in an area and the biomass of fish harvested from the ocean.

The potentially heavy mortality due to fishing on artificial reefs is even more important when the fish attraction properties of artificial reefs are considered. Fast and Pagan (1974) found that fish moved from natural to artificial reefs, but not in the other direction. Similar unidirectional movement to an artificial reef was detected at Monterey, California (Matthews 1985, Solonsky 1985). Out of the 272 fish tagged in the Monterey study, all of the fish that were recaptured away from their original location had moved from the natural reefs to the artificial reef. An absence of movement from the artificial reef to the natural reef could have resulted from the high fishing pressure on the artificial reef, so that fish that moved to the artificial reef were captured by anglers. High fishing mortality was suggested by the fact the 87% of the fish recaptured in the Monterey study were caught by sportfishermen (Matthews 1985).

The Monterey study suggests that fishing on artificial reefs may dramatically lower the survivorship of fish on the reefs. The impact of fishing would depend on many factors, including fishing pressure relative to natural reefs and the characteristics of different species. Clearly, fishing on artificial reefs will impact different species dissimilarly. Some species, such as gobies and blacksmith, are not caught by fishermen and so are unlikely to be affected by fishing. Fishing mortality is potentially very important for many other species, such as kelp and sand bass. The impact of fishing will vary according to species, time and place. Fishing pressure could also be controlled with restrictive regulations.

Mortality due to fishing could affect fish production on two spatial scales. From the standpoint of an individual reef, higher fishing mortality could reduce the amount of fish produced on the reef, although it might not have regional, or population-wide, consequences. However, if artificial reefs lead to a greater total biomass of fish being harvested from the ocean, they could result in lower standing stocks, particularly in a location such as Southern California, where many stock are heavily exploited and there is already concern about overfishing. By reducing the standing stocks of some species, higher fishing mortality caused by artificial reefs could potentially reduce the amount of fish produced in an entire region.

8.2.5 Discussion

Application of the phrase "attraction versus production" to the issue of fish production on artificial reefs is perhaps misleading because it implies that attraction and production are mutually exclusive. This is not the case. On very simple artificial reefs or Fish Attracting Devices (FADs) attraction alone may be operating. However, the existing evidence suggests that most artificial reefs (and certainly the quarry rock reefs considered here for mitigative purposes) increase fish production to some degree. The relevant question is not "is there attraction or production," but rather "what is the *net* increase in fish production on an artificial reef (taking into account possibly increased fishing mortality)." It is also important to realize that an artificial reef might increase the production of some species but not others.

There are no data on the actual amount of fish produced on an artificial reef. The production of some species, such as gobies and blacksmith, is almost undoubtedly increased by artificial reefs. Both of these species recruit to artificial reefs in Southern California and neither is fished; in addition, gobies at least are so sedentary that they probably do all of their feeding near their settlement sites. Unless these small, sedentary, unfished species are recruitment-limited, artificial reefs increase their production.

However, for other species the gains in some components of fish production might be reduced or eliminated by losses in others. For many Southern California fish species, some components of production are certainly increased, but we do not have enough information to determine how these increases might be discounted by decreases in other components, particularly fishing mortality, so overall changes in production cannot be estimated. For example, kelp bass (*Paralabrax clathratus*) and sand bass recruit to artificial reefs, but the proportion of their food that is obtained from artificial reefs is not known, and they both are heavily fished. Thus, for most species in Southern California we do not have enough specific information about their use of artificial reefs, nor do we understand their ecology well enough, to determine whether (or to what degree) their production is increased by an artificial reef.

Unfortunately, the species that we are confident have increased production on artificial reefs are not the economically important species, nor are they species that are likely to be heavily impacted by SONGS. However, there are ways to reduce the uncertainty about fish production on artificial reefs. The principal disadvantage of an artificial reef is that it might increase fishing mortality; however, fishing mortality can be controlled by restrictive regulations or reef size or design (see Section 8.5). Since there is evidence that fish recruit as well to artificial reefs as natural reefs and that benthic organisms (on which fish feed) are similar on artificial and natural reefs (Ambrose 1987a), it is reasonable to conclude that artificial reefs of appropriate size, design and location can increase fish production.

Even if it can be assume that *some* fish production will occur on artificial reefs, it is critically important for out-of-kind mitigation purposes to estimate *how much* production results from constructing a reef. Estimates of the amount of fish produced on artificial reefs are needed to establish definitively the size of reef required for mitigation; this subject is discussed in more detail in Section 8.3.3.

In spite of the uncertainty about the amount of fish they produce, artificial reefs provide one of the few opportunities available for enhancing nearshore marine resources, so they could be a valuable technique for mitigating unavoidable marine losses. The challenge will be to insure that the size and design of artificial reef used for mitigation is appropriate for the impact.

8.3 Design and Location

With the caveat that important aspects of fish production have not been adequately evaluated, and that gains in production could be negated by heavy fishing pressure on artificial reefs, it seems that artificial reefs could be appropriate for mitigating resource losses or enhancing fish populations. If artificial reefs are to achieve these objectives, important questions about the appropriate design must be addressed.

8.3.1 Design

The most common distribution of materials in artificial reefs in the United States is to deposit all of the reef material in one place. In California, however, the material for most recent reefs has been placed in discrete piles, or modules, separated from each other by expanses of sandy substrate. One possible advantage of separate modules is that the amount of ecotonal habitat (i.e., habitat along the sand/rock interface) is higher than if the same amount of material is placed in only one pile (Grant *et al.* 1982). There are few data available to test the importance of ecotonal area to fish. However, higher densities of older juvenile barred sand bass, young-of-year senorita, and blackeye goby (*Coryphopterus nicholsi*) on the ecotone compared to the crest of Pendleton Artificial Reef (DeMartini 1987) suggest that ecotonal area is important. Fish densities in the sand areas between modules at PAR were also higher than in the surrounding sand area (DeMartini 1987, Anderson *et al.* 1989). In addition, barred sand bass sampled during the Fall 1986 survey were found predominantly at the sand/rock interface of all reefs (Ambrose 1987a). Unfortunately, there has never been a study comparing modular and "single-pile" reefs, so the nature and extent of the advantages of modular construction, if any, are not known.

When designing a modular artificial reef, a decision must be made regarding the appropriate distance between modules. The distance between the modules will influence the degree of movement of fish between modules, the density and species composition of fish in the area between modules, and the effective area of the reef. Unfortunately, there have been no studies on the effects of different spacing patterns. Recently, California Department of Fish and Game constructed an artificial reef with two sets of modules that are separated by different distances, and this information should be available in the future.

Most of the artificial reefs in Southern California have been constructed from quarry rock. Quarry rock has the advantage of being a natural substrate, and it is relatively inexpensive in California. However, two of the reefs included in the Fall 1986 survey were made from concrete. A comparison of the communities on these concrete reefs to communities on four rockpile reefs built from quarry rock is presented in Table 8-7. The number of fish species found on the concrete reefs was slightly higher than on the rockpile reefs, but the overall density of fish was somewhat lower (although the standard errors are large). The density of young-of-year fish on concrete reefs was less than a third of the density on rockpile reefs.

Algae and invertebrates also occurred at consistently lower densities. The concrete reefs were relatively deep, which confounds any analysis of the influence of the concrete alone. Nonetheless, these data suggest that concrete reefs might provide somewhat fewer resources for fish, which could affect fish production.

Table 8-7

Comparison of concrete and rockpile reefs.

Two concrete reefs (Newport Beach and Hermosa Beach) and four rockpile reefs (Torrey Pines, Pendleton, Marina Del Rey and Pitas Point) were sampled (Ambrose 1987a). Percent cover information was collected using a random point contact method, algal and invertebrate densities were collected using 1 m^2 or 10 m^2 quadrats, and fish information was collected from visual transects: detailed methods are presented in Ambrose (1987a).

	— CONCRETE —		— ROCKPILE —	
	MEAN	SE	MEAN	SE
ALGAE				
Total % cover of algae	1.2	1.0	6.1	1.73
Understory kelp density (No./100 m^2)	0	0	1.0	0.60
INVERTEBRATES				
Total % cover of sessile invertebrates	42.5	30.50	63.2	13.60
Total density of invertebrates (No./m^2)	6.9	6.32	43.7	10.74
FISH				
Number of species	21.5	0.5	16.8	3.30
Benthic Density - all lifestages	380.9	120.7	537.7	178.0
Benthic Density - young-of-year	54.2	4.15	192.0	106.9

Reef height may be important for attracting or supporting certain fish species (such as blacksmith); its importance has also been suggested in other studies (see Mottet 1981). Jessee *et al.* (1985) suggested that the relief and height of PAR contributed to the high fish densities on PAR compared to nearby natural reefs. Data from the 1986 survey suggest that reef height might influence the density of some species (Ambrose 1987a), but there is no evidence that higher artificial reefs produce more fish. Patton *et al.* (1985) suggest that the densities of many fish species are "saturating functions" of reef height, so that tall artificial reefs may actually be "over-engineered" and may not provide a cost-effective way of producing fish. It seems that a variety of heights in an artificial reef might be more important than maximum height of the reef, since the increased diversity of microhabitats might have a greater effect on fish production, but this possibility has not been studied.

The structural complexity of an artificial reef is also likely to play an important role in determining the densities of fish on the reef (Smith *et al.* 1979). The variety of microhabitats existing on a large, complex artificial reef could increase the number of species that reside on the reef. On a smaller scale, a structurally complex reef could provide abundant refuges for many species. The most common fish species in the Fall 1986 survey, blacksmith, appears to benefit from the complexity of artificial reefs: blacksmith rely on holes and crevices for shelter (Ebeling and Bray 1976, Bray 1981, Anderson *et al.* 1989), and artificial reefs have abundant shelter sites in the interstices of their rocks. Although structural complexity seems likely to be important, there has not been a thorough study relating it to the production, or even densities, of fish on artificial reefs, so it is not possible to predict the effects of high or low structural complexity, or the influence of different types of complexity.

8.3.2 Location

The site chosen for an artificial reef may be more important than the design of the reef (Ogawa 1982). Two aspects of reef location that could influence the communities that occur on a reef are the depth of the reef and its proximity to natural reefs.

The depth of a reef can have a substantial influence on the community that develops on it. In some locations, shallow reefs may not be feasible because of navigational safety considerations; otherwise, a wide range of depths is available. In the past, most of California Department of Fish and Game's artificial reefs were constructed in water that was at least 20 m deep. More recently, California Department of Fish and Game has constructed reefs in relatively shallow water, including PAR (15 m) and the Pitas Point Artificial Reef (11 m). The most obvious difference between deep and shallow artificial reefs is the high abundance of algae on shallow reefs, especially the kinds of algae that are likely to enhance fish populations (Ambrose 1987a). *Macrocystis*, which also may enhance fish populations, grew only on the shallow artificial reefs surveyed in Fall 1986. In addition, the density of some benthic fish, including young-of-year, was higher on shallow reefs.

Perhaps as a consequence of their shallow depth, breakwaters had some of the highest abundances of algae seen on artificial reefs in the Fall 1986 survey.

Three of the four artificial reefs with kelp were breakwaters. The diversity and density of fish on breakwaters also tended to be higher than on the other artificial and natural reefs. For example, the highest densities of sport fish young-of-year occurred on breakwaters. In addition, the highest biomass of fish in the water column on artificial reefs occurred on breakwaters. It appears that a breakwater-type configuration might be an effective way to generate a rich and abundant fish fauna. However, there is not enough information to evaluate which aspects of breakwaters contribute most to their biological communities.

Since the fish assemblage that occurs on a reef will depend on the depth of the reef, an artificial reef should be constructed at a depth that will develop the desired assemblage. At present, there is not enough information to predict precisely the communities that will develop on reefs at different depths. California Department of Fish and Game has recently constructed a series of experimental artificial reefs with sets of modules between 15 m and 25 m deep, so information for that depth range should be available in the future. Currently, it seems most reasonable that an artificial reef constructed for in-kind replacement of reef resources be placed at about the same depth as the impacted reef; there is not enough information to develop guidelines for the depths of reefs constructed for out-of-kind mitigation.

A second aspect of reef placement concerns the distance to the nearest natural reef. Most artificial reefs are placed in relatively unstructured habitats, such as sandy bottoms, in a location that is isolated from natural reefs. Although this type of location may maximize an artificial reef's ability to attract fish, and is frequently cited as a criterion for siting a reef to be used to enhance fishing, it is not necessarily the best location for mitigative purposes.

Only two reefs in California have been constructed near natural reefs. The San Luis Obispo County Artificial Reef (SLOCAR), which was built to enhance rockfish recruitment, was constructed near natural rocky regions to allow ready colonization and movement of species occupying rocky habitats. Pitas Point Artificial Reef (formerly called Ventura Artificial Reef) was constructed in relatively shallow water approximately 500 m from a natural kelp bed. For species with planktonic larvae, distance to a natural reef would probably have little influence on recruitment to an artificial reef. However, movement of juveniles and adults would be facilitated by the close proximity of artificial and natural reefs. The proximity of a natural reef would also be important for the recruitment of species that are live-bearing (such as surfperch) or have larvae that disperse over short distances. Species with limited dispersal may find it difficult to reach an isolated artificial reef. In particular, giant kelp (*Macrocystis pyrifera*) only disperses over short distances under most circumstances (see Section 9.2.1.2), and the failure of kelp recruitment on most existing artificial reefs may be due in part to the lack of nearby kelp beds. (In this regard, it is interesting to note that Pitas Point, which is near a kelp bed, is the only artificial reef that is not a breakwater that supports kelp.) Positioning an artificial reef adjacent to an existing kelp bed would greatly enhance the probability of establishing kelp on the artificial reef (see Section 9.2.1.2). Placing an artificial reef near a natural reef might also reduce the fishing pressure on the artificial reef because the natural reef would provide adjacent fishing sites.

8.3.3 Size

One of the most critical decisions about reef design involves the size of reef that will be required to achieve a certain level of resources. The size of reef needed to mitigate a particular impact depends on the quantity of resources lost due to the impact, and the resources that will be provided by the artificial reef. The amount of resources lost can usually be estimated, but the productivity of an artificial reef is difficult to predict because of the uncertainties about fish production on artificial reefs in general. In addition, the processes used to estimate the size of reefs needed for in-kind versus out-of-kind mitigation are different.

8.3.3.1 In-kind

One approach to the problem of determining the size of artificial reef needed as in-kind mitigation for damages to a natural reef would be to require 1:1 replacement of habitat area; that is, for every hectare of natural reef impacted, a hectare of artificial reef would have to be built. This approach assumes that production per unit area would be the same on the replacement artificial reef and the natural reef. It seems reasonable that an artificial reef that mimics the characteristics of an impacted natural reef (including size) would produce as many resources as the natural reef. A large reef could furnish many different types of habitats and microhabitats. Placed in an appropriate location, it could support a rich assemblage of algae and associated invertebrates, thereby providing food for a number of fish species.

If we knew more about the production of fish on artificial reefs, we might be able to build a smaller artificial reef that would still replace all of the lost resources.

The biomass density (i.e., weight per unit area) of fish is higher on artificial reefs than on natural reefs (Table 8-8; Ambrose 1987a). If we assume that (1) fish production per unit area is proportional to biomass density, and (2) large artificial reefs will have the same average densities as the small artificial reefs surveyed by Ambrose (1987a), then a smaller artificial reef might suffice. However, there are no data to indicate that either of these two assumptions are true. The smaller size estimate presupposes that an artificial reef can be constructed to produce resources at a higher density than the natural reef it replaces. In fact, it does seem likely that different design features of artificial reefs affect the amount of resources produced, and that these features could be manipulated to maximize the production potential of a reef. Some of the existing data are suggestive of possible relationships (e.g., Section 8.3.1 and Ambrose 1987a), but these are untested relationships based on densities, and there are no data on the amount of *production* that could be expected from a particular design. At this point, there is no evidence to support the construction of an artificial reef that is smaller than the area impacted on a natural reef.

To insure adequate mitigation, it may be necessary to build an artificial reef that is larger than the area impacted on a natural reef. Because an artificial reef on such a scale has not been built, it is difficult to predict the nature of the fish community that would develop on one. Fish densities on a very large artificial reef would probably not be as high as on the existing smaller artificial reefs because the area of attraction would be proportionately smaller; there is no information available on how fish production might vary. Furthermore, if the artificial reef is to support giant kelp (see Chapter 9), there is uncertainty about establishing a kelp bed and the kelp probably would not cover the entire reef. Given these

Table 8-8

Estimated standing stock of benthic fish on artificial and natural reefs.

Size of reef and biomass density are from Ambrose (1987a). Standing stock was estimated by multiplying biomass density on a reef by the size of the reef. Some natural reefs were sampled at 2 or 3 sites; to estimate standing stock for these reefs, the mean biomass density for the sites was used.

		BENTHIC			WATER COLUMN		
	Area (ha)	*Biomass Density (MT/ha)*		*Standing Stock (MT)*	*Biomass Density (Mt/ha)*		*Standing Stock (MT)*
ARTIFICIAL REEFS							
Torrey Pines AR	0.18	0.665		0.120	0		0
Pendleton AR	1.40	0.359		0.503	0.0003		0.0004
Newport Beach AR	2.50	0.783		1.958	0		0
LA Harbor Breakwater outside	5.81	0.477		2.771	0.048		0.278
LA Harbor Breakwater inside	4.75	0.422		2.005	0.073		0.347
King Harbor Breakwater	3.86	0.244		0.942	0.007		0.025
Hermosa Beach AR	0.24	0.252		0.061	0		0
Marina Del Rey AR	0.32	0.481		0.154	0		0
Pitas Point AR	0.45	0.620		0.279	0.012		0.005
Rincon Oil Island	2.81	0.221		0.621	0.030		0.84
MEAN (SE)	**2.2 (0.65)**	**0.452 (0.061)**		**0.941 (0.304)**	**0.017 (0.008)**		**0.150 (0.087)**
NATURAL REEFS							
Marine Street Reef	220.00	0.136	0.207	45.540	0.012	0.012	2.64
La Jolla Cove Reef		0.277			0.012		
Del Mar Reef	214.00	0.174		37.236	0.001		0.193
Barn Kelp	80.00	0.164		13.120	0		0
Las Pulgas Reef	53.00	0.154		8.162	0		0
Box Canyon	16.00	0.130		2.080	0		0
San Onofre Kelp Main (4-1)	104.00	0.191	0.298	30.992	0.157	0.087	9.058
San Onofre Kelp North (002)		0.404			0.016		
San Mateo Kelp	114.00	0.363	0.578	65.892	0.067	0.036	4.070
Two Man Rock		0.792			0.005		
Laguna Beach North	23.00	0.211		4.853	0.141		3.252
Pelican Point	31.00	0.399		12.369	0.027		0.828
Point Vicente	551.00	0.495	0.501	276.051	0	0.040	22.040
Don't Dive There		0.921			0.116		
Flat Rock		0.086			0.004		
Rincon Kelp	6.80	0.327		2.224	0.004		0.025
MEAN (SE)	**128.4 (47.78)**	**0.286 (0.045)**		**45.320 (23.893)**	**0.032 (0.014)**		**3.828 (2.003)**

uncertainties about artificial reefs, the conservative approach would be to build an artificial reef that is larger than the impacted area of the natural reef. The MRC has recommended that 1.5 ha of artificial reef be constructed for every 1 ha of natural reef impacted (Appendix D); since the MRC estimates a loss of 80 ha of kelp due to the operation of SONGS, a 120-ha artificial reef is recommended.

The lack of information about processes on artificial reefs means that a large artificial reef used to mitigate impacts to a natural reef should be viewed as experimental. Nonetheless, such a reef would be appropriate mitigation because it is reasonable to expect that it could replace lost reef resources if it (1) mimics the impacted reef's structure, (2) is placed in an appropriate location, and (3) is sufficiently large.

8.3.3.2 Out-of-kind

Unlike the situation with in-kind mitigation, there is no clear link between the Bight-wide losses of fish and the size of reef needed to completely mitigate those losses. Furthermore, there is no established method for developing such a link. The MRC estimates that a 60-ha high-relief artificial reef would adequately mitigate the impacts of SONGS on midwater fish; the procedure used to derive this estimate is presented in Appendix D.

8.3.4 Costs

In general, the costs of constructing a quarry-rock artificial reef near San Onofre are well known because the California Department of Fish and Game has recently built a number of reefs in this area. To construct a reef in the area between Dana Point and Pendleton Artificial Reef, the quarry rock would cost approximately $30/ton installed (DFG, *personal communication*).

Of course, the cost for any specific reef will depend on its design as well as location. Neither of the two artificial reefs proposed as mitigation has been designed in detail, although they are roughly described as "high-relief" and "low-relief" reefs. To estimate the approximate costs of these reefs, I have used Pendleton Artificial Reef (PAR) as the basis for comparison. PAR has an average maximum height of 4.3 m (Ambrose and Anderson 1989); I consider this to be a high-relief reef. In contrast, I consider a low-relief reef to be one-quarter the height of PAR, and so it would use one-quarter the amount of rock needed to construct PAR.

PAR was constructed from 10,000 U.S. tons of quarry rock. The total area of PAR, including the sand areas between its eight modules, is about 3 ha; the rock itself covers about 1 ha. A high-relief reef, constructed with the same topography as PAR and a maximum height of about 4.3 m, would therefore use about 10,000 tons of quarry rock/ha, costing about $300,000/ha (or $120,000/acre). It would cost $15-18 million to construct the 60-ha high-relief artificial reef recommended by the MRC as mitigation for midwater fish impacts.

A low-relief artificial reef would use only one-quarter as much rock as the high-relief reef, and so would cost about $75,000/ha (or $30,000/acre). It would cost about $9 million to construct the 120-ha low-relief artificial reef recommended by the MRC as mitigation for the impacts to the San Onofre Kelp forest community.

(Note: this cost does not include the cost of establishing kelp on the artificial reef, which could be an additional $1-2 million.)

8.4 Impacts to soft-bottom communities

Artificial reefs are almost invariably constructed on extensive sandy plains, typically at great distances from rock bottom, because these areas are viewed as being generally unproductive, and hence most amenable to habitat modification. However, artificial reefs could adversely impact the existing soft-bottom communities in several ways. First, the infauna (organisms that live beneath the surface of the sediments) directly beneath an artificial reef will be buried. For most reefs, the actual area of soft-substrate covered is relatively small, so this loss would not be very great, although the cumulative effect of many artificial reefs could eventually be substantial. Second, artificial reefs can alter wave and current patterns (Turner *et al.* 1969), resulting in changes in the physical structure of the nearby soft-bottom habitat (to which infaunal organisms are very sensitive). There is some evidence suggesting that the effects of artificial reefs on the surrounding soft-bottom habitat may be very localized. Davis *et al.* (1982) noted shallow scour effects up to 15 m from Bureaucratic Reef (Torrey Pines Artificial Reef in Table C-1), but there were no measurable effects on sand ripple patterns, grain size or organic carbon beyond the scoured areas. Third, predators associated with a reef may feed on the organisms that live in the adjacent sediments. Finally, construction of an artificial reef could result in the reduction of suitable habitat for flatfish and other fish associated with soft-bottom habitats, potentially detracting from their populations. These last two possible effects are discussed below under the general topics of infaunal and epifaunal organisms and fish populations.

8.4.1 Infaunal and epifaunal organisms

Davis *et al.* (1982) found that only two taxa, both epifaunal, were affected by Bureaucrat Reef. Sea pens (*Stylatula elongata*) were eliminated from within 30 m of the reef, and reduced in density up to 80 m away, due to grazing by reef-associated fishes. The tube-dwelling polychaetes *Diopatra splendidissima* and *D. ornata* experienced increased densities near the reef. No relationship with distance from the reef was detected for any infaunal species or taxonomic category; in all cases, variability between samples collected the same distance from the reefs was more important than differences between groups of samples collected at different sites along transects. Davis *et al.*'s data suggest that infaunal populations are less sensitive to disturbances associated with artificial reefs than large, sessile epifauna. They suggest that the life histories of many infauna in Southern California permit rapid recolonization of areas disturbed by reef construction.

A similar study of infauna around Pendleton Artificial Reef, conducted in Fall 1986, is summarized in Ambrose and Anderson (1989, *in prep.*). The effect of the reef on the tube-dwelling worm *Diopatra ornata* was most obvious; *Diopatra* occurred only near the modules (*personal observation*). For all other species and taxonomic groups, no consistent relationship between density and distance from module was detected. Furthermore, there were no consistent differences among the transects placed on the upcoast, downcoast, inshore and offshore sides of the reef, suggesting that current and/or swell exposure does not dramatically affect infauna densities. High variability among replicates may have obscured some effects, but the data from this study suggest that the effect of PAR on adjacent infaunal densities is small.

8.4.2 Fish populations

Because artificial reefs could result in the reduction of suitable habitat for flatfish, the construction on an artificial reef might be expected to have a negative effect on resident flatfish populations. Walton (1982) has shown that artificial reefs can actually enhance flatfish populations; however, his reefs were specifically designed with semi-enclosed structures that are rarely incorporated into artificial reefs. A subsequent study by the Washington Department of Fisheries did not find an increase in flatfish density surrounding concrete reefs that were not placed in a semi-enclosed pattern (Hueckel 1981). It seems that a reef with the appropriate design features may result in increased flatfish populations, but otherwise flatfish populations are not likely to be enhanced by artificial reefs.

Except for the studies by Walton and Hueckel on flatfish, there is virtually no information about the effect of an artificial reef on resident fish populations. Obviously, an artificial reef removes some sand habitat; however, the proportion of habitat covered by artificial reefs is so small that it seems unlikely that they would significantly affect the overall standing stock of sand-associated fishes.

Artificial reefs could increase the density of fish in a sandy area by allowing reef-associated fish that feed in soft-bottom habitats to occur in otherwise inaccessible areas. There are no data comparing the density of fish on an artificial reef to the density of fish that occurred in the area before the reef was constructed. However, DeMartini (1987) has estimated the density of fish in the area around the Pendleton Artificial Reef modules. On two transects that extended to 75 m away from the modules, fish were found on the sand close to the modules, but no fish were observed between 30 m and 75 m on these transects. These data suggest that fish density near the modules was somewhat higher than normal for a sandy bottom, but that this effect did not extend beyond 30 m.

8.5 Overall Evaluation

There are still questions about the suitability of using artificial reefs for mitigation, mostly revolving around the amount of fish production that occurs on artificial reefs. Artificial reefs have frequently been assumed to produce fish, although there have been no studies of fish production of artificial reefs in the marine environment to substantiate this assumption. In fact, it is known that artificial reefs attract fish, but some of the assumptions about the production of fish on artificial reefs are questionable or scientifically unsupported. For this reason, it is important to consider the evidence for fish production on artificial reefs (reviewed in Ambrose 1986a, 1987a and this chapter). In the context of this evidence, I believe that the uncertainty can be reduced to acceptable limits by setting constraints on how an artificial reef is used in mitigation, and that many of the concerns can be traced to two prevailing aspects of most artificial reefs.

First, most artificial reefs are not built like natural reefs. Quarry rock is the material of choice in California, but is rarely used elsewhere. Instead, cars, ships, tires, appliances, concrete rubble, discarded toilets, etc. may be used, and virtually any pile of junk on the ocean bottom can be considered an artificial reef. There are legitimate questions about whether reefs constructed from piles these materials produce as many fish as natural reefs. Even prefabricated reefs, such as fiberglass reinforced plastic reefs, are so different that it is not immediately obvious how much fish production they will support. Furthermore, many artificial reefs are constructed as discrete modules or in other configurations that differ markedly from most natural reefs. Careful scientific study is needed to determine how many fish can be produced by these "unnatural" artificial reefs.

Second, most artificial reefs are small, much smaller than most natural reefs that would be impacted by coastal development (see Table 8-8). Both artificial and natural reefs probably attract fish, and it seems probable that the proportion of fish on a reef that have been attracted to that reef will be higher for small reefs. Furthermore, small artificial reefs, which are almost always marked on nautical charts, attract fishermen as well as fish. Fishermen are attracted to artificial reefs because a small reef size allows fishermen to concentrate their efforts and the higher densities of fish on artificial reefs provide higher fishing success. A large artificial reef would presumably attract fewer fish per ha and so would have lower fish <u>densities</u>. Such a reef might be less attractive to fishermen because they might not catch fish as quickly as on a small artificial reef, and the large size would preclude concentrating fishing mortality in a small area. Thus, a large artificial reef would <u>minimize</u> the potential negative aspects of artificial reefs by minimizing the increased fishing mortality imposed on fish populations.

It seems reasonable to conclude that an artificial reef that perfectly mimics a natural reef would, given enough time, produce as many fish as the natural reef. Note that there are two qualifying conditions to this statement: given enough time and perfectly mimicking a natural reef. We know little about how much time is needed; observations on Pendleton Artificial Reef suggest that 10 years or more may be required before an artificial reef achieves a high degree of similarity to a similar natural reef (see Ambrose and Anderson 1989). As for mimicking a natural reef, the assumption is that function follows form, i.e., that providing the physical structure on the ocean bottom will lead to the development of the resources necessary for fish production, and the resources that develop on an artificial reef are the same as would have developed on a natural reef at the same location. Again, this assumption seems reasonable if not proven. The challenge will be to mimic an impacted natural reef well enough to provide in-kind replacement of lost resources.

Artificial reefs could be used for either in-kind or out-of-kind mitigation. By making the reasonable assumption that similar resources (including fish) are produced on similar reefs, we can avoid having to know exactly how much fish production occurs on an artificial reef in order to allow it to be used as in-kind mitigation. But there are definite constraints on how far this approach can be taken. Most importantly, it cannot be used to design an artificial reef for use as out-of-kind mitigation. For out-of-kind mitigation, it is necessary to know, in absolute terms, how many new resources will be produced in order to trade off with the dissimilar lost resources. (The procedure used to decide the trade-of is a separate, difficult problem.) These two possible applications of artificial reefs are discussed below.

8.5.1 In-kind replacement of reef resources

At the San Onofre Nuclear Generating Station, the reef resources that are at risk are the resources in the San Onofre Kelp bed, specifically giant kelp, benthic algae and invertebrates, and kelp bed fish. The main criteria for deciding whether it is feasible to use an artificial reef to replace these resources are: (1) Are the resources on artificial reefs similar to the resources that will be lost? And (2) Can they be produced to equal the losses?

A number of studies have indicated that communities on artificial reefs are similar to those on natural reefs. Algal and invertebrate assemblages were generally similar on the two types of reefs (Ambrose 1987a). Because the benthic algae and invertebrates are sessile or sedentary, the production of individuals found on an artificial reef can safely be assigned to the reef. Producing giant kelp on an artificial reef will be discussed in detail in Chapter 9, but a properly designed and located artificial reef should be able to support a kelp bed.

For fish, the species composition of assemblages on artificial and natural reefs is generally similar, and species richness is at least as high on artificial reefs. As discussed in this chapter and elsewhere, the absolute amount (if any) of fish produced on artificial reefs remains unknown, but undoubtedly depends on the specific reef and species of fish involved. It has been established that artificial reefs enhance some aspects of fish production, such as fish recruitment. It has also been established that many species feed on artificial reefs, although we do not know the degree to which growth might be enhanced.

The above information indicates that artificial reefs could provide resources that are suitable for in-kind replacement of natural reef resources, but the question of fish (and other resource) production is still unresolved. Many of the differences between artificial and natural reefs that could influence fish production are dependent on the size of the reef. One difference is that fish on artificial reefs may be more transient, only staying on the reef for a short time before moving to another site; in addition, it is likely that many of the fish found on artificial reefs are temporarily attracted to the reefs. This problem might be minimized on a large artificial reef, where the large size would reduce the relative zone of attraction around the reef, and the size and greater variety of habitats might increase the residence time of fish found on the reef. A second difference is that predation may be higher on artificial reefs because of the higher density of predators on these reefs. However, if attraction is contributing to the high densities of fish on artificial reefs, large artificial reefs should have lower densities of all fish species, including predators, than small reefs. Finally, fishing pressure is often higher on artificial reefs, leading to increased mortality due to fishing. As mentioned earlier, the densities of fish might be lower on large artificial reefs; combined with a larger area of hard substrate available for fishermen, it seems likely that fishing pressure (and fish) would not be concentrated at a small area, so per capita mortality from fishing should not be higher than on a natural reef.

These arguments suggest that many of the concerns about fish production on artificial reefs may be alleviated when considering a large, complex artificial reef. The components of fish production that result in lower production, increased natural mortality and especially increased fishing mortality, should be no different on a large artificial reef than on a natural reef of the same size. Thus, it seems feasible to replace resources from a natural reef by building a large artificial reef.

If a decision to replace reef resources by constructing an artificial reef is made, many questions about design, location, and especially size must be resolved. The conservative approach would be to construct the artificial reef to be as similar as possible to the impacted natural reef; this approach carries the least risk to the resources. It is possible that a more efficient design would produce the same amount of resources but allow the reef to be smaller and less expensive; however, there are two serious problems with trying to identify such a design. First, changing the configuration of the reef is likely to change to some unknown degree the types of resources that develop on the reef, resulting is somewhat less similar resources being produced. More importantly, much more precise quantitative information must be known about the resources lost and the resources that will be produced by a particular design. Both of these requirements are problematic, but it is clear that there is not enough information to quantitatively predict how different designs affect resource production (see Section 8.3). Therefore, attempting to design a "more efficient" reef, although possible, is a risky alternative given our present state of knowledge about artificial reefs. In fact, the uncertainty about the processes that operate on artificial reefs mean that the artificial reef should probably be larger than the area of impacted reef.

8.5.2 Out-of-kind substitution of resources

The use of artificial reefs for out-of-kind substitution of resources presents more difficulties than their use for in-kind replacement. Two aspects must be considered in order to insure that the artificial reef provides complete replacement of lost resources: the absolute amount of resources produced by an artificial reef must be known, and an objective value must be assigned to both the lost resources and the resources produced by the reef.

The problems with attempting to determine the absolute amount of fish production on an artificial reef have been discussed above. For in-kind replacement of resources, this problem can be circumvented by building a reef that mimics the impacted natural reef (and allowing an extra margin of safety when considering the appropriate size). Replicating an impacted habitat is not an option if an artificial reef is to be used for out-of-kind mitigation. Instead, an accurate estimate of the amount of fish produced by an artificial reef is required. Currently, there are no data to provide this information. Several types of estimates, with varying degrees of inaccuracy, could be attempted (see DeMartini 1987), but these would comprise little more than guesses. (Note: The Ports of Long Beach and Los Angeles are currently funding a project that will provide the first useful information in this regard, but the results will probably not be available for a year or two.)

It is also difficult to place a value on natural resources. This problem is intrinsic to any attempt to provide out-of-kind compensation. No method for determining an objective value for dissimilar resources on an artificial reef has been devised, so determining the value of resources on an artificial reef will necessarily involve some subjectivity. The approach we have taken to this problem is described in Appendix D.

Avoiding resource losses would eliminate the need to consider using an artificial reef, with its uncertainties about the amount of fish produced and the relative values of different types of resources, as out-of-kind mitigation. At SONGS, however, the resources are already being impacted. Short of shutting the plant down or constructing cooling towers, some resources *will* be lost, and some technique must be used to replace these resources. In spite of the uncertainty about the amount of fish they produce, artificial reefs provide one of the few opportunities available for enhancing nearshore marine resources. Restoring a wetland can also enhance marine resources (see Chapter 10), although the type of resources differ from those produced on an artificial reef. These two techniques are simply the most feasible methods for replacing nearshore resources. Much more information is needed, particularly about fish production on artificial reefs, before artificial reefs should be used routinely as mitigation. Nonetheless, they do provide an option for minimizing the deleterious effects of coastal developments.

CHAPTER 9

KELP BED CREATION

The operation of SONGS adversely affects a portion of the San Onofre Kelp Bed (SOK); in this case, the impact is on-going, so restoration of the affected portion of SOK would not be suitable. Thus, if feasible, the creation of a new kelp bed elsewhere would be the most straightforward mitigation technique because it would result in in-kind replacement of resources.

The MRC has recommended that a kelp bed be created on an artificial reef as in-kind mitigation for the impacts of SONGS on the San Onofre Kelp forest community. This chapter addresses the feasibility of creating a new kelp bed by reviewing previous attempts to create kelp beds and discussing the technical considerations that must be addressed in any project to create a kelp bed. (A general evaluation of artificial reefs, including artificial reefs used for in-kind mitigation, is given in Chapter 8). The major conclusions of this chapter are: Most attempts to create new kelp beds have failed; however, kelp does grow on many man-made structures. A conservative approach to creating a kelp bed for mitigating SONGS' effects would be to build the new bed adjacent to existing kelp stands. Drawing from the experiences of past attempts and knowledge about *Macrocystis* biology, this approach seems to have a reasonable chance for success.

9.1 History

Kelp beds are one of the most valuable marine habitats in Southern California; perhaps as a consequence of their relative rarity (compared to the vast expanses of soft bottom or even kelp-less hard-bottom habitat), many resource management decisions have implicitly assumed that kelp habitat is more valuable than other types of habitats, particularly sand habitats. Giant kelp (*Macrocystis pyrifera*) plants almost always attach to a hard substrate (Foster and Schiel 1985), so most attempts to create new kelp beds have relied on providing new hard substrate. Thus, it is not surprising that artificial reefs have been viewed as possible means of increasing the areal extent of kelp beds in Southern California.

There have been several instances when giant kelp has grown on artificial reefs. These cases are discussed below, separated according to whether the kelp recruited naturally to the reef or was purposely transplanted there to establish a kelp bed. There are numerous other cases, not discussed here, where kelp has grown on man-made structures such as chain networks (Neushul and Harger 1985) and underwater pipelines (Foster and Schiel 1985).

9.1.1 Natural recruitment to artificial reefs

Giant kelp has grown naturally, for a short time at least, on several artificial reefs. A car reef in Paradise Cove (in Santa Monica Bay) supported *Macrocystis* for several years, even serving as a source of kelp for transplants to other Santa Monica Bay artificial reefs. The kelp was first noted in October 1958; by December, density was as high as 22 plants/m^2. By April 1959, each car had 35-50 plants up to 3m tall. The kelp survived for a few years before disappearing; since the car bodies disintegrated a short time after the kelp disappeared, there was no substrate available for kelp to become re-established.

Bureaucrat Reef (near La Jolla) also developed a natural stand of giant kelp shortly after its construction. In June 1975, only two months after construction, juvenile *Macrocystis* were observed on the reef. The juvenile plants were near unattached adult plants that had drifted onto the reef. By March 1976, juvenile *Macrocystis* occurred in densities of up to 20 plants/m^2 (Davis *et al.* 1982). A dense surface canopy had developed by July 1976, 15 months after the reef was built. The kelp bed persisted for two years, but was destroyed by storms in 1978 and has not become re-established. Small *Macrocystis* plants have been observed at Bureaucrat Reef in recent years (Wilson *et al.* 1984, Ambrose, *personal observation*), but have not persisted.

The most recent natural recruitment of giant kelp to an artificial reef in Southern California occurred at the Pitas Point Artificial Reef (PPAR) in Ventura County, which was constructed in 1984. A stand of giant kelp had established itself by 1986 and has now persisted for several years. Although attempts were made to transplant giant kelp to the reef, most kelp plants in the bed apparently recruited naturally (Ambrose, *personal observation*). Most of the plants occurred along the crest and upper slope of the modules and away from the transplant sites (Wilson and Togstad 1987, Ambrose, *personal observation*). Observations in June 1987 suggested that at least some of the *Macrocystis* plants were two or more years old (Wilson and Togstad 1987). PPAR was specifically designed to support giant kelp; it is one of the shallowest artificial reefs in Southern California (only 11m deep), is a relatively low-profile reef, and is the closest artificial reef to an existing natural kelp bed (between 100 to 500m away). In spite of the apparent success of PPAR, it is worth noting that the kelp bed has so far persisted for only a few years, so it is too early to conclude that the long-term persistence of kelp on PPAR will be greater than on the Paradise Cove and Bureaucrat Reefs.

One artificial reef off the coast of Central California (the San Luis Obispo County Artificial Reef, or SLOCAR) has also supported a kelp bed (but not *Macrocystis*) for several years. Bull kelp (*Nereocystis*) recruited in very high numbers to SLOCAR shortly after it was constructed in 1985, and has persisted since then. Several factors probably contributed to its success. SLOCAR is close to natural rocky areas, so *Nereocystis* propagules did not have to disperse very far to reach the reef. The oceanographic conditions in Central California may be more suitable for kelp growth than those in Southern California, except for severe winter storms (which do not affect *Nereocystis* because it is an annual). Finally, herbivorous fish are not common in the area, and grazing at SLOCAR was insignificant.

9.1.2 Transplants

Kelp has been transplanted to artificial reefs on numerous occasions. The first kelp transplant efforts to artificial reefs were to the Santa Monica Bay reefs in 1959 and 1961 (Turner *et al.* 1969). Some plants were protected from herbivores after transplantation because unprotected plants were quickly eaten by herbivorous fish (opaleye and halfmoon); however, even the protected plants survived only a few months. It was thought that the failure of initial transplants may have been caused by high water temperatures, but an effort to overcome temperature limitations by using plants from Baja California also failed. Turner *et al.* (1969) believed that the ultimate failure of the transplants was due to the turbidity of the water in Santa Monica Bay, which severely limited the amount of light available for photosynthesis.

Considerable effort was also spent trying to establish *Macrocystis* on Pendleton Artificial Reef. Both adult and juvenile giant kelp plants were transplanted to PAR on several occasions (Wilson *et al.* 1981, 1984, California Department of Fish and Game 1983). However, a kelp bed was never established. Transplanted plants appeared to have been severely grazed by fish (Wilson *et al.* 1985), and other factors may have been important as well. Although recruits were seen near transplanted adults, only occasional solitary adult plants have been observed at PAR.

There has been one case in which transplant efforts have produced a self-sustaining kelp bed on an artificial substrate. Beginning in 1977, a transplant operation to an artificial substrate in 9 m of water in the Los Angeles Harbor successfully generated a kelp bed (Rice 1983). Over a period of four years, more than 700 adult plants from Abalone Cover (on the Palos Verdes Peninsula) and Baja California were transplanted to the San Pedro breakwater. The plants were attached to floats, which were in turn attached to nylon line and anchor chain. In addition, young plants (sporophytes) reared in the laboratory on twine were also transplanted. By August 1978, kelp was successfully established and growing along the breakwater. In spite of storm and fish damage to the plants, natural recruitment occurred in the transplant area in 1979. By 1987, the bed was approximately 1524 m long and 25 m wide along the inside of the breakwater (Rice 1987), and several smaller beds had developed in other areas of outer Los Angeles harbor.

Although transplants to natural substrates have been successful (e.g., the Palos Verdes kelp bed restoration), the Los Angeles Breakwater operation was the only transplant that resulted in a persistent, self-sustaining kelp bed on an artificial substrate. There are undoubtedly many reasons why the attempts to establish kelp on artificial reefs have failed; likely factors include low light levels (due to depth and turbidity), high water temperature and low nutrient availability, and grazing pressure. These factors will be discussed in more detail in Section 4.2; the published information on the influence of these factors has been reviewed in Ambrose (1987b).

There has been one attempt to establish an extensive kelp bed on a sandy substrate. This project, conducted by Kelco under contract with California Department of Fish and Game, focused on a kelp bed in Santa Barbara County. Although success seems feasible at the Santa Barbara site, where the Channel Islands provide protection from large swells and natural kelp beds occur on sand, a kelp bed would be unlikely to survive on sandy substrates near San Onofre.

9.2 Technical considerations

Data on the factors influencing kelp growth, recruitment and survival have been compiled in Ambrose (1987b), and are reviewed in Foster and Schiel (1985). If a kelp bed is to be created as mitigation, these factors must be considered when the project is being designed; however, these details are not reviewed here. Instead, general factors that might influence the dynamics of a man-made kelp bed are discussed, and some of the techniques that can be used to create kelp beds are briefly reviewed.

9.2.1 Persistence and stability of kelp beds

Natural kelp beds undergo frequent and sometimes extreme fluctuations, and local extinctions are relatively common. A number of studies have documented these fluctuations and attempted to explain kelp bed dynamics (e.g., Dayton *et al.* 1984, Ebeling *et al.* 1985, Harrold and Reed 1985), but the diversity and complexity of factors influencing kelp beds make it very difficult to predict the dynamics of any particular bed. The dynamics of kelp beds are considered here because a man-made kelp bed constructed for mitigation should be at least as persistent as the bed it is replacing.

Local extinctions of *Macrocystis* beds are frequently associated with global or regional oceanographic conditions (Dayton and Tegner 1984, Ebeling *et al.* 1985), and so affect a large number of beds simultaneously. There is little that can be done to avoid widespread extinctions such as these, and any man-made kelp bed would be as likely as a natural bed to be affected by general oceanographic conditions.

However, characteristics of individual beds undoubtedly affect their stability and persistence. Dayton *et al.* (1984) have explored a number of factors influencing the patch dynamics and stability of kelp communities. They concluded that relative patch stability was determined by biological relationships (e.g., competition for light and nutrients, spore dispersal, grazing) within a given area and physical differences (e.g., storms, wave surge) between areas. Some of the factors that might be important are discussed below.

9.2.1.1 Location

The location of a *Macrocystis* bed is important: beds that are regularly subjected to violent storms are obviously more likely to experience storm damage, probably fluctuate more, and might be less persistent than more protected beds. The kelp beds off the coast of Santa Barbara County are an example of beds that are relatively protected from storms, and consequently have persisted for long periods. (Note, however, that even these beds were destroyed several years ago by particularly heavy storms.)

If a kelp bed is to be created as mitigation for SONGS' impact, the choice of location may be constrained by the desire to produce the new resources as close to the impacted site as possible. Thus, it might be possible to choose a location that is more protected than the San Onofre region, such as the lee side of Santa Catalina Island or Santa Barbara County, but creating a kelp bed far from San Onofre would result in a significant loss of kelp resources in the region around San Onofre. Because kelp beds are relatively rare in this region, such a local loss should be avoided, if possible. However, the created kelp bed cannot be too close to SONGS or it too will be impacted by the plant.

9.2.1.2 Proximity to existing beds

A kelp bed may be more likely to recover quickly from perturbations if it has a high probability of receiving spores from other beds. Most studies of *Macrocystis* dispersal have reported very limited dispersal ability, on the order of a few meters (Anderson and North 1967, Dayton *et al.* 1984, T.A. Dean and F.R. Jacobsen, *personal communication*). Thus, it seems there could be a problem with natural re-seeding of kelp beds that have disappeared.

Recent studies have suggested that, under certain circumstances, *Macrocystis* spore dispersal may be greater than previously thought (D. Reed, *personal communication*). Kelp beds in Santa Barbara County (Ebeling *et al.* 1985) and the California Channel Islands (Ambrose *et al.* in press) have recovered rapidly due to long-distance colonization of *Macrocystis*. In fact, several artificial structures have developed kelp beds shortly after being emplaced in spite of being located several kilometers from the nearest kelp beds (Turner *et al.* 1969, Fager 1971, Davis *et al.* 1982).

The dispersal mechanisms leading to recruitment at distant reefs are probably varied. However, in the San Onofre region, "bouncers" (kelp plants that have so much buoyancy relative to the rock to which they are attached that they "bounce" along the coast) are common and could provide a consistent input of recruits to an isolated reef. In fact, the problem of establishing a kelp bed on an isolated reef may not be so much one of getting kelp to recruit to the reef, but rather getting enough recruitment to overcome other factors such as fish grazing. For example, there were a number of natural recruitment events at PAR (Calfornia Department of Fish and Game, *personal communication*), but *Macrocystis* never recruited in sufficient numbers to become firmly established on the reef.

These examples indicate that long-distance dispersal of *Macrocystis* is a normal phenomenon, but it may be relatively infrequent. For example, the kelp bed at Barn Kelp, south of San Onofre, disappeared in 1980. Barn Kelp is quite isolated from other kelp beds, and kelp has not yet re-established itself. It seems likely that long-distance dispersal of *Macrocystis* will eventually lead to the re-establishment of Barn Kelp, but the distance from Barn Kelp to extant kelp beds has probably prolonged the period without kelp.

Proximity to kelp beds may also affect the success of efforts to establish new kelp beds. Many of the attempts to establish new kelp beds on artificial reefs appear to have failed because transplanted kelp was eaten by herbivorous fish, and there was limited recruitment from the manipulated plants. These problems have been implicated in the failure to the transplant attempts at Pendleton Artificial Reef. Placing a new kelp bed close to an established bed would eliminate a number of potential factors. Herbivorous fish would not concentrate as heavily on any transplanted plants because the nearby natural bed would provide an ample supply of food, and the natural bed would provide spores for recruitment.

Close proximity to a natural kelp bed is probably not a prerequisite for establishing a new kelp bed, but it could improve the odds of success. Being close to an existing bed would enhance the chances of recruitment and might reduce the intensity of fish grazing at the new kelp bed. It could also enhance the stability of the bed by providing a nearby source of spores, which could lead to more rapid re-establishment after a local extinction.

9.2.1.3 Substrate

Substrate stability will also influence the persistence of kelp beds because most *Macrocystis* plants (including those in the vicinity of SONGS) require a hard substrate for attachment. Heavy sedimentation and/or sediment movement can cover hard substrates and reduce the area available for kelp.

The burial of hard substrate is not the only problem. When placing rocks on a soft-bottom, there is the danger that the rocks will "sink" into the bottom and disappear. A number of studies have documented scouring around isolated rocks that eventually results in the disappearance of the rocks; this problem is most severe on unconsolidated bottoms.

9.2.1.4 Size

There have been no studies relating the size of kelp beds to their variability or the probability that they will go extinct. However, it is reasonable to expect that small kelp beds will experience more extreme fluctuations, and perhaps more extinctions, than large beds. If a kelp bed created for mitigative purposes is too small, high variability and/or frequent extinctions could lead to a lower long-term average of kelp resources in the bed than expected.

In addition, it may be easier for fish to graze a small kelp bed heavily than a large kelp bed (K. Wilson, *personal communication*).

9.2.2 Techniques

Most of the effort for establishing kelp beds has been devoted to developing transplant techniques. However, site selection and preparation are also important. One focus of site preparation has been the removal of dense understory algae that could inhibit the recruitment of juvenile *Macrocystis* (Ambrose and Nelson 1982, Reed and Foster 1984). A more important focus of site preparation has been the control of sea urchins that graze on kelp plants (Wilson and McPeak 1983). Urchins are not likely to be a major problem on a new artificial reef, but if necessary they can be killed or manually removed.

Fish grazing, particularly by opaleye (*Girella nigricans*) and halfmoon (*Medialuna californiensis*), can also cause considerable damage to transplanted kelp. Fish grazing apparently damaged kelp transplanted to the Santa Monica Bay reefs, Pendleton Artificial Reef, and the Palos Verdes Peninsula. At Palos Verdes, attempts to control fish grazing included fish traps, spearfishing, gill nets, and fish exclosures; none of these methods were successful, and efforts to control grazing were eventually abandoned (Wilson and McPeak 1983).

Most projects have relied on transplanting adult kelp plants (sporophytes) to establish a new kelp bed. At Palos Verdes, two methods were used to attach the plants to the substrate (Wilson *et al.* 1979). Some plants were attached to floats that were attached to anchor chains by 0.5-m nylon lines. Smaller plants were secured directly to the substrate with inner tube circlets. Other methods for transplanting adults that have been developed more recently include placing holdfasts in weighted mesh bags (Neushul and Harger 1985).

Although most kelp restoration projects have transplanted adult or juvenile *Macrocystis* plants, earlier life stages can also be used. North (1981) used embryonic *Macrocystis* sporophytes to attempt to establish kelp beds in Southern California, but success could not be demonstrated. Neushul attempted to establish kelp on the

Pitas Point Artificial Reef by spraying the reef boulders with a solution containing kelp gametophytes before the boulders were placed in the water, but the boulders were apparently too hot when gametophyte solution was applied and no kelp plants were produced (J. Benson, *personal communication*). Microscopic sporophytes were outplanted as part of the effort to establish a kelp bed in the LA Harbor (Rice 1983). As with most restoration attempts, outplants using early life stages have not had suitable controls, so although adult plants did grow in the harbor, it is not possible to know whether they can be attributed to this technique.

9.2.3 Costs

The cost of creating a new kelp bed depends, of course, on the techniques and intensity used to establish the kelp. When the new kelp bed is created as mitigation for ongoing impacts, as in the case of SONGS, efforts should be made to establish the bed as soon as possible in order to minimize the net loss of resources. Such an effort would be labor intensive; even on a small scale, such as with PAR, it could cost hundreds of thousands of dollars. For a large-scale mitigation project, the cost of actively creating a kelp bed would probably be several million dollars.

The MRC has recommended that a kelp bed be created on a 120-ha artificial reef (Section 8.3.3.1). A low-relief reef this size would cost about $9 million (Section 8.3.4), in addition to the cost of actively creating a kelp bed.

9.3 Summary

The techniques used to transplant giant kelp are well-established, so there is little doubt that a kelp bed can be established over the short term. However, very few new, self-sustaining kelp beds have been created in Southern California, despite all the artificial reefs that have been constructed and all the attempts to establish kelp on artificial structures. Thus, any attempt to create a new kelp bed as mitigation must recognize that there is considerable uncertainty involved. The problem is not whether kelp will grow on artificial reefs--we know that it will. Rather, the problem is how much certainty we can have that kelp will grow on a particular reef constructed for mitigation. We know enough to provide general guidelines, but there remains too much uncertainty to be confident about predictions of kelp growth.

Previous attempts to establish kelp beds have not incorporated experimental designs that would help evaluate success or failure, so cause(s) of the failures cannot be determined. Nonetheless, an evaluation of these previous attempts provides some insight into the important factors influencing kelp bed creation. Most artificial reefs (which were not designed to have kelp) have been placed too deep for *Macrocystis*. They have been placed in turbid water (e.g., Santa Monica Bay). Most artificial reefs are small and isolated, which limits the natural dispersal of *Macrocystis* to the reef and might exacerbate the grazing problem (because herbivorous fish concentrate on the reef and macroalgae is not available nearby). These conditions have probably contributed to the absence of kelp on artificial reefs, and should be avoided in future attempts to create kelp beds.

Despite limited success in the past, it should be possible to create a persistent, self-sustaining kelp bed under the proper conditions. Foster and Schiel (1985) note that timing of placement, proximity to natural kelp stands, and physical relief appear to be particularly important for the rapid development of a kelp forest on an artificial reef. They also suggest that reefs should be "seeded" with *Macrocystis* spores soon after placement, and may have to be manipulated at various times (e.g., remove grazers or sessile organisms). Placing an artificial reef adjacent to an existing kelp bed would provide two important benefits. First, such a location would be likely to have the oceanographic conditions necessary for kelp growth and reproduction (e.g., adequate light, nutrients, and protection from storms). Second, the natural kelp bed would provide a source of spores as well as biomass for herbivorous fish. In addition, if the new kelp bed is created in the vicinity of the San Onofre Kelp Bed, the new kelp bed resources would be close to the lost resources (i.e., it would be nearly on-site mitigation).

As with artificial reefs, it is necessary to determine the type of kelp bed that must be created in order to achieve 100% compensation of lost kelp resources. Two variables could affect the size of kelp bed needed: the density of kelp and the size of the bed. If the loss of kelp plants is to be mitigated by a one-for-one replacement of plants, it would theoretically be possible to create a smaller, but more dense, kelp bed. However, the processes that determine the density of kelp at a site are very complex (see Technical Report K), and one could not be certain that kelp densities would remain high over the long term. Furthermore, the area covered by kelp may be more important for the organisms that live in kelp beds than the number of plants. Therefore, it would be most appropriate to base the decision about complete compensation on the size of the bed.

In many areas, including the region around San Onofre, the availability of suitable hard substrate seems to limit the size of kelp beds. However, not all available natural substrate is covered with kelp, so the area covered by rock would have to be larger than the area of kelp needed. There is also uncertainty about how much of a reef designed and built by man will be suitable for kelp, and whether the kelp community on an artificial reef would be as productive or diverse as a natural community. Finally, there remains some uncertainty about being able to create a self-sustaining kelp bed, as discussed in this chapter, even though I have concluded that a properly designed and located reef has a good chance of developing a kelp bed. These considerations indicate that an artificial reef would need to be larger than the area covered by the lost kelp resources in order to be reasonably certain of providing adequate compensation.

There are no scientific data that can be used to determine how large the artificial reef needs to be. Rather, the size of the reef must reflect a judgement about the importance of the various uncertainties involved. The MRC decided that a 1.5:1 ratio would be appropriate for SONGS (see Appendix D). Since the estimated loss of kelp bed area is 80 ha, the recommended mitigation reef size is 120 ha.

CHAPTER 10

RESTORATION OF COASTAL WETLANDS

The San Onofre Nuclear Generating Station will not have any direct effects on wetland habitats. However, wetland restoration could provide in-kind replacement for some fish species impacted by SONGS that utilize coastal wetlands. Except for these fish species, wetland restoration would constitute out-of-kind mitigation for SONGS' impacts.

In this chapter, I review the general value of wetlands, particularly in Southern California, and discuss how wetlands could provide in-kind or out-of-kind compensation with respect to the losses resulting from the operation of SONGS. I also examine some of the necessary steps for completion of a successful wetland restoration project, and discuss the potential for wetland restoration in Southern California.

The major conclusions of this chapter are: Coastal wetlands are valuable habitats, and there is a major effort by state and federal agencies to restore degraded wetlands in Southern California. Wetland restoration could provide in-kind mitigation for a few species at risk at SONGS, but for the most part it would constitute out-of-kind mitigation. As out-of-kind mitigation, a restored wetland would produce marine resources, including fish; it could also provide important habitats for endangered species and migratory birds and valuable aesthetic and educational resources. Because restoration plans have already been made for most wetlands, it may be difficult to find an appropriate wetland that could be restored as mitigation for SONGS' effects. The portion of the Huntington Beach Wetland owned by Southern California Edison is one alternative; although restoration of this wetland is technically possible, a number of obstacles would have to be overcome before it could be applied as mitigation for SONGS, including determining the amount of credit to be assigned for the restoration.

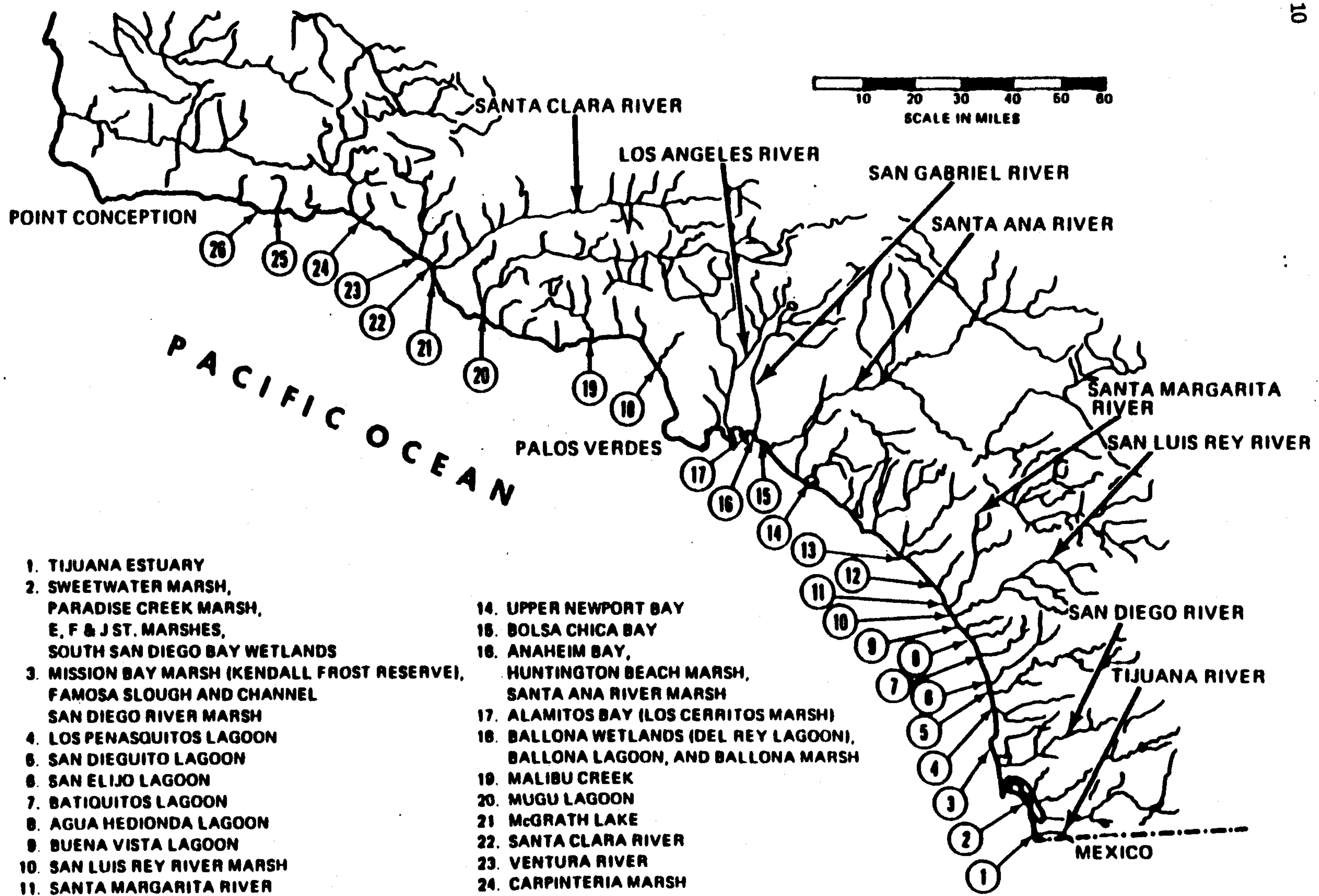
10.1 Value and use of coastal wetlands in Southern California

The value of wetland habitats stems in part from the functions they provide, which include (Adamus and Stockwell 1983): (1) *Hydrologic functions*, including flood reduction, shoreline stabilization and groundwater recharge. For example, wetlands can function as holding basins that control flooding during storms and reduce erosion from runoff by temporarily storing surface water, and root systems of the marsh vegetation tend to bind sediments and retard erosion (Thayer *et al.* 1978). (2) *Water quality improvement* from sediment accretion and nutrient uptake. As runoff water passes through coastal wetlands, current flow slows and sediments are deposited, thus increasing water quality. Water quality is also improved by the removal of nutrients through physical processes such as settling, absorption, filtration, and chemical processes such as chemical precipitation, chelation, and exchange reactions (Bourne and Wolfgang 1983). (3) *Food chain support* from the provision of habitat and food, especially for commercially important fish and shellfish. In general, estuaries and marshes are among the most productive marine systems because of the addition of primary organic material from vascular plants (Thayer *et al.* 1978). Coastal wetlands are an interface between marine and terrestrial environments and typically provide a wide variety of microhabitats that range from emergent vegetation to tidal creeks and channels.

The extent of coastal wetlands in California is very limited (Figure 10-1). Before 1900, there were about 380,000 acres of salt marshes, mudflats, bays, lagoons, sloughs and estuaries along the California coast. Only about 105,000 acres of wetland remain. The loss in Southern California has been greatest; less than 25% of the acreage present in 1900 remains today (USFWS 1979, reported in Sorensen and Gates 1983). More than 60% of the coastal wetlands remaining in the state have been severely degraded (California Coastal Zone Conservation Commission 1975) and Southern California's share of undisturbed wetland is very small (Onuf *et al.* 1978).

In contrast to the broad coastal plains elsewhere in the United States, coastal wetlands in Southern California are small and discrete and are confined to narrow river valleys that are separated by coastal hills and mountains (Zedler 1982). Additionally, the semi-arid climate produces hypersaline soils, which are stressful to vascular plants (Zedler 1983). Since California's coastal wetlands differ from wetlands in other parts of the country, they may be valuable for different reasons than those cited for wetlands in general. For example, estimates from Mugu Lagoon in Southern California indicate that productivity is low compared to wetland areas on the Atlantic and Gulf Coasts of the United States (Onuf *et al.* 1978). Onuf *et al.* (1978) suggest that the critical values of Central and Southern California coastal wetlands derive from their rarity rather than from any exceptional richness of the systems. Southern California wetlands are very important as habitats and feeding grounds for endangered wildlife and migrating birds (Boland 1981). In addition, they are valuable educational and aesthetic resources because they are open space, usually close to urban areas, that has abundant wildlife.

Figure 10-1: Location of Southern California coastal wetlands and major rivers.



1. TIJUANA ESTUARY
2. SWEETWATER MARSH,
   PARADISE CREEK MARSH,
   E, F & J ST. MARSHES,
   SOUTH SAN DIEGO BAY WETLANDS
3. MISSION BAY MARSH (KENDALL FROST RESERVE),
   FAMOSA SLOUGH AND CHANNEL
   SAN DIEGO RIVER MARSH
4. LOS PENASQUITOS LAGOON
5. SAN DIEGUITO LAGOON
6. SAN ELIJO LAGOON
7. BATIQUITOS LAGOON
8. AGUA HEDIONDA LAGOON
9. BUENA VISTA LAGOON
10. SAN LUIS REY RIVER MARSH
11. SANTA MARGARITA RIVER
12. LAS FLORES MARSH
13. SAN MATEO MARSH
14. UPPER NEWPORT BAY
15. BOLSA CHICA BAY
16. ANAHEIM BAY,
    HUNTINGTON BEACH MARSH,
    SANTA ANA RIVER MARSH
17. ALAMITOS BAY (LOS CERRITOS MARSH)
18. BALLONA WETLANDS (DEL REY LAGOON),
    BALLONA LAGOON, AND BALLONA MARSH
19. MALIBU CREEK
20. MUGU LAGOON
21 McGRATH LAKE
22. SANTA CLARA RIVER
23. VENTURA RIVER
24. CARPINTERIA MARSH
25. GOLETA SLOUGH
26. DEVERAUX LAGOON

Southern California bays, estuaries, marshes and tidal creeks and channels are utilized by a variety of fish species (Table 10-1). The most abundant species include topsmelt, arrow gobies, California killifish, shiner perch, diamond turbot, striped mullet, and Pacific staghorn sculpin. There have been few estimates of the densities of fish in Southern California coastal wetlands, but Allen (1982) estimates a total biomass density of about 75 kg/ha in Upper Newport Bay. (For comparison, the biomass density of benthic fish on natural reefs sampled by Ambrose [1987a] ranged from 86 to 921 kg/ha, with a mean of 327 kg/ha [N = 16 reefs].) A few of the species that utilize wetlands, such as California halibut and shiner perch, are valuable commercial or sport fish species. However, the primary contribution of California coastal wetlands to fishery values seems to be the provision of food to higher trophic levels, including terns, herons and other fishes (Zedler and Nordby 1986).

Most of the fish species that are found in Southern California wetlands are not strictly wetland-dependent. Many fish species school close to shore, and young fish may be swept into lagoons and tidal channels with the incoming tide (Onuf *et al.* 1978). Although these fish may benefit from faster growth rates and a lower risk of predation in estuaries, they would almost certainly survive if they could not utilize estuaries (Lenanton and Potter 1987). However, there are some fish that are truly dependent on wetlands. Species such as the arrow, shadow, and cheekspot gobies and the longjaw mudsucker spend most of their lives within wetland habitats. Wetlands also appear to be essential nursery grounds for California halibut. Recent work, including studies commissioned by the Marine Review Committee (Allen *et al.* 1984), has indicated that juvenile halibut are common in bays and lagoons in

Table 10-1

The occurrence of fish species in coastal wetlands in Southern California. Included are species that were sampled at at least two sites or were present as larvae. R indicates rare; C indicates common; A indicates abundant; P indicates present; – indicates not caught in samples. ^{j} indicates juveniles; ^{l} indicates larvae; ^{r} indicates resident; ^{n} indicates nursery.

COMMON NAME	MUGU LAGOON[1,2]	COLORADO LAGOON[3]	ANAHEIM BAY[4]	UPPER NEWPORT BAY[5]	TIJUANA ESTUARY[6]
topsmelt	A^{nj}	A	A^j	A	A
specklefin midshipman	–	–	C^j	–	R
bay blenny	R	–	–	–	C
California halibut	C^{nj}	–	C^{jn}	–	A
Pacific sardine	–	–	–	–	P^l
Pacific staghorn sculpin	C^{nj}	C	C	R	A
California tounguefish	C^j	–	R	–	R
California killifish	C^{nj}	C	C	A	A
barred surfperch	–	–	–	–	R
pile surfperch	–	R	C	–	–
walleye surfperch	–	–	R	–	R
black perch	R^j	R	–	–	–
shiner perch	A^{nj}	C	C^j	C	R
deepbody anchovy	–	R	C^j	C	C
slough anchovy	–	C	–	C	C
northern anchovy	R^j	C	R	R	P^l
arrow goby	–	–	A^r	C	A
longjaw mudsucker	C^{nj}	–	C^r	C	C
cheekspot goby	–	–	R^r	R	C
shadow goby	R^j	R	C^r	R	C
opaleye	R^j	–	–	–	C
striped mullet	–	R	–	R	A
diamond turbot	C^{nj}	–	C	R	A
spotted turbot	–	–	–	–	A
hornyhead turbot	–	–	–	–	P^l
spotfin croaker	–	–	C	–	–
white croaker	C^j	–	R	–	R
California corbina	–	–	C	–	R
queenfish	R^j	–	R^j	–	P^l
Pacific mackerel	–	–	–	–	P^l
kelp bass	R^j	–	–	–	R
spotted sandbass	–	R	R	–	C
barred sandbass	R^j	–	R^j	–	C
California barracuda	–	–	–	–	P^l
bay pipefish	C^{nj}	–	R	R	R
speckled sanddab	C^j	–	R	–	–
grunion	–	C	–	R	–

[1] Onuf and Quammen 1983; [2] Onuf *et al.* 1978; [3] Allen and Horn 1975; [4] Klingbeil *et al.* 1975; [5] Allen 1982; [6] Zedler and Nordby 1986

Southern California, but extremely rare along the open coast (see also Kramer and Hunter 1987).

A rich and productive assemblage of invertebrates occurs in the soft-bottom habitat of Southern California wetlands. Combining data from a number of studies, Zedler and Norby (1986) report that more than 75 species of invertebrates occurred in the Tijuana Estuary. The most common benthic invertebrates in wetlands include bivalves, polychaete worms, gastropods, and decapod crustaceans. Onuf (1987) sampled invertebrates in many different habitats in Mugu Lagoon; his data, summarized in Table 10-2, indicates an average benthic invertebrate density of about 1500/m^2. Although small gastropods were not abundant in Onuf's samples, they can reach extremely high densities in some habitats; for example, *Assiminea californica* and *Cerithidea californica* can each reach densities of 1000/m^2 or more in coastal marshes (Zedler 1982). As would be expected, the composition of the invertebrate assemblage varies among wetlands; for example, densities of common invertebrates in Mugu Lagoon and Tijuana Estuary are given in Table 10-3. Benthic invertebrates are an important source of food for birds that use wetlands.

Table 10-2

Abundance of benthic invertebrates in the eastern arm of Mugu Lagoon. Mean densities are for all transects reported by Onuf (1987) for 1977. Taxonomic categories after Onuf; individual taxa are presented in Onuf (1987).

TAXON	MEAN DENSITY (NO./M^2)
Large worm-like	470
Small worm-like	516
Large gastropod	22
Small gastropod	185
Bivalves	175
Large crustaceans	112
Small crustaceans	74
Sand dollars	2
TOTAL	1556

Table 10-3

Abundance of most common benthic invertebrates at Mugu Lagoon and Tijuana Estuary (from Peterson 1975).

SPECIES	COMMON NAME	DENSITY (NO./M^2)	
		MUGU LAGOON	TIJUANA ESTUARY
Bivalves			
Cryptomya californica	False mya	273	2
Protothaca staminea	Littleneck clam	59	35
Sanguinolaria nuttalli	Purple-hinged clam	47	76
Tagelus californianus	Jacknife clam	9	14
Decapod crustaceans			
Callianassa californiensis	Ghost shrimp	88	3
Echinoderms			
Dendraster excentricus	Sand dollar	37	23
All others		35	31
	TOTAL	547	184

10.2 Potential application at SONGS

10.2.1 In-kind replacement of resources

A number of fish species are at risk at SONGS. Since wetlands provide habitats for fish, wetland restoration could potentially furnish in-kind replacement of fish losses at SONGS. However, many of the species that are likely to incur the greatest losses, such as queenfish and kelpfish, are not abundant in coastal wetlands.

Most of the commercial or sport fish species that are at risk at SONGS, such as California corbina, kelp bass and yellowfin croaker, are also rarely found in wetlands. Nonetheless, some of the species at risk at SONGS (Table 10-4), including the arrow goby and diamond turbot, are often abundant in coastal wetlands. Out of 27 species identified in Table 10-4 as being impacted by SONGS, 15 are reported to occur in wetlands. Seven of the 15 species can be common in wetlands, and three species (arrow goby, diamond turbot and topsmelt) can be abundant. Restoration of wetlands could provide in-kind replacement for these species.

Wetlands also provide habitats for numerous species of marine invertebrates and some algae (Zedler 1982). However, there is little possibility of providing in-kind replacement of invertebrates and algae impacted by SONGS. In contrast to fish, which are highly mobile during their lifetimes and can utilize wetlands during one life stage, benthic invertebrates and plants have limited mobility after settlement and have specialized habitat requirements. Wetland conditions are unique, and the invertebrates and algae impacted by SONGS generally do not occur in those conditions.

Thus, restoring a coastal wetland would provide some in-kind replacement value, but most of the species of invertebrates, algae, and fish that are impacted by SONGS do not occur in wetlands. A few of the fish species that are impacted by SONGS are abundant in wetlands; however, these species have relatively low economic value or are likely to experience relatively minor impacts from SONGS. Some of the species that are common in wetlands, such as northern anchovy and white croaker, are not wetland-dependent, and it is not clear that restoring a wetland would enhance their populations.

Table 10-4

List of species of fish that are at risk at SONGS and/or occur in Southern California coastal wetlands. ^{C} indicates common and ^{A} indicates abundant, based on abundances in the five wetlands summarized in Table 10-1.

SPECIES	SPECIES AT RISK AT SONGS			SPECIES FOUND IN COASTAL WETLANDS
	INPLANT LOSS OF EGGS, LARVAE & JUVENILES	INPLANT LOSS OF JUVENILES & ADULTS	LOSS IN KELP BEDS	
queenfish	X	X		X
white croaker	X	X		X^C
kelpfish spp.	X		X	
California grunion	X	X		X^C
black croaker	X	X		
California corbina	X	X		X^C
cheekspot goby	X			X^C
reef finspot	X			
arrow goby	X			X^A
jacksmelt	X	X		
shadow goby	X			X^C
diamond turbot	X			X^A
California clingfish	X			
northern anchovy		X		X^C
Pacific butterfish		X		
walleye surfperch		X		X
yellowfin croaker		X		
white seaperch		X		
salema		X		
barred sand bass		X	X	X^C
kelp bass		X		X
spotfin croaker		X		X
topsmelt		X		X^A
Pacific electric eel		X		
black perch			X	X
rainbow perch			X	
California sheephead			X	

10.2.2 Out-of-kind substitution of resources

Wetland restoration could be used as out-of-kind mitigation for the effects of SONGS. Although resource agencies prefer in-kind replacement of lost resources to out-of-kind replacement (USFWS 1981, Ambrose 1986b), out-of-kind mitigation can be considered when no feasible method for in-kind replacement exists, or when the lost resources are abundant elsewhere in the region and the substituted resources are rare and valuable (Grenell 1988). Both of these criteria apply to wetland restoration. Although both an artificial reef and a restored wetland would provide a limited amount of in-kind replacement of fish losses, for the most part there is no feasible method for producing mid-water fish. Furthermore, the most-impacted species, queenfish and white croaker, are abundant throughout the Southern California Bight, whereas coastal wetlands are rare and valuable habitats in Southern California.

Southern California wetlands clearly have exceptional value. As noted by Onuf *et al.* (1978), much of their value comes from their rarity. California coastal wetlands are important habitats for many endangered species. Fourteen of the species that use coastal wetlands are listed as rare or endangered by the federal and/or state government, including the Aleutian Canada goose, American peregrine falcon, Bald eagle, California least tern, California and Light-footed clapper rails, California black rail, California brown pelican, Santa Barbara sparrow, Belding's savannah sparrow, salt marsh harvest mouse, Morro Bay kangaroo rat, Santa Cruz long-toed salamander, and the San Francisco garter snake (USFWS 1979, National Audobon Society 1986). Three of the endangered bird species are residents in

Southern California salt marshes. The Light-footed clapper rail builds floatable nests out of cordgrass in the low intertidal marsh, Belding's savannah sparrow nests in pickleweed dominated midmarsh areas, and the California least tern nests in coastal dunes and feeds in marshes (Zedler 1987). In addition, an endangered plant species, the saltmarsh bird's beak, grows only in a narrow zone at the upper limit of tidal influence in salt marshes (Zedler 1982).

California's coastal wetlands provide important wintering habitat for migratory birds. Approximately five percent of the waterfowl population in the Pacific Flyway inhabit California coastal wetlands during the mid-winter and almost 100 percent of the population of Canvasback ducks and Brant and Aleutian geese use the wetlands at some time during their annual migrations. Coastal wetlands are also used as staging areas for migratory birds enroute to and from wintering grounds in the Central Valley, Mexico, and Central and South America (National Audubon Society 1986).

Southern California coastal wetlands also provide significant values that are not directly tied to natural resources. Because they furnish open space with abundant wildlife, wetlands are valuable aesthetic and educational resources. In Southern California, wetlands are important as open space because most are surrounded by densely populated urban areas. A number of proposed wetland restoration projects in Southern California (for example, the Ballona Wetland restoration plan, National Audubon Society 1986) include programs for public access and educational centers. Coastal wetland areas are also important research sites. The impacts of disturbance on wetland functions are not clearly understood and the criteria for determining the success of wetland restoration projects based on wetland functions are not yet established. Coastal wetlands are a diminishing resource in the United States and there is an immediate need for continued research to address these problems (Zedler 1983).

10.3 Successful coastal wetland restoration

Two factors that are important in promoting the success of any wetland restoration project are the design of the restoration and the monitoring program.

The success of past wetland restoration projects is difficult to evaluate because in most cases the objectives of the restoration plans were not clearly outlined and the projects were not monitored after the permitting process was completed (Josselyn and Buchholz 1982, Race and Christie 1982, Quammen 1986, 1988). There have been a number of reviews of restoration projects in California and the conclusions about the number of successes are variable, often because the criteria used to judge success differ (Race 1985, Harvey and Josselyn 1986, Race 1986, Quammen 1986, 1988, San Francisco Bay Conservation and Development Commission 1988). Few studies have addressed the question of how effectively the restored wetlands replaced the lost functions and habitats of destroyed or degraded sites (Quammen 1988, Zedler *et al.* 1988).

10.3.1 Designing wetland restoration projects

Before a successful wetland restoration project can be designed, the goals of the project should be clearly identified. The success of local projects, particularly those that encompass small areas, will be enhanced if regional plans have already been developed to identify the habitats and functions that are most important in the ecoregion. Los Angeles and Orange counties have developed a regional plan that stresses the importance of preserving the region's present wetlands and their value, and increasing habitats for endangered species. It also outlines site-specific goals and guidelines for the design of restoration projects (State Coastal Conservancy 1982).

There are a number of important factors to consider when developing the design of a restoration project. These have been outlined in detail elsewhere (Williams and Harvey 1983, Zedler 1984) and only a few of them are mentioned here.

Once regional goals have been established, the plan for a specific site should not propose to fulfill all the regional goals but should capitalize on those that are natural attributes of the site (Zedler 1984). Therefore, before a site plan is developed, the site should be carefully sampled to determine existing resources and wetland functions. This is particularly important not only for development of the plan but also for subsequent determination of the success of the project. Specific species, groups of species or wetland functions should be targeted for enhancement so that the design can incorporate the proper mix of habitat types to maximize resource values. For example, the design of a wetland restoration to be used as in-kind mitigation for fish losses at SONGS should maximize the amount of fish habitat (e.g., tidal creeks, channels and ponds).

Particular attention should be paid to the topography of the restoration site. The period and depth of tidal inundation are major factors determining the distribution of wetland organisms and are greatly influenced by topography (Williams and Harvey 1983). Small changes in elevation (0.5 to 1.0 foot) can have important effects on plant communities (Zedler 1984). Other factors affecting hydrology are also important. In Southern California rainfall is very seasonal and large inputs of fresh water can occur over a short period of time, with little fresh water input during the rest of the year. As a result, tidal circulation is extremely important to coastal marshes (Zedler 1982, Zedler *et al.* 1986).

The potential for sedimentation at the restored site should also be carefully considered. Wetlands are natural sediment sinks (Zedler 1982). Natural sedimentation can be used to create mudflats that will, in time, be invaded by marsh vegetation (Williams and Harvey 1983). However, sedimentation can also fill in tidal creeks, channels and pools. If channels are dredged during restoration, they may require subsequent dredging to be maintained. An additional problem can arise if dredge spoils are left on the wetland site. Few species are tolerant of the extreme salinity of the dredge spoils and they often remain unvegetated for years (Zedler 1984).

Another important design consideration is a buffer zone that will separate the environmentally sensitive wetland habitat from the surrounding area. Buffer zones are particularly important in urban areas because they restrict public access and can protect wetland species from impacts of unnatural surroundings (Sorensen and Gates 1983, Zedler 1984). The additional open space provides wetland wildlife with habitat that can serve as a refuge during peak flooding periods.

10.3.2 Monitoring wetland restoration projects

The success of wetland restoration projects cannot be determined unless they are carefully monitored. In the past, monitoring of restorations for mitigation was rarely required as a part of the permit requirements (San Francisco Bay Conservation and Development Commission 1988). Monitoring requires a long-term, well-designed study that must be started before the restoration begins and compared to reference sites (Quammen 1986, 1988, Zedler *et al.* 1988). It is important that quantitative data be collected before restoration using the same methods and sites, and over a sufficiently long period of time, so that a statistically and ecologically meaningful comparison can be made with post-restoration data.

Monitoring studies must be long-term because coastal marshes are dynamic systems and natural disturbances are common (Zedler *et al.* 1986). A monitoring program must continue for several years to determine the response of the community to a wide range of environmental conditions that can vary seasonally and among years. High annual variability in community characteristics may be the rule and data from many years may be necessary to determine "average states" (Zedler *et al.* 1988). If vegetation is planted, or new species are introduced or encouraged to recruit to the site, it may take years to determine if they will successfully reproduce and if populations will become self-sustaining (Zedler *et al.* 1988). Many current wetland restoration proposals in California require a 5 year monitoring period (R. Holderman, California State Coastal Conservancy, *personal communication*).

Sampling at the restoration site should occur at least once a year to determine annual variability. However, different species or functions may have to be monitored at different times during the year if they are influenced by factors that vary seasonally. If monitoring occurs at least annually, problems such as the invasion of exotic species can be corrected.

A monitoring program should not focus on only a few of the most visible wetland characteristics (such as dominant vegetation or endangered species), but must sample a wide range of ecosystem attributes. The list of characteristics to be monitored should include those that are important indicators of ecosystem function, as well as those that the public views as important assets (Zedler 1984). For example, data should be collected on characteristics of hydrology, topography, soils, nutrient dynamics, algae, vascular plants and consumers at the restoration site (Zedler *et al.* 1988).

10.3.3 Determining the success of a restoration project

Evaluating the success of a wetland restoration project is currently highly controversial (references in Zedler *et al.* 1988). The determination of what constitutes a "success" will depend on the project objectives, the criteria used for evaluation, and the reference sites used for comparisons. Projects should be considered successful if the restored wetland shows a high potential for achieving natural functional attributes (Zedler *et al.* 1988).

Zedler *et al.* (1988) have developed a list of functions of Southern California salt marshes that should be assessed to determine the similarities between the restored marsh and natural, undisturbed, "reference" marshes. In particular, they have allowed wetland restoration to be used as mitigation for Port development projects. Because of the high demand, most suitable wetlands have already been claimed, and land ownership is a major factor in determining the feasibility of using wetland restoration for mitigation.

10.4.1 Availability of wetlands

Because wetlands are in high demand in Southern California, the availability of a particular wetland can change rapidly depending on recent political or commercial events. Wetlands that could potentially be available for restoration as mitigation for SONGS' impacts include the Ballona Wetland, San Dieguito Lagoon, San Diego Bay Salt Works, and the Tijuana Estuary; however, the availability of these wetlands is far from certain. It is also possible that unanticipated events will make other wetlands available in the future. Nonetheless, there is only one wetland that would certainly be available to SCE for restoration, the Huntington Beach Wetland.

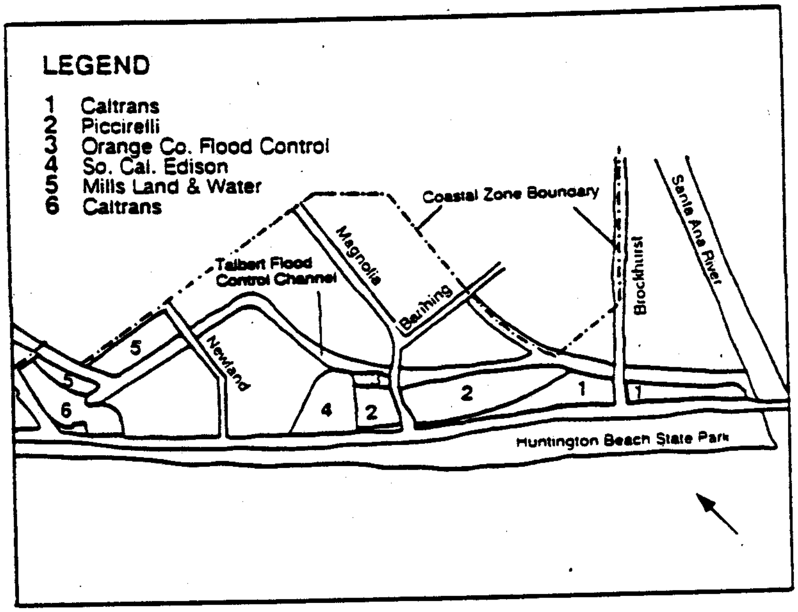
The factor of land ownership favors the Huntington Beach Wetland as the most likely wetland to restore as mitigation for SONGS' effects. The Huntington Beach Wetland was once part of an extensive wetland system that covered more than 2950 acres. Most of the system was destroyed by development and agriculture, but 115 acres remain in the Huntington Beach area (Coats *et al.* 1987). A plan to restore a 25-acre site in the remaining degraded wetland was developed through the combined efforts of the California State Coastal Conservancy, the City of Huntington Beach, the Huntington Beach Wetlands Conservancy, and the owners of the property (Coats *et al.* 1987, Eliot and Holderman 1988), and the marsh was opened to tidal exchange in February 1989. SCE owns 14 acres of land in the degraded Huntington Beach Wetland that had not yet been committed to any particular use, and which could potentially be restored for use in mitigation.

The wetland area that includes the 25-acre restoration site and the property owned by SCE is bounded by the Talbert Channel on the northeast and east, and the Pacific Coast Highway on the southwest (Figure 10-2); privately owned land separates the 25-acre parcel from SCE's land. Three city streets pass through the area. A high levee separates the wetland from the Talbert Channel and there is currently no surface tidal flow into SCE's property. The wetland character of the site is maintained by periodic fresh water runoff and the tidal and seasonal fluctuations of the local water table. However, wetland functions are degraded compared to functions in the salt marshes of the historic wetland area when it was linked to the ocean by tidal flushing (Coats *et al.* 1987).

Pickleweed is the dominant plant in the wetland area. Other wetland species found at the site include sickle grass, cattail, alkali bulrush, widgeon grass and fleshy jaumea. Few species of water birds are able to use the site in its present condition. Only a few ducks, shorebirds and herons have been seen during the winter. None of the three endangered bird species that are often found in Southern California coastal wetlands, the California least tern, Light-footed clapper rail and Belding's savannah sparrow, has been observed in the wetland in its present condition (Coats *et al.* 1987). There is no open water habitat on the SCE property in the summer months (*personal observation*). Most of the vegetation on the site is coastal salt marsh (Figure 10-3). However, much of the salt marsh area is covered with roads and tire tracks (Figure 10-4). Furthermore, about half of SCE's property is salt flat,

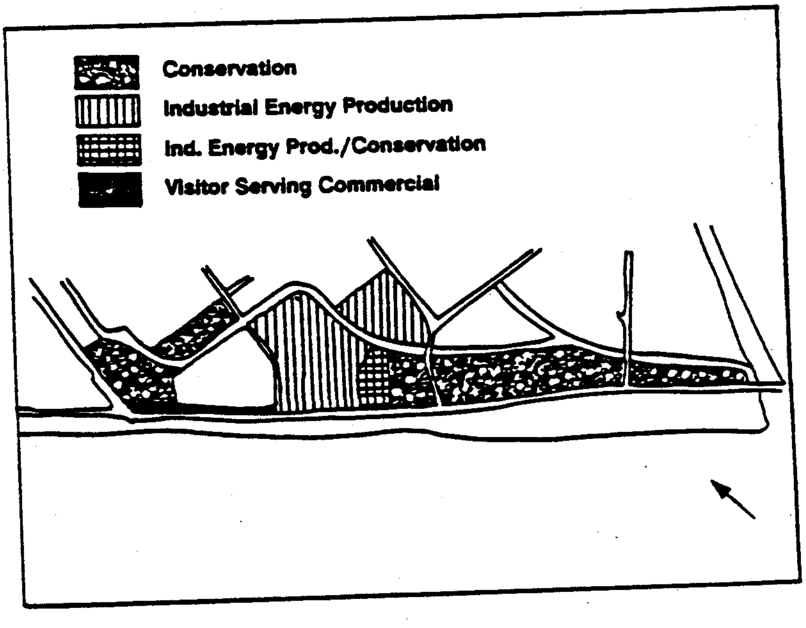
Figure 10-2

A.



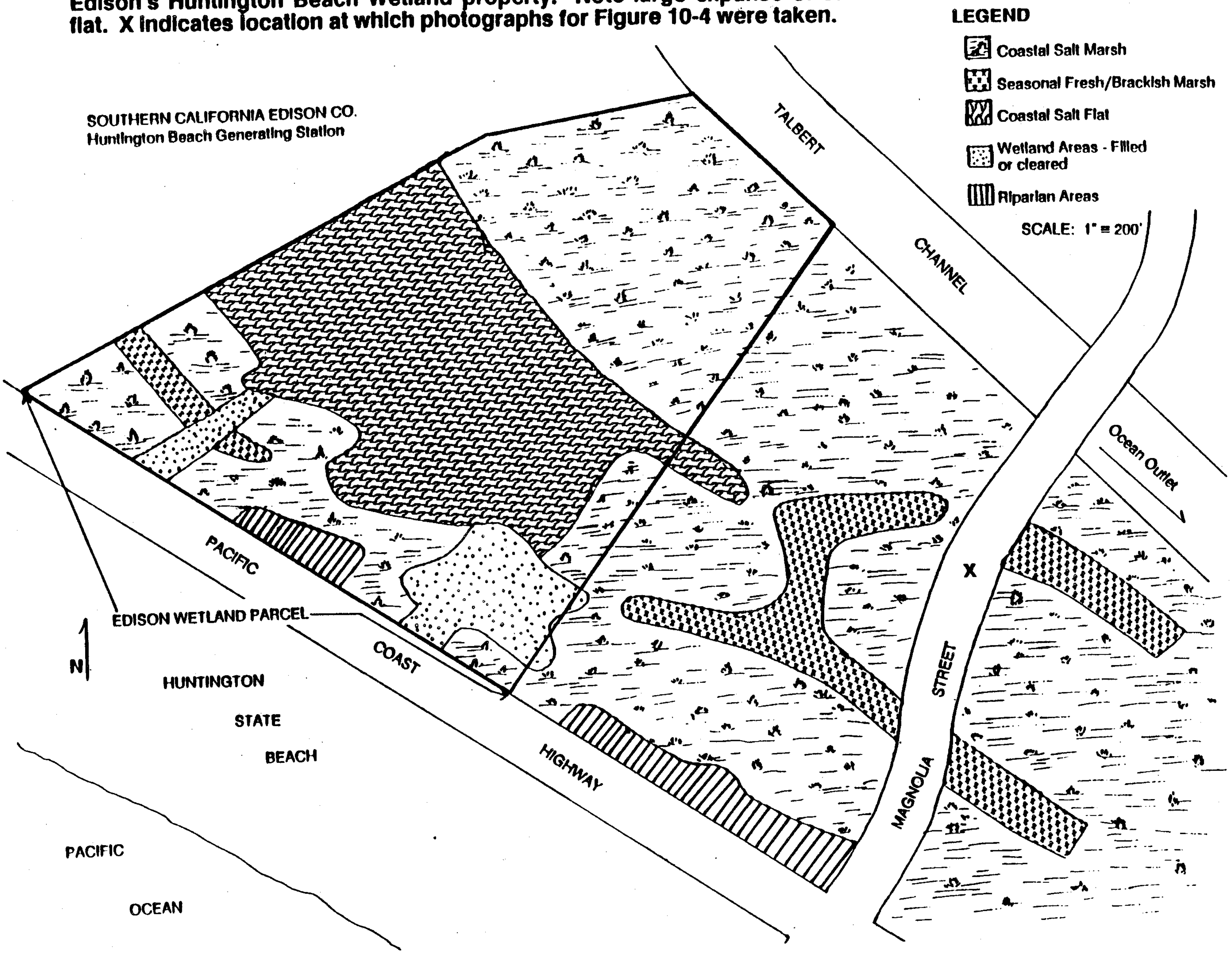
A. Huntington Beach Wetland: ownership. Ownership of the Huntington Beach Wetland is divided among public and private owners.

B.



B. Certified Land Use Plan. The coastal land use plan of the city of Huntington Beach was approved by the Coastal Commission on October 8, 1986, and provides protection for 147 acres of wetland.

Figure 10-3: Distribution of vegetation types on Southern California Edison's Huntington Beach Wetland property. Note large expanse of salt flat. X indicates location at which photographs for Figure 10-4 were taken.



with virtually no vegetation (Figure 10-3). It is clear that the value of the wetland is low compared to what it would be if it was restored.

Before restoration, the channel system in the 25-acre restoration site also dried up by mid-summer during low tide, although one moderately deep pool retained water and supported a few fish. During a five-month period in 1979, when culverts were installed to open the restoration site to tidal flushing, the area was reportedly a productive wetland. Ponds, which were sampled by the California Department of Fish and Game at that time, contained opaleye, kelp bass, California halibut, topsmelt, shiner surfperch, staghorn sculpin, California killifish, and yellowfin goby. (No data are available on the abundance of these species.) The channels also contained dense clam beds (Coats *et al.* 1987).

The 25-acre site was restored in February 1989 by removing the levee that separated the area from Talbert Channel to restore tidal flow. Existing channels in the marsh were enlarged to increase the area of mudflat and low marsh and create openings into the flood control channel. Several ponds were created to insure that the marsh retains some water during low tide as refugia for resident fish. The restored area should eventually provide habitat for the three endangered bird species, fish and invertebrates; the value of the wetland should be greatly enhanced. Preliminary monitoring results (Gorman *et al.* 1989) indicate that (1) the area is undergoing revegetation with wetland plant species, (2) the diversity of marine invertebrates has increased greatly, (3) both the diversity and the abundance of fish are increasing with time since tidal flushing was restored, (4) the number of bird species and individual birds using the wetlands increased greatly following restoration, and a higher proportion of the birds are wetland rather than upland

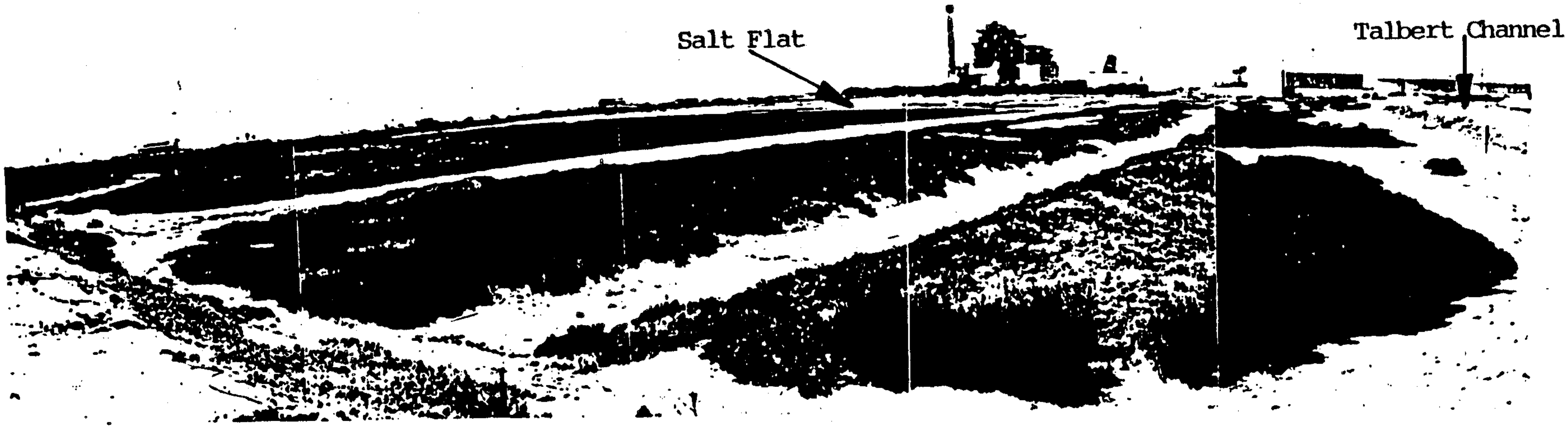


Figure 10-4: Huntington Beach Wetland. View from Magnolia Street looking northwest toward Southern California Edison's power plant (in background). Talbert Channel is to the right in photograph. Photo taken in July 1988. Note the absence of surface tidal flow to SCE's property. Photo by S. Swarbrick.

species, (5) the endangered California least tern has been successfully using the area for foraging, and (6) water quality is near normal. These results indicate that the value of this wetland has already been enhanced. In the future, cordgrass will be planted in the low marsh zone and pickleweed in the middle and high zones, monitoring will continue, and work on displays for an interpretive center will continue (Gorman *et al.* 1989).

Although no restoration plan has been produced for the 14-acre site owned by SCE, its restoration could presumably be similar to that of the 25-acre site. Removing the levee for the Talbert Channel would provide the SCE site with tidal flow. Although the two sites are separated by additional degraded wetland acreage, they would be connected through the flood channel, which would increase the value of both sites. Because the SCE site is so degraded, there is great potential for enhancing its value. If the intent of the restoration is to maximize in-kind mitigation for fish losses at SONGS, then the amount of open water habitat at the SCE site should be maximized. If out-of-kind mitigation is acceptable (or preferable), the restoration plan could be quite similar to the plan for the 25-acre site, with maximum habitat for endangered species.

Although SCE's land in the Huntingtion Beach wetland has the undeniable advantage of already belonging to SCE, its value for mitigating SONGS' effects is limited by several factors. First, it is not clear that SCE's holding is large enough to provide complete compensation for the fish losses caused by SONGS. Of course, SCE might be able to acquire additional land in the wetland, since much of the remaining degraded acreage is privately owned. Second, it may not be able to provide enough open-water habitat. Most of the resources losses that would need to be mitigated by wetland restoration involve fish species; the restoration plan for the 25-acre parcel does not emphasize fish, and it is likely that SCE's parcel also is not ideally suited for providing fish habitat.

If the Huntington Beach wetland is to be restored as mitigation for SONGS' effects, the value of the restoration will be set by the constraints of the site's characteristics, including its size. It would be possible to manipulate the abundance of some types of habitats in order to maximize the habitat value of the site, but it will not be possible to create some habitat types. For example, the amount of standing water on the site could be changed to suit the particular mitigation need, but a relatively deep embayment could not be created. Thus, the challenge is likely to revolve around the questions of (1) the design of the wetland that will produce the maximum resource value that can be obtained on the site, and (2) how much resource loss can be mitigated by that particular restoration design.

Although SCE does not already own land in other potential wetland restoration sites, the restoration of other coastal wetlands could also be an acceptable means of mitigating SONGS' impacts. The San Dieguito Lagoon is larger and contains more open water than the Huntington Beach wetland. Restoration of the San Dieguito Lagoon was until recently considered for mitigating development in the Ports of Long Beach and Los Angeles; however, this proposal was recently rejected by the California Coastal Commission, so it is possible that the lagoon would be available for restoration by SCE. The wetland has an area of about 120 acres, with a water area of about 35 acres. Thus, the San Dieguito Lagoon would be able to provide substantially more resources and resources that are more similar to the impacted resources than the Huntington Beach wetland.

A number of other coastal wetlands, including Ballona Wetland and the Tijuana Estuary, might potentially be considered for restoration. There is already a plan to restore 175 acres of the Ballona Wetland as part of the mitigation for a separate development project (Metz 1988), but it might be possible for SCE to share some of the costs and receive mitigation credit.

10.4.2 Costs

Costs for restoring wetlands vary tremendously, in part depending on the particular goals of the restoration and the pre-existing condition of the wetland, but largely depending on whether the land must be acquired.

The recently completed restoration of 9.7 ha (25 acres) at the Huntington Beach wetland cost $488,000, or $50,000 per ha. The proposed restoration of Bataquitos Lagoon (as mitigation for development in the Ports of Long Beach and Los Angeles) is expected to cost about $15 million for 160 ha, or $94,000 per ha. Restoration costs could be higher if the cost of acquiring the land is unusually high. For example restoring 18 ha in the Huntington Beach wetland might involve purchasing the land for $250,000/ha and restoring the wetland for $55,000/ha, for a total cost of $5.5 million, or $305,000 per ha. If land acquisition costs are higher, then of course the total restoration costs will also be higher.

10.5 Discussion

SONGS has no direct effect on wetland habitats. Wetland restoration could provide in-kind mitigation for species at risk at SONGS that use wetlands during part of their life. In large part, however, restoring a wetland would constitute out-of-kind mitigation. Restoration of wetland habitat as mitigation for SONGS' effects would necessarily be off-site.

Wetland restoration may be an acceptable means of mitigating SONGS' impacts because wetlands are rare and extremely valuable resources in Southern California. However, this method of mitigation presents a number of problems. One potential obstacle, discussed above, is the possibility that a suitable wetland cannot be acquired for restoration. Two additional problems will be discussed here. The first, the use of out-of-kind and off-site mitigation, involves the philosophy of mitigation, while the second, the valuation of dissimilar resources, presents a technical challenge.

10.5.1 Out-of-kind/off-site mitigation

The current mitigation philosophy of federal and California resource agencies deems that out-of-kind, off-site mitigation is generally the least-preferred alternative. This philosophy is based on the argument that overall project impacts will be minimized when mitigation produces resources that are as similar as possible to the lost resources. The acceptance of out-of-kind resources could be risky, especially if the impacted resources are highly valued, rare, and/or subject to substantial cumulative impacts. On the other hand, out-of-kind mitigation can be acceptable for common resources with relatively low resource value (USFWS 1981), such as perhaps mid-water fish.

Off-site mitigation could result in an inequitable geographic distribution of resources. It seems likely that a restored wetland would be far away from SONGS (especially if the Huntington Beach wetland is chosen) and therefore, the impacted area would locally have a net loss in resource values in spite of mitigation. The importance of the distance between the impact and mitigation sites may depend on the specific resources that are being mitigated. For example, for wide-ranging and ubiquitous species, such as the mid-water fish species impacted by SONGS, a shift in the geographic distribution of resources may not be important. But local replacement might be essential for mitigating the loss of important species, such as giant kelp, that are relatively uncommon or patchily distributed in the area of the impact.

With respect to SONGS' impacts, wetland restoration would be used to mitigate fish (primarily mid-water fish) losses. Because, for the most part, the impacted fish are common, have relatively low resource value, and are wide-ranging, and because restoring a wetland would enhance rare and valuable resources, wetland restoration would be an appropriate technique for mitigating SONGS effects.

10.5.2 Value of a restored wetland

Perhaps the largest technical problem inherent in using wetland restoration as mitigation for SONGS' effects arises because the resources are very different. Ideally, an objective, quantifiable method of assigning a value to dissimilar resources should be devised. In the case of SONGS, the resources that are impacted are primarily mid-water fish. (Kelp bed fish, invertebrates associated with kelp beds, and giant kelp are also impacted, but the MRC recommends that these impacts be mitigated using other methods.) Restoring a degraded wetland would provide wetland resources, including associated species of birds, fish and invertebrates. For 100% compensation of lost resources, the value of the lost resources must balance the value of the restoration. (Note that, from the perspective of mitigation bookkeeping, the value of the restoration is the *increase* in wetland resources over the resources present before restoration.) Yet how can these very different types of resources be equated?

There presently is no consensus regarding a technique to be used for valuing resources, especially when the resources are dissimilar. Several methods have been developed for assessing the value of wetland habitats (e.g., HEP, McCollum 1988; Adamus procedure, Adamus and Stockwell 1983), but none is very satisfactory and none is tailored for coastal wetlands in Southern California (Zedler *et al.* 1988). For SONGS, wetland restoration may be most useful for mitigating the loss of mid-water fish, but to our knowledge the value of mid-water fish *per se* has never been assessed. To date, mitigation for projects that adversely affect mid-water fish have focused on providing similar habitat values. For example, a modified HEP procedure was used to determine (1) the value of open-water habitat that would be lost as a result of port development in Los Angeles, and (2) the amount of open-water habitat that would need to be created in Bataquitos Lagoon in order to compensate for this loss. In this case, the development project would result in the loss of mid-water fish habitat rather than directly causing fish mortality, so a habitat-based evaluation could be used. However, SONGS will not cause the loss of mid-water fish habitat, so the values of the mid-water fish themselves will have to be determined.

If wetland restoration is chosen as a technique for mitigating some of the effects of SONGS, it seems likely that determining the amount of credit that should be assigned for a particular restoration project will be difficult and perhaps controversial. The scientific basis for any evaluation methodology has not been developed, so some subjective evaluation will be necessary. (Even the U.S. Fish and Wildlife Service's modified HEP involved the subjective "best professional judgement" of qualified experts.) As Onuf (1985) states, "the determination of the relative values of grossly different kinds of habitat is a matter of interpreting policy, not the application of a method of habitat assessment which assumes that the same resources are at issue."

The MRC has proposed that, depending on the particulars, 30 to 60 ha would adequately mitigate for the loss of fish caused by SONGS. This size was not derived by applying an evaluation methodology because no appropriate methodology exists. Rather, the MRC judged the relative values of two proposed mitigation techniques, artificial reefs and wetland restoration. The MRC has estimated that 60 ha of high-relief artificial reef would adequately mitigate the mid-water fish impacts caused by SONGS (see Appendix D). The MRC judged that, depending on the specific wetland and restoration plan, restoring a wetland would provide from equal value to twice the value of an artificial reef (on a per-ha basis).

The MRC's judgement of the value of a restored wetland compared to an artificial reef is based on a number of factors discussed in this chapter, including the high productivity of coastal wetlands, their important roles as nursery areas for marine fish and feeding grounds for birds, their provision of habitat for rare and endangered species, and their visual and educational value. As one example, we can consider the relative productivity of coastal wetlands and subtidal reefs in Southern California. As noted in Chapter 8, no estimate of fish production is available for Southern California subtidal reefs. However, Allen (1982) has estimated fish production for a coastal wetland (Upper Newport Bay), and compared production in this wetland to a variety of other habitats (Table 10-5). Estimates for two sites, the Newport Bay littoral zone and Mexican coastal lagoon, might be considered indicative of the levels of fish production that could be achieved in a restored wetland in Southern California. These two habitats ranked among the most productive of all habitats, and were much more productive than the purely marine (English Channel and Georges Bank) habitats, which *might* be representative of fish production on a temperate subtidal reef.

There is one final concern about restoring a wetland as mitigation for SONGS' impacts. Wetland restoration has frequently been used as a mitigation technique, and in some respects, the technology of wetland restoration is fully established. There is reasonably little doubt about the ability to modify and superficially improve a wetland. However, recent evaluations of wetland restorations have suggested that they frequently do not achieve their goals, and there is doubt about the ability of these restored wetlands to assume the full functions of a natural wetland. The potential for restoring valuable, degraded wetland resources is appealing, but there is enough uncertainty about the success of wetland restorations that this technique should be applied cautiously, with the realization that it is still experimental.

Table 10-5

Comparison of annual fish production for marine and estuarine habitats. Modified from Allen (1982), where references to the eight original studies can be found. Values are for all species except where noted.

LOCALE AND HABITAT	ESTIMATED ANNUAL PRODUCTION (G DRY WT/M^2)
Delaware salt marsh creek	10.2
Newport Bay littoral zone	9.4
Mexican coastal lagoon	8.6
Cuban freshwater lagoon	6.2
No. Carolina eelgrass beds	4.6
Bermuda Coral Reef	4.3
Texas lagoon (Laguna Madre)	3.8
English Channel pelagic and demersal fishes	1.0
Georges Bank commercial fishes	0.4

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CHAPTER 11

FISH HATCHERIES

11.1. Introduction

A fish hatchery could potentially provide in-kind replacement of lost fish resources by providing juvenile fish that could be released in the wild. The successful use of hatcheries to spawn adults and rear larvae requires a thorough knowledge of the life history characteristics of a species, at least through the juvenile life stage. There must be a reliable source of reproductive adults and the techniques for hatching and rearing larvae must be available. Equally important for successful release of hatchery stock is an understanding of the ecology of juveniles. The questions that need to be answered include: Where do juveniles live? What size should they be when released? What factors influence survival in the juvenile habitat? Is the species recruitment-limited? How can post-release survivorship be maximized?

The major conclusions of this chapter are: Existing (salmon) hatcheries have had limited success in spite of substantial financial costs and extensive studies. The use of hatcheries to enhance marine fish is in an early stage of development, with little known about rearing techniques or the effectiveness of releasing hatchery-reared fish in the wild. Because these and other problems are unlikely to be solved in the near future, a hatchery does not seem like a feasible technique for mitigating SONGS' effects on fish.

11.2 Hatchery case studies

11.2.1. Salmon

The current use of hatcheries to enhance salmon stocks provides a useful model to evaluate the feasibility of hatcheries as a source of recruits to adult populations. Pacific salmonids provide one of the best opportunities for success because they have been studied extensively (see McNeil and Himsworth 1980). Brood stock is readily available and the requirements of the early life stages are known. Salmon species are anadromous; adults migrate from the ocean into coastal streams and rivers to spawn and juveniles return to the ocean, where they mature. Hatcheries are usually located in streams and rivers. Spawning adults are gathered as they move upstream to spawn and, depending on the species, juveniles are released into either streams or lakes (Brannon 1984), where they remain until they return to the ocean.

All nations with major salmon fisheries are currently enhancing salmon stocks (Healey 1980). One of the most ambitious efforts is the Salmonid Enhancement Program (SEP), which was established in response to the steady decline in Pacific salmon stocks and has been operating in British Columbia, Canada, since 1977. However, after 10 years it cannot be clearly demonstrated that the hatchery program is a success. In fact, for one important species, chinook, the program has not been successful, as measured by the size of the commercial coast-wide catch. For example, despite a constant increase in the hatchery production and release of chinook smolts over the past 5 years, the chinook catch in the Georgia strait in 1987 was the lowest in 25 years (Hume 1988). The success of similar salmon enhancement programs in Oregon and Washington states has also been limited (Hume 1988).

The lack of success with many of the hatchery programs for Pacific salmon points out a number of risks associated with the use of hatcheries in general. One potential problem is a reduction in the gene pool of the stock (Department of Fisheries and Oceans 1985). Because hatcheries need fewer spawners than wild stocks to produce relatively large populations, genetic diversity might decline, which could be hazardous if the ability to adapt rapidly to changes in the environment is affected. Since influence of natural selection in the early life stages is probably weaker for hatchery fish than for native fish, hatchery release could swamp the gene pool with the less well adapted genotypes of the released fish. Weaker fish may be produced as a consequence, and ultimately fecundity could decrease and natural mortality could increase. Only long-term observations can establish whether depletion of the gene pool has these detrimental effects (Department of Fisheries and Oceans 1985).

There is also the risk that hatchery stocks will replace rather than supplement natural stocks. Replacement will occur when a stock with a high survival rate is fished at the same time as a stock with a lower survival rate. If fishing quotas are determined by the yield of the stock with the higher rate of survival, the weaker stock is, in effect, overharvested and will decline. The survival of hatchery stocks in the open ocean could be higher than natural stocks if hatchery smolts are larger than natural smolts when they return to the sea. This could easily occur if the growth of natural smolts is food-limited and the growth of hatchery smolts is not. If hatchery fish merely replace natural fish, net benefits will be lost.

The limited success of the hatchery program in Washington has been attributed to the replacement of natural production by hatchery production (Brannon 1984). The extent of stock replacement in the SEP program is presently unknown, but preliminary data suggest that 13% of total SEP production during 1980 to 1984 was replacement of natural stocks (Department of Fisheries and Oceans 1985).

Although the number of hatchery smolts released in British Columbia has increased steadily, increases in adult stocks have not met expectations. This indicates that factors that affect fish after they return to the ocean are important determinants of adult stock size and may reduce the effectiveness of a hatchery program. One possible explanation for the poor chinook catch in Georgia Strait in 1987 is that oceanic conditions were not favorable that year (Hume 1988). During unfavorable years, the resources spent on large scale hatchery production will be wasted if the mortality of smolts is unusually high. This is particularly important if the carrying capacity of the juvenile habitat is reduced during poor years.

Juvenile habitats could become saturated even in years when oceanic conditions are favorable. Production at a large hatchery will be very high. Smolts are often released within a narrow time interval and if they are released from a single site, hatchery fish could exceed the carrying capacity of the juvenile habitat near the release area even in good years.

11.2.2 Marine fish species

Compared to salmon, the use of hatcheries to enhance marine fish stocks is a recent development whose feasibility is just beginning to be evaluated. Two species have been targeted by the California legislature and the Department of Fish and Game for research with regards to establishing a hatchery program: the white seabass, *Astractoscion nobilis*, and the California halibut, *Paralichthys californicus*. These programs are still in their early stages, so there are no data on their effectiveness.

The rearing program for the California halibut has been undertaken jointly by DFG and Southern California Edison at Edison's laboratory in Redondo Beach. Halibut have been successfully reared from egg to post-feeding juveniles (approximately 2 cm long). The techniques for raising larvae have been developed, although there is still some difficulty inducing spawning in adult halibut (K. Herbinson, *personal communication*).

The program for rearing white sea bass is being conducted at Hubbs Research Center in San Diego. The program has been successful at getting two groups of white sea bass to spawn at any desired time, regardless of the normal spawning period. Techniques for collecting and hatching eggs have been worked out, and the program is now experimenting with the effects of different rearing densities and food types (D. Kent, *pers. communication*). Some animals have survived at least two years; work is continuing on estimates of survivorship.

Even if the potential for rearing young marine fish is realized, it is not clear that a hatchery program will satisfactorily compensate for impacts to fish. For example, the bottleneck for California halibut may be the nursery habitat for young-of-year (Allen *et al.* 1985); if so, only a certain number of young halibut will survive no matter how many are released, and a hatchery is not likely to be effective for enhancing the stock.

11.3 Discussion

There are at least two serious technical problems that limit the feasibility of using a fish hatchery as mitigation for fish losses caused by SONGS. First, few marine fish have been raised in a hatchery situation. It seems likely that, given sufficient time and money, nearly all species *could* be raised in a hatchery. However, there are many potential pitfalls with little previous experience to provide guidance, and there is no guarantee that any particular species could be raised within reasonable limits of time and money. Furthermore, replacing fish losses with hatchery production would require a continuous outlay of money for operations and maintenance. Second, little is known about the critical factors limiting many marine fish populations. It is clear that much more information about the life histories of marine fish, the processes underlying the dynamics of the populations and the nature of potential bottlenecks, is necessary before it can be determined whether a hatchery could even *potentially* enhance a population. Blindly restocking a population from a hatchery has a high likelihood of failure.

The possibility of restoring marine fish populations through a fish hatchery is attractive, and hatcheries could one day provide a valuable mitigation technique. However, they do not appear to be feasible at present, and it would be extremely difficult to link the value a hatchery could provide to the resources impacted.

CHAPTER 12

OTHER MITIGATION TECHNIQUES

There are a number of techniques not covered in the preceding five chapters that could be considered for mitigating the impacts of SONGS. None of the three techniques discussed in this chapter are traditional, in the sense that they are consistent with the FWS Mitigation Policy guidelines and/or have been applied previously in coastal mitigation projects. However, each of these techniques offers particular advantages, especially when considered for mitigating impacts to resources (such as midwater fish) for which it is difficult to envision an appropriate technique for in-kind replacement.

12.1 Coastal preservation

Land acquisition has been used as mitigation for some coastal development projects (Ashe 1982). Acquiring and preserving coastal land could serve to mitigate impacts to the marine environment resulting from the operation of SONGS. However, resource preservation appears to be inconsistent with the mitigation policy set forth by FWS because it merely preserves existing resources rather than producing new resources to compensate for project-related resource losses. This inconsistency can be seen by considering the consequences of having land acquisition as the sole mitigation technique: as more and more projects were completed, more and more land would be preserved, but the total amount of resource would dwindle.

Land acquisition could be appropriate mitigation if the acquired land would otherwise be degraded. The protection of rare and valuable habitat (such as a wetland) might be seen as preferable to the in-kind replacement of seemingly less-valuable resources (such as midwater fish). Judgements about the relative value of different resources are subjective and difficult to quantify, and in the long term the value of preservation depends on the nature of the (unknown) future development of the land. Viewed strictly from the standpoint of absolute resource value, preservation guarantees the protection of some resources at the cost of others. But if the protected resources are at great risk, preservation might in the long run be the most valuable alternative. For example, wetland habitat is at great risk in Southern California in spite of its perceived value, and Zedler (1982) argues that development in and around wetlands will continue unless wetlands are purchased for public management.

Land acquisition and preservation can be traditional mitigation if the acquisition is tied to restoration. In this case, the resource value of a degraded habitat is enhanced through restoration, and there need not be a net loss of resources. It seems likely that most, if not all, of the land that could be acquired in Southern California would be somewhat degraded; the acquisition and restoration of land could therefore be a valuable mitigation technique. (The restoration of wetlands and estuaries is discussed in detail in Chapter 10.)

12.2 Research

Knowledge about particular resources or mitigation techniques could be very valuable where actions or recommendations by government agencies have been hampered by a lack of information. There have been a number of cases in which studies have been recommended as at least part of the mitigation requirement. Recent examples in Southern California (N. Gilbert, USFWS, *personal communication*) include: (1) A study of an adjacent lagoon in response to building on a mesa, which was to provide information about the value of the lagoon that would be valuable for future management decisions. (2) A study of the impact of isolation on the ecological functioning and integrity of vernal pools, recommended as part of an overall mitigation package that included preserving existing vernal pools. (3) A study of the effects of shading on eelgrass in response to development that would impact eelgrass beds. In addition, a research institute was established as part of the mitigation settlement for Hudson River power plants (Barnthouse *et al.* 1988).

There are potentially serious problems with utilizing research as the sole means of mitigating a particular impact. By itself, research does not directly change resource values, and there would be some net loss in resource value, at least in the short term. In this sense, research does not follow the FWS Mitigation Policy. However, the long-term benefits of properly directed research could be substantial, and could ultimately result in increased resource values through the application of novel or refined techniques. This technique would be particularly appropriate as mitigation for resources for which no other feasible technique of replacing the resource exists.

Research was an explicit component of the mitigation settlement for the impacts of power plants on the Hudson River. In this case, the dispute over the impacts of entrainment of fish larvae by power-plant cooling systems could not be resolved in spite of many years of hearings. Because lack of information about the ecology of the Hudson River was viewed as a major impediment to policy decisions concerning the use of the river, research on Hudson River ecology was seen as appropriate mitigation. As a result of the out-of-court settlement, the Hudson River Foundation was established to coordinate and fund research on the ecology of organisms living in the Hudson River.

Utilizing studies to *complement* other mitigation techniques would be extremely valuable. In each of the cases cited above, a study was recommended as a means of acquiring information about habitats that would certainly be impacted by future development projects; the information would help the resource agencies make future judgements about proposed impacts to those habitats. And in two of the cases, the study would provide information about the habitat being impacted.

It is worth noting that monitoring studies to determine whether a particular mitigation project was successful would not be appropriate mitigation. These monitoring studies are very important, providing information that could be applied to future mitigation projects. However, they should be considered a necessary part of the mitigation requirement, rather than mitigation in their own right.

12.3 Water quality improvement

Mitigation for a terrestrial project sometimes takes the form of reducing impacts that are similar to the project impacts but are produced by a separate, unrelated project. For example, the California Air Resources Board has required that new sources of air pollution, if permitted, should cause a net benefit in the air quality of the region. The policy is based on the theory that air quality impacts in one area can be mitigated by air quality improvements at another site within the "airshed" (Ashe 1982). For example, Standard Oil had agreed to reduce emissions at a Southern California Edison power plant as mitigation for one of Standard's proposed refineries (Ashe 1982). Similarly, mitigation for oil drilling and processing developments impacts on air quality in the Santa Barbara Channel may include improvements to emissions of other operations off-site (B. Douros, *personal communication*). In both cases, the underlying idea is that the project-related impacts are mitigated because the overall air quality has not been degraded.

A similar approach could be used for water quality in the Southern California Bight. As mitigation for adverse effects of water quality as a result of discharged water from SONGS, SCE might improve the water quality at another site within the Bight. Any number of different impacts to water quality could be improved, including sewage treatment plants or industrial discharges. SCE might also be able to reduce the water quality impacts at their other Southern California power plants.

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SECTION II

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SECTION III

RECOMMENDATIONS

CHAPTER 13

RECOMMENDATIONS

This chapter discusses the basis for the MRC's mitigation recommendations. First, I discuss the Permit and CCC guidelines that have governed the MRC's approach to mitigation. (A general overview of mitigation, including the generally accepted mitigation priorities, is given in Chapter 1.) Second, I briefly review techniques that could potentially be used to mitigate the impacts of SONGS. Finally, I present two options for mitigating the effects of SONGS, "Changes to the Cooling System" and "Prevention and Mitigation." The purpose of this chapter is to relate the information presented in the first two sections of this report to the recommendations made in the MRC's Final Report to the CCC.

13.1 Approach

The MRC's approach to developing recommendations has been mandated by Coastal Commission Permit 183-73 and subsequent guidelines issued by the CCC. Although various laws and policies related to mitigation have been considered (see Chapter 1), the recommendations have not been constrained or limited by them.

The Permit states that the MRC is responsible for recommending to the Commission "any changes it believes necessary in the cooling system for Units 2 and 3" (Condition B.4). Condition B.6 provides that:

> Should the study at any time indicate that the project will not comply with the regulatory requirements of State or Federal water quality agencies, or that substantial adverse effects on the marine environment are likely to occur, or are occurring, through the operation of Units 1, 2, and 3, the applicants shall immediately

> undertake such modifications to the cooling system as may reasonably be required to reduce such effects or comply with such regulatory requirements (which can be made while construction is going on and could be as extensive as requiring cooling towers if that is the recommendation). The State Commission shall then further condition the permit accordingly.

In November 1979 the CCC expressed interest in evaluating means of mitigating adverse effects other than changes to the cooling system, and directed the MRC as follows:

> <u>Mitigation Alternatives to Design Changes</u>. The Commission also recognizes that operational changes or mitigation measures might adequately compensate for any marine life damages resulting from the operation of Units 2 and 3. The Commission, therefore, requests the MRC to study the feasibility and effects of selected promising mitigation measures, including construction of an artificial reef, as suggested by Southern California Edison. The MRC should recommend what measures might be taken to assure there would be no net adverse effect on the marine environment from operation of SONGS Units 2 and 3. (Staff Reports 11/9/79, 4/4/80)

The Permit states that the Committee is responsible for "recommending ... any changes it believes necessary in the cooling system for Units 2 and 3" (Condition B.4), with no mention of operational changes or mitigation. **Option 1: Changes to the Cooling System**, below, responds to this charge. On the other hand, **Option 2: Prevention and Mitigation**, below, considers recommendations in light of the November 1979 resolution as well as the Permit. Under Option 2, the MRC first recommends techniques for reducing as many of SONGS' impacts as can reasonably be accomplished, and then recommends replacement techniques to mitigate the remaining losses to the point of no net adverse effect. This priority was chosen because the Permit stresses reduction of impacts; preventing losses is also given precedence over replacing lost resources by state and federal resource agencies (Chapter 1). For each mitigation technique, initial and ongoing costs and the amount of resources mitigated are estimated. However, many of these estimates are rough at best, and some techniques should not be required until tests determine that they will substantially reduce the impacts of SONGS.

Condition B.6 implies that recommendations should pass a criterion of "reasonableness," and although the Commission makes the ultimate judgement of what is reasonable, this chapter summarizes information on this matter, particularly with regards to the risks and expenses of each technique. Several technically feasible techniques are not recommended because of associated impacts, uncertainty, expense or a combination of factors, all of which bear on the "reasonableness" of recommended techniques.

13.2 Summary of potential mitigation techniques

The previous chapters of this technical report describe and evaluate a variety of techniques that could potentially be used to prevent the loss of resources due to the operation of SONGS or compensate for the value of lost resources. These techniques are listed in Table 13-1.

Table 13-2 lists the most promising techniques for mitigating the impacts of SONGS and indicates the resource losses each technique could serve to mitigate. Two techniques, cooling towers and reduced flow, could reduce nearly all identified categories of impacts. With cooling towers, the existing once-through cooling system would be converted to a closed system, virtually eliminating all of the impacts studied by the MRC. (Some additional impacts to the marine environment

Table 13-1

List of potential techniques for mitigating the effects of SONGS

All techniques, including those that would not be feasible or would not provide adequate mitigation at SONGS, are included in this list. The most promising techniques are noted by *.

Loss reduction techniques

Intake

- Modified travelling screen (e.g., low-pressure wash, small mesh)
- Infiltration bed
- Porous dike
- Barrier systems
- Moving intake
- *Sonic devices (poppers and hammers)
- *Mercury lights
- Electric fields
- Strobe lights
- Bubble curtains
- Water jets

Discharge

- *Relocate discharge (to shallow or deep water, upcoast or downcoast)
- Cover diffuser ports with rock
- Modify diffuser ports (e.g., increase height/exit diameter, change discharge angle)
- Change to single-port discharge
- Modify bottom topography
- Reduce flow/reduce power

Replacement of cooling system

- *Cooling towers
- Cooling ponds

Modification of operations

- *Reduce flow/maintain full power
- *Reschedule flow
- Modify heat treatment procedures

Replacement techniques

- *Construct artificial reef
- *Create new kelp bed
- *Restore coastal wetland
- Construct fish hatchery
- Coastal preservation
- Research
- Information dissemination (e.g., book)
- Water quality improvement

Table 13-2

Summary of potential mitigation techniques and losses that could be reduced or compensated.

Both loss prevention and compensation techniques are presented. Each compensation technique could potentially be used as out-of-kind mitigation for any loss; however, for this table the following different types of out-of-kind mitigation are noted: (1) out-of-kind but would result in the substitution of the same general type of resource (e.g. fish) and produce some of the impacted species, and (2) out-of-kind that only substitutes the same general type of resource.

	Loss Prevention						Replacement		
Losses	Reduce Flow	Reschedule Flow	Move Discharge	Intake Poppers	Screenwell Poppers & Lights	Cooling Towers	Artificial Reef w/ Kelp	Artificial Reef w/o Kelp	Wetland Restoration
Fish larvae and eggs	✓	✓				✓	(1)	(1)	(1)
Midwater fish	✓			✓	✓	✓	(2)	(2)	(1)
Kelp bed fish	✓		✓			✓	in-kind	in-kind	(2)
Kelp bed invertebrates	✓		✓			✓	in-kind	in-kind	
Kelp	✓	✓	✓			✓	in-kind		

might result from the small volume of discharged water from cooling towers, and terrestrial and other impacts would certainly occur; see Section 5.1.2.)

Reducing the flow of water through SONGS would not completely eliminate any impacts, but it could potentially reduce all categories of losses to some extent. For organisms that are entrained by SONGS, reducing the flow of water through the plant would directly reduce the losses due to SONGS. The relationship between flow rate and resource loss is less certain for giant kelp, kelp bed fishes and kelp bed invertebrates (Section 6.2.1), but reduced flow might result in some reduction in impacts.

The remaining five loss prevention techniques would reduce impacts on two or three resources. Rescheduling the operation of SONGS could reduce the losses of fish larvae and giant kelp. Changes to the diffuser system (either moving the discharge or modifying the diffuser ports) could reduce the impacts on giant kelp, kelp bed fish and kelp bed invertebrates. Finally, sonic devices, such as intake poppers (pneumatic guns), and light systems could reduce the loss of entrapped fish.

The most promising replacement techniques include constructing an artificial reef and restoring a degraded wetland. An artificial reef could serve as in-kind replacement for kelp bed fish and invertebrates and, if it supported giant kelp, kelp itself. The amount of in-kind resources that would be provided by a restored wetland would depend on the particular wetland and its restoration plan. A restoration that provided large open-water areas could provide high in-kind value, or at least would enhance the production of the same type of resources (e.g., fish) as impacted by SONGS.

Either an artificial reef or a restored wetland could provide out-of-kind value for any of the resource losses caused by SONGS. However, Table 13-2 also distinguishes out-of-kind replacement that would result in the substitution of the same general type of resource (e.g., fish). Although this type of replacement has not be distinguished in established publications or policies, it would be preferred over out-of-kind mitigation resulting in completely dissimilar resources. Both an artificial reef and a restored wetland could produce fish as out-of-kind mitigation for midwater and bottom fish species impacted by SONGS. Wetland restoration could also produce fish as out-of-kind mitigation for kelp bed fish species impacted by SONGS.

The two mitigation options considered in the Final Report to the CCC are summarized in Table 13-3. The components and alternatives of these options are considered in the rest of this chapter.

13.3 Option 1: Changes to the Cooling System

Conditions B.4 and B.6 of the Permit state that, if the MRC finds that SONGS causes substantial adverse effects on the marine environment, the Committee is responsible for recommending "such modifications to the cooling system as may reasonably be required to reduce such effects...".

There are reasons besides the mandate of the Permit to prefer structural changes as a means of reducing the impacts of SONGS. Structural changes could remove or reduce the mechanisms of impact, thereby insuring that SONGS has the least possible impact on the marine environment. Such changes not only minimize

Table 13-3

Options for reducing or mitigating the impacts of SONGS

Option	Technique	Objective	Recommendation
1: Changes to cooling system			
Option 1a	Cooling towers	Reduce all losses	Reject (WM, BM) Accept (RF)
Option 1b	Moving discharge	Reduce discharge losses	Reject
2: Prevention and mitigation			Accept (Unanimous)
Fish Losses	Reduce flow[1] Reschedule operations[1] Artificial reef (60 ha)[1] Restore wetland (30 to 60 ha)[1]	Reduce larval fish losses (1-10% reductions in standing stocks of some species)	
	Reduce impingement losses	Reduce fish intake losses (21 tons/yr)	
Kelp forest community impacts	Artificial reef (120 ha)	Replace kelp community losses (80 ha kelp and associated invertebrates and fish)	

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[1] A combination of these techniques could be used as long as overall result was complete mitigation.

the impact a project has on the local ecosystem, they also avoid the extremely difficult problems associated with trying to (1) estimate the value of resources produced by imperfectly understood mitigation techniques, and (2) compare the values of dissimilar resources.

In this section, I address changes to the cooling system at SONGS that would reduce the substantial impacts of SONGS. I focus on the two alternatives, constructing cooling towers and moving the discharge, that were considered by the MRC in its Final Report to the California Coastal Commission.

13.3.1 Option 1a. Cooling towers

The substantial adverse impacts of SONGS are directly related to the intake and discharge of a large volume of water at SONGS; cooling towers could reduce this flow by 90% or more, thereby substantially reducing all of SONGS' effects on the marine environment that the MRC has measured.

Cooling towers present their own suite of problems (discussed in Chapter 5). Any one of several different cooling tower designs could be used at SONGS, but all have technical or environmental problems. One design that seems suited to the San Onofre environment, dry cooling towers, has never been used at a plant larger than 200 MW, so it is uncertain whether the engineering obstacles of applying this technology to a 1100 MW scale could be resolved; furthermore, dry cooling towers would be expected to decrease plant capacity by 20%. Wet cooling towers would also result in a significant decrease in plant capacity. Any decrease in efficiency would likely increase emissions in the Los Angeles Basin, because Basin power plants would need to operate more to make up the lost power.

Salt water would be used for wet cooling towers at San Onofre because of the scarcity of fresh water, and the resulting salt drift could cause substantial terrestrial impacts within a few miles of the towers. Although a smaller volume of water would be discharged from SONGS than with the present once-through cooling system, the discharged water would have higher concentrations of toxic chemicals and other contaminants (which are used to prevent corrosion, scaling and biofouling).

Retrofitting SONGS for cooling towers would be a complex engineering and logistical project. SCE does not own the land on which the cooling towers would be built, but would need to acquire it from either Camp Pendleton or the State Park. There may not be enough room to build the towers next to Units 2 and 3; if not, they would need to be located at least a mile away from the plant on the other side of the freeway. The intake pipes, which are pointing the wrong way, would need to be extended in a sweeping circular pipe out and back up the beach. If the towers are located across the freeway, the pipes would need to be buried deep beneath the freeway (the Department of Transportation would have to give permission to tunnel beneath the freeway) and up into the hills, and additional pumps would be needed to move the water uphill against a head of about 200 feet. The sea cliffs would probably have to be destroyed no matter where the cooling towers were constructed.

Cooling towers are also likely to affect human safety by increasing the frequency of ground-level fogging around San Onofre. The cooling towers would have to be located adjacent to Interstate 5, where weather conditions that produces a visible plume from the towers would sometimes reduce visibility on the highway. Although this would probably occur only rarely (according to the 1973 Final Environmental Statement for Unit 1, SCE estimated that conditions conducive to fog would probably occur during 90 hrs/year), the probability of automobile accidents near SONGS would be slightly higher as a result of constructing cooling towers.

Finally, cooling towers are expensive, with an estimated cost of about $500 million to $1 billion for construction. In addition, the decrease in plant capacity would be expected to cost at least another $1 billion over the life of the plant.

Cooling towers were considered in the Final Environmental Statement for Units 2 and 3 and by the MRC in its 1980 report to the CCC, and in both cases rejected as unnecessary for the anticipated level of impacts. None of the recent information indicates that they would now be a better alternative.

If cooling towers are required, their environmental impacts would be substantially different from the impacts measured by the MRC; these impacts should be monitored even though they would be lower than the present impacts. The appropriate monitoring would depend on the design characteristics of the towers, so it is not possible to anticipate the specific monitoring that would be needed.

13.3.2 Option 1b. Moving the discharge

An alternative to cooling towers is to move the discharge so that the plume does not pass over the San Onofre Kelp Bed. This would eliminate the impacts on the kelp bed.

This option has the following disadvantages (Section 4.6): (1) Changes to the discharge system must accommodate the plant's finely-tuned hydraulic requirements, and this restricts the distance at which a new discharge could be located. (2) There would be new impacts on the marine environment, some of which we are not able to predict. (3) It would not reduce the adverse effects on fish populations, which are caused by the entrapment of fish. (4) Although impacts to the San Onofre Kelp Bed would cease, it would take a period of time (perhaps long) before the kelp bed would recover, during which there would be a net loss of resources. (5) The exact cost would depend on the specific location and design of the new discharge (and would require a detailed analysis), but would be hundreds of millions of dollars.

Moving the discharge is technically feasible, would eliminate ongoing impacts to the San Onofre Kelp Bed, and would cause only minor new environmental impacts. However, moving the discharge will be very expensive, and the impacts to the kelp forest community can be adequately mitigated with an artificial reef at substantially lower cost.

The MRC was unanimous in not recommending this technique for mitigation of SONGS' impacts.

13.4 Option 2: Prevention and mitigation

Option 2 consists of techniques that, combined, could be used to compensate for the resources lost as a result of the operation of SONGS. The goal of this option is to have no net adverse effect resulting from the operation of SONGS.

The MRC has evaluated more than 30 different techniques that could be used for preventing or mitigating losses due to SONGS (Table 13-1), most of which have never been adequately tested. Furthermore, development and testing of these techniques has generally focused on power plants that are much smaller than SONGS and are not located on the coast of a temperate ocean. It is therefore difficult to evaluate the feasibility of these techniques at SONGS, and there is uncertainty associated with even the most promising of them. In addition, there have been few attempts to mitigate nearshore coastal impacts, so there is little precedence or experience for guidance. The relatively few techniques included in Option 2 are the techniques the Committee feels are the most likely to be successful with no unacceptable effects.

The detailed recommendations in this section are organized according to two major categories of losses: fish losses, and kelp forest community impacts.

13.4.1 Fish losses

The MRC has recommended a possible combination of four different techniques for mitigating the fish losses: (1) reduce the number of larvae entrained (by reducing the flow rate at SONGS or other coastal power stations or by scheduling SONGS so it does not operate during periods of maximum abundance of fish larvae), (2) construct an artificial reef, (3) restore a wetland, and (4) reduce the in-plant loss of juvenile and adult fish.

Rescheduling operations and reducing flow would prevent losses of some fish larvae, but a substantial number of larvae would still be killed. There is no feasible technique for replacing all of these larvae in-kind; although some in-kind replacement would occur on an artificial reef or with wetland restoration, these techniques would be primarily out-of-kind. An artificial reef or wetland restoration would also serve as mitigation for any in-plant fish losses that cannot be prevented.

This section discusses each of these techniques. In addition, the MRC recognizes that different combinations of the first three techniques could each result in complete mitigation, and a framework for combining the techniques is presented.

13.4.1.1 Reschedule operations and reduce flow

These two techniques, considered together because they could perhaps be implemented in a complementary manner, would be used to decrease the loss of fish larvae by reducing the volume of water that flows through SONGS. We present the techniques in relation to SONGS, but note that an equivalent reduction in entrainment from lower flow at other SCE coastal stations could be an acceptable substitution.

Reschedule operations

The water flow through SONGS is shut off regularly for routine maintenance and refueling. By scheduling this downtime during the period of maximum abundance of fish larvae, the number killed could be reduced substantially. If the 60 days a Unit is down for refueling and maintenance occurred during March and April, losses of fish larvae could be reduced by about 50% (Table 13-4). Obviously, more days with no flow will give greater savings but higher costs (approximately $4-7 million/week) to SCE.

Flow could be stopped each year during the period of highest larval abundance with either a 12-month or a 24-month refueling cycle. There are technical and financial objections to a 12-month cycle. Although difficult to achieve, a 24-month cycle, with Units 2 and 3 down in alternate years, would have the advantages of fewer manpower or safety conflicts (which would occur if Units 2 and 3 were down at the same time), a lower volume of radioactive wastes, and lower costs. Even an 18-month refueling cycle, centered around the goal of reducing flow in March and April, would provide a substantial reduction in the number of fish killed.

In spite of the advantages of a 24-month cycle, unanticipated interruptions in the operation of SONGS and other factors will make it difficult to adhere to any set schedule (Section 6.1.2). In fact, it may be impractical to require SCE to schedule refueling and maintenance at Units 2 or 3 during any specific period of time. The period scheduled for refueling is subject to a complex suite of factors, many of which are not under SCE's control. Nonetheless, larval fish losses can be substantially

Table 13-4

Reduction in ichthyoplankton entrainment under different flow schedules

A. Total ichthyoplankton

	MONTHS WITH NO FLOW				
MONTHS WITH 67% FLOW	NONE	MAR	MAR & APR	FEB, MAR, & APR	MAR, APR, & AUG
None	0%	32%	49%	68%	55%
Feb to May	26%	47%	58%	71%	64%

B. Species with estimated Adult Equivalent Losses > 1%.

	MONTHS WITH NO FLOW				
MONTHS WITH 67% FLOW	NONE	MAR	MAR & APR	FEB, MAR, & APR	MAR, APR, & AUG
None	0%	28%	48%	55%	59%
Feb to May	23%	42%	54%	59%	65%

reduced if SONGS can be scheduled to avoid operations during March and April, and the adoption by SCE of a policy that minimizes operations during periods of high larval abundances should be encouraged.

Reduce flow

Reducing the rate of water flow through SONGS while operating the plant at full power would also reduce losses of fish larvae. The flow rate could potentially be reduced by 33%; a 33% reduction would maintain the thermal standard of < 4°F increase at 1000 feet from the diffusers, although a waiver would be required to allow an increase across the condenser of 30°F instead of 20°F. Operating the plant at 67% flow for February through May (and full flow the rest of the year) would reduce fish larval losses by 26% (Table 13-4). (Most of the savings in February comes from anchovies.) Savings would be somewhat higher if flow was reduced for more months; however, fish larval abundances are not particularly high in October through January, and higher water temperatures after June would reduce the efficiency of the turbines and substantially increase costs.

The costs of this technique include $10 million to retrofit the pumps, plus annual costs that depend on (1) when flow is reduced and (2) the number of days with reduced flow. For technical and financial reasons, it might be best to reduce flow during the months with low ambient water temperatures. (One exception: the potential savings in species with high adult equivalent losses could make operating at reduced flow in August worthwhile.) Alternatively, it might be best simply to allow SCE adjust the flow in response to ambient conditions and power requirements, as long as the required reduction in entrainment was achieved. For the proposed February-to-May reduction, the annual costs could be as high as $5 million for both units (Section 6.2.3).

In addition to reducing the flow rate through SONGS, SCE might be able to reduce larval entrainment by reducing the volume of water passing through coastal power plants besides SONGS. Studies at SONGS indicate that the thermal effluent from the plant is of little environmental concern. We believe that the environmental advantages of reduced flow that can be achieved by having a higher condenser temperature will generally outweigh any potential environmental hazards at coastal power plants. The greatest environmental protection might result from a waiver of thermal standards at SCE's coastal power plants, since this would minimize the volume of water pumped through the plants.

Reschedule operations and reduce flow

The most cost-effective means of reducing losses of fish larvae would be to schedule SONGS, whenever possible, so it does not operate when fish larvae are most abundant and to reduce the flow of water through the plant during a few other months. Of course, the actual savings in larvae will vary depending on the specific timing implemented; no flow during March and April and 67% flow during February and May would reduce larval fish losses by nearly 60% (Table 13-4). Even with only one month of no flow, reduced flow from February to May would yield a combined savings of nearly 50%.

No biological monitoring would be required for rescheduling or reducing the flow rate through SONGS.

13.4.1.2 High-relief artificial reef

An artificial reef would produce a variety of reef resources, the algal, invertebrate and fish communities on artificial reefs are similar to those on natural reefs, and there are data indicating that some fish production does occur on artificial reefs. Artificial reefs are one of only two techniques (the other being wetland restoration) available for producing nearshore marine resources, and their use for mitigating unavoidable losses could be appropriate if approached cautiously. For example, the problems associated with using an artificial reef as out-of-kind mitigation include uncertainty about the amount of fish produced (Section 8.2) and the need to compare the value of dissimilar resources. The size and design of an artificial reef used as out-of-kind mitigation should take into account these uncertainties.

Any estimate of the size of reef needed will be mainly a best guess, and since there is no impact to a specific habitat it is not possible to come up with replacement ratios. To estimate the reef size needed to compensate for the fish losses, I have converted the fish losses from biomass of mid-water fish to area of reef. This approach relies on many rough estimates, since virtually none of the necessary information is accurately known, and on a judgement about the relative worth of midwater fish versus a rocky reef community. These calculations, and the assumptions upon which they are based, are given in Appendix D. Using the values described in Appendix D, I estimate that a 60-ha artificial reef would compensate for the all of the unavoidable fish losses. (As discussed in Section 13.4.1.4, a smaller artificial reef could also be combined with other techniques to mitigate the fish losses.)

Monitoring the mitigation reef is an integral part of this recommendation. The physical structure of the reef should be monitored immediately after construction to verify that it meets the design specifications; if it does not, additional construction should be required to bring it up to the specifications. The principal evaluation of this technique should take the form of a comprehensive study of the amount of fish produced on the reef, to be completed over a period of perhaps five years (and probably commencing some years after reef construction). Uncertainty about the amount of fish produced on artificial reefs hampers their use in mitigation, so the information from this study will be extremely valuable for evaluating future proposals to use artificial reefs as mitigation.

Cost of constructing a high-relief artificial reef is estimated to be $250,000 per ha (Section 8.3.4), so the cost of constructing a 60-ha reef would be about $15 million.

13.4.1.3 Restore wetland

Coastal wetlands are valuable habitats because they serve as nurseries for some marine fish, are productive, and provide habitat for rare and endangered species. In Southern California, less than 25% of the original wetlands remain and nearly all of these have been degraded. Wetland restoration would be an appropriate means of mitigating the loss of fish larvae caused by SONGS.

Two difficulties with implementing this technique are: (1) *Location.* Wetlands in Southern California are in high demand for restoration and the alternatives are limited, but SCE owns some property in the Huntington Beach wetland and there are several other possibilities (including purchasing more Huntington Beach property or restoring another wetland such as the Ballona Wetland; Section 10.4.1). (2) *Amount of restoration needed.* As with all out-of-kind techniques, it is difficult to determine the amount of mitigation needed to achieve the appropriate amount of replacement; this is particularly difficult under the present circumstances, where the impacted resources are tied to a habitat (open water) that we cannot restore. Furthermore, the amount of restoration needed will depend on the specific design of the restoration: shallow-water habitats such as estuaries and embayments will provide more in-kind, and perhaps out-of-kind, value than most salt marshes, although marsh habitat that supports endangered species would be especially valuable. While it is impossible to determine precisely the amount of restoration needed, we propose that, depending on the particulars, 30 to 60 ha would adequately mitigate for the fish losses (Section 10.5.2).

If wetland restoration is chosen to replace losses, the restoration must be monitored carefully to insure that it is successful. Previous monitoring efforts have generally evaluated only whether transplanted vegetation grew as expected; this is not sufficient. Specific criteria for success (i.e., particular hydrological, physical and biological characteristics that must be realized) and the time frame for their achievement should be established when the restoration plan is developed. If monitoring indicates that these objectives have not been accomplished on schedule, additional efforts should be required to ensure that the best possible effort is made to establish the target community. The monitoring would be completed over a period of perhaps five years.

The cost of restoring a wetland will vary tremendously depending on the specific project, and especially whether of not the land must be purchased. Using a general estimate of $100,000 to $300,000 per ha (Section 10.4.2), the cost of restoring 30 to 60 ha would be between $3 million and $18 million.

13.4.1.4 Combined approach to mitigating losses of fish larvae

Different combinations of the previous three techniques (reducing entrainment, constructing an artificial reef, and restoring a wetland) could each result in complete mitigation for the loss of fish larvae. A framework for combining these techniques would allow the CCC to choose a mix of the three techniques, but would insure that the impact is fully mitigated.

The relative value of reducing the entrainment of fish larvae is straightforward: each percent reduction in entrainment losses would be one percent of the amount needed for complete mitigation. Of course, short of constructing cooling towers, the entrainment of fish larvae cannot be completely prevented, so some other technique must be combined with this one.

From the perspective of the resources saved it does not matter whether SCE reduces entrainment by rescheduling the operations of SONGS, reducing the flow of water through the plant, or both. However, these two techniques for reducing entrainment are not equal in ease of achievement or accounting. Rescheduling the operation of SONGS will be particularly problematic in this regard, since unexpected events will certainly impinge on any desired schedule. It might be most reasonable to expect a particular level of performance over an average of several years, rather than requiring a strict schedule in any particular year. In any case, combining both reduced flow and rescheduling would provide additional flexibility for meeting a target reduction in larval losses.

Our best estimates indicate that either constructing a 60-ha artificial reef or restoring a 60-ha wetland would completely compensate for the loss of fish larvae (This estimate for wetland restoration is used here for illustration purposes; the actual wetland value will depend on the nature of the restoration proposed.) Based on these numbers, one ha of artificial reef is worth 100%/60=1.67% of the total mitigation needed, and each ha of wetland is worth 100%/60=1.67% of the required total.

Complete mitigation for the fish larval losses would be achieved when the combination of techniques adds up to 100%. For example, complete mitigation would be accomplished by the combinations given in Table 13-5.

Table 13-5

Combining mitigation techniques - Examples

	EXAMPLE 1		EXAMPLE 2	
METHOD	AMOUNT	RELATIVE VALUE	AMOUNT	RELATIVE VALUE
Reduction in entrainment	20%	20%	58%	58%
High-relief artificial reef	24 ha	40%	25 ha	42%
Wetland restoration	24 ha	40%	0	0%
		100%		100%

By this method of combining techniques, each technique is considered equally acceptable for mitigation. In fact, there is an advantage to *preventing* the entrainment of larvae, since this will reduce the loss of real fish (as opposed to compensating on the basis of inferred losses) and does not rely on the assumptions needed to determine the appropriate amount of out-of-kind mitigation. On the other hand, an artificial reef or wetland restoration would satisfactorily mitigate any unavoidable fish losses. Although there is a great deal of uncertainty about the appropriate sizes for these projects, one factor favors using these techniques: they will continue to produce resources after SONGS has stopped operating. An artificial reef or wetland restoration has the potential for actually having a greater long-term resource value than a prevention technique.

13.4.1.5 Reduce fish impingement losses

SONGS already employs two techniques for reducing midwater fish losses: velocity caps on the intakes, and the Fish Return System. Although these two techniques reduce the number of fish entrapped and killed by the plant, at least 20 to 50 metric tons (MT) of fish are still killed each year.

There may be new techniques that could be used to reduce the impingement of fish. Mercury lights and sonic devices are two techniques that could potentially reduce the impacts of SONGS on midwater fish populations. Neither technique has been adequately tested in the field, so they should be experimentally evaluated before being required at SONGS. The arrangement of intakes for Units 2 and 3 is particularly suitable for controlled tests of these systems; a system could be operated at one unit, and entrapment when the system is operating compared (using simultaneous 24-hour samples) to entrapment over the same period and flow rate at the other unit. To control for differences in the species entrapped by the two Units, the test and control units could alternate between Units 2 and 3 during a series of trials. Effectiveness should be evaluated in terms of overall fish entrapped and on a species-by-species basis; both numbers and biomass should be considered. The tests should be performed during normal operations and during heat treatments.

Mercury lights

Mercury lights would be used in the Fish Return System chamber to attract fish out of the screenwell. This could increase the diversion efficiency of the FRS at all times, but would be particularly important during heat treatments because the fish killed during heat treatments tend to be the largest and most economically important of those killed by SONGS (Section 3.3.3.1). Mercury lights (perhaps in conjunction with sonic devices) might be able to save up to 3 MT of these large fish per year. The cost of mercury lights is estimated to be roughly $100,000.

Mercury lights are recommended because they appear to be a simple and inexpensive way to reduce losses. But they might not be worth implementing if they are not effective or do not prove to be simple and inexpensive, so a feasibility study should be performed before they are implemented.

Sonic devices

Sonic devices, such as pneumatic guns ("poppers") or "hammers," could be placed in the screenwell area to increase diversion of fish into the Fish Return

System and/or at the intakes to reduce entrapment of fish. Sonic devices in the screenwell area are likely to be effective for all species and sizes of fish entrapped, although large individuals might benefit the most because they are disproportionately killed during heat treatments. Sonic devices (perhaps in conjunction with mercury lights) might be able to save up to 3 MT of fish per year (Section 3.3.1.1). The cost of sonic devices in the screenwell area is roughly estimated to be about $100,000.

Sonic devices at the intake would probably be most effective for schooling fish. Transient schooling species such as northern anchovy would be in the vicinity of SONGS' intakes for only a short time, so sonic devices might effectively disperse these fish away from the intakes without habituation to the devices. If the sonic devices can reduce the entrapment of schooling fish by 50%, they will save about 0.4 MT of fish (Section 3.3.1.1). The species that would be saved comprise a large *number* of the fish entrapped by SONGS, but they are the smaller and younger fish of those entrapped and do not contribute much to the weight entrapped. The cost of sonic devices at the intakes is roughly estimated to be $300,000.

13.4.2 Kelp forest community impacts

13.4.2.1 Low-relief artificial reef with kelp

The fraction of the kelp community lost at San Onofre Kelp Bed could be replaced by constructing an artificial reef that develops and maintains a kelp bed. Few artificial reefs have been used for mitigation because there is substantial uncertainty about the resources they provide (Sections 8.2 and 9.1.2). To insure that an artificial reef provides adequate mitigation for kelp losses, the reef should be larger than the impacted reef, since (1) kelp would probably not cover the entire reef, (2) the density of kelp might be lower on the artificial reef, and (3) the kelp community on the artificial reef might not be as productive or diverse as the natural community. This approach, in which the ratio of created habitat to impacted habitat is greater than one, has been used extensively in mitigation. The MRC has recommended that the artificial reef be 1.5 times the impacted area; in the case of SOK, where the impacted area is 80 ha, the artificial reef should be 120 ha.

In order to insure that the community that develops on the mitigation reef is as similar as possible to the impacted community at SOK, the physical structure of the reef should be as similar as possible to SOK's. In particular, there are few kelp beds in Southern California in which the kelp plants grow on "cobbles" or scattered boulders as in SOK, and this physical structure would be needed to replace the characteristic organisms that live in this habitat. Ideally, the substrate itself should mimic SOK, that is, it should consist of cobbles and boulders identical to those at SOK. However, there is a risk that a low-relief artificial reef will be more prone to being inundated by sand than a high-relief reef; this risk could be minimized by using some larger rocks and having occasional areas of somewhat higher relief.

Two difficulties with implementing this technique are: (1) *Location*. Ideally, the reef should be located as close as possible to SOK, but if it is too close it also will be impacted by SONGS. Likely locations for the mitigation reef include upcoast and downcoast of SMK and several km downcoast of SOK. Because there is a possibility of unfavorable physical conditions (e.g., high turbidity and sedimentation) in unknown locations, potential sites should be thoroughly surveyed before the final location is determined. As an additional safeguard, the reef could be constructed in stages, with ongoing monitoring and a careful evaluation of the data before each stage to insure that the site is suitable. (2) *Techniques for establishing kelp*. Although kelp is now present on several artificial reefs, there have been many problems with establishing kelp on artificial reefs. Different techniques are available for establishing kelp, including transplanting adults, transplanting sporophylls, and outplanting juveniles. These techniques could be employed in an experimental design during the first year after construction, with a decision about the technique(s) to be used in successive years made after their effectiveness has been evaluated.

Independent monitoring of the artificial reef is an integral aspect of this recommendation. First, it is essential that giant kelp become established quickly on the reef and that it persists. Performance criteria could be used to establish a timetable for giant kelp development, for example, establishment of giant kelp within 3 years; if monitoring indicates that giant kelp has not been established on schedule, additional efforts should be required until the target community is established. Because the densities of fish and benthic algae and invertebrates should eventually be similar to the densities that would have occurred at SOK in the absence of SONGS' impacts, these organisms also should be monitored.

The cost of a low-relief artificial reef is estimated to be roughly $75,000 per ha (Section 8.3.4); the cost of establishing kelp on the artificial reef is estimated to be several million dollars (Section 9.2.3). The total cost of constructing a 120-ha low-relief artificial reef with kelp is estimated to be about $10-12 million.

13.5 Summary

Two options for mitigating the impacts of SONGS on the marine environment, corresponding to Coastal Commission directives, have been considered by the MRC.

The first option consists of large-scale changes to the cooling system at SONGS, either replacing the open-cycle system with a closed-cycle cooling tower or moving the discharge from SONGS away from the San Onofre Kelp Bed. Although each of these techniques would substantially reduce the impacts of SONGS, each also has associated technical difficulties, other environmental impacts, and high costs. Dr. Fay recommended constructing cooling towers; the MRC was unanimous in not recommending moving the discharge (Table 13-3).

The second option consists of a variety of techniques to prevent and mitigate losses due to SONGS; this option was unanimously recommended by the MRC. Impacts to fish resources could be mitigated by reducing the flow of water through SONGS, rescheduling the plant to avoid periods of high larval abundance, constructing a high-relief artificial reef, restoring a coastal wetland, and implementing new techniques for reducing impingement losses. The first four of these techniques could be used in various combinations to achieve complete replacement of lost resources. Impacts to the kelp forest community could be mitigated by constructing a 120 ha low-relief artificial reef in the San Onofre region.

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APPENDICES

APPENDIX A

DESCRIPTION OF COOLING SYSTEM AT SONGS

Note that, throughout this appendix, we use gallons per minute (GPM) and feet per second (FPS) rather than the metric equivalents because these units are used almost exclusively by engineers and in the relevent documents.

Operation of Songs Units 2 and 3

SONGS Units 2 and 3 are similar in design and operations. They differ in only 2 aspects; they are mirror images and the discharge pipe for Unit 2 extends farther offshore than the pipe for Unit 3 (Figure A-1). The following sections describe the structure and operation of both units.

Intake

Each unit has a separate intake structure located 970 m offshore at a depth of 9.1 m; the intakes are 200 m apart alongshore. Each intake is 8.5 m (28 ft) in diameter and extends vertically so that the opening is 2.9 m (9 1/2 ft) above the bottom (Figure A-2). There is a 3 m (10 ft) lip around the opening. The intake has a velocity cap that is supported by columns and lies 2.1 m (7 ft) above the opening (Figure A-2). About 52.4 m^3/s (830,000 gpm) of water is drawn into the intake at a current speed of 0.5 m/s. The water is transported to the plant at a velocity of 2.2 m/s (7.3 fps) through a 5.5 m diameter pipe that is buried about 1.2 m under the surface of the ocean bottom. A much smaller, auxiliary intake is located about 30 m shoreward of the primary intake and is available for emergencies (e.g., when something happens to the primary intake, some water is still able to enter the plant through the auxiliary intake).

Inplant

The intake pipe connects to a 4.5 m (16 ft) square box-conduit onshore, at the seawall. On the plant-side of the seawall, there is an open slot in the top of the conduit for a stop-gate (also called the tsumami gate). A reinforced concrete gate can be lowered, from the plant yard, down this opening to close off the box conduit and prevent water from entering the plant through the intake pipe. Down stream from the stop-gate opening is a gate connecting the intake and discharge conduits which is opened to recirculate heated water during heat treatments. The intake conduit then transitions into the screenwell structure (Figure A-3). Baffles at the entrance of the screenwell spread the water flow over the channel as it widens and the water velocity slows to 0.8 m/s (2.7fps). The channel widens to 12.5 m (41 ft) over a distance of 21.7 m (71.5 ft) and then narrows. As it narrows, the main volume of water turns through a 70° angle and passes through traveling bar racks and screens. Guiding vanes aligned with the incoming water-flow in the narrowing channel direct the water so that the flow over the bar racks is uniform, thus reducing turbulence. The remaining water is funnelled into the collection bay of the Fish Return System (FRS).

There are 6 adjacent sets of traveling bar racks and screens (Figure A-3). Each bar rack is made of articulated panels of vertical slats. The slats are about 1/4" wide, 2 1/2" deep and 2 ft. high; the 1/4 " surface faces the oncoming flow of water. The gap between adjacent slats is about 1 1/2". Debris is trapped on the slats as water passes through the rack. The rack rotates like a tank tread for cleaning. Rotation is triggered automatically (usually a few times a day) by the pressure difference across the rack. Horizontal shelves, about 4" wide, attached to the panels help lift the accumulated debris out of the water. Debris is washed from the racks with a high pressure spray, and travels through a sluice to a collection bin. Debris that passes through the bar rack is collected on a 9.5 mm (3/8") mesh traveling screen directly downstream (Figure A-3). The screen also rotates and is cleaned by a high pressure spray (Figure A-4). The debris from the screens travels through a second sluice and is collected in another bin. Eventually, all the debris is transferred to large trash containers and hauled away to a landfill.

After passing through the screens, a small volume of water is withdrawn for the rack and screen wash and for nuclear component cooling (Figure A-5). The pumps for the bar and screen wash remove water at a rate of about 0.13 m^3/s (2000 gpm), but the water is discharged back into the screenwell. Pumps for the nuclear component cooling loop each withdraw about 1.1 m^3/s (17,000 gpm) of water; one to four pumps (usually two) operate simultaneously. The remaining water (51.2 m^3/s) is pumped from the screenwell by four large circulating pumps. Each pump is a wet pit-type pump, rated at 13.0 m^3/s (207,500 gpm) and 11.6 m (38.0 ft) of head. (One foot of head is the energy required to pump x amount of water to a height of 1 foot above sea level.) Less than 0.1 m^3/s (1,000 gpm) of the water is used for the Fish Return System, 2.1 m^3/s (34,000) goes to the auxiliary turbine plant cooling loop, and the remainder travels to the condenser where it cools the steam generated by the reactor to operate the turbines (Figure A-5).

The elevation of the bottom of the screenwell structure is -26 ft, where 0 elevation is mean sea level (Figure A-6). As the pumps withdraw water from the screenwell, water from the intake pipe rushes into the screenwell under the force of gravity to take the place of the water that was removed. There is an "energy cost" associated with the transport of water into the screenwell from the intake structure. This cost results from friction between the inner surface of the intake pipe and the flowing water, and turbulençe as the water passes through the baffles into the screenwell. The cost is measured in feet of head (the same measure used to rate the circulating pumps, see above). As a result of the loss of head feet as water passes through the intake pipe and into the screenwell, when all pumps are operating, the level of the water in the screenwell is about 8 feet below mean sea level. Since sea level changes with the tides, the water level in the screen well can vary from about 3 ft to 10 ft below 0 elevation during extreme tides. As the intake pipe becomes fouled by sessile marine organisms such as mussels and barnacles, the head loss due to friction increases. This causes a further drop in the water level in the screenwell. The intake pipes of both units are periodically flushed with heated water to remove fouling organisms and thus minimize the head loss due to friction.

The circulating pumps are placed so that the intake ports are at an elevation of about -21 ft. The intake ports must sit well below the surface of the water in the screenwell so that air is not drawn into the pumps. If a pump sits in water that is too shallow, a vortex will be created as the pump sucks water from the screenwell and air bubbles will be drawn into the pump (cavitation). The bubbles can damage the propeller by pitting the surface of the blades. If too much air in drawn into the pump, it will lose prime and shut down.

The condenser has two shells (also called waterboxes). About 12.5 m^3/s (199,00) of water is transported from each pump to the condenser through a 2.4 m (8 ft) square box conduit. The conduits from two pumps supply the near shell and the conduits from the other two pumps are routed to the far shell (Figure A-5).

Each conduit transitions to a pipe which rises vertically and then turns to enter the condenser waterbox. As the water passes through the condenser at a velocity of 2.1 m/s, the temperature increases 10.7°C (20°F).

Two pipes from each shell of the condenser carry the heated water to a common 4.9 m (16 ft) square box conduit for discharge. Water from the nuclear component cooling and the turbine plant cooling loops also flow into the common discharge conduit. The combined flow then passes over the seal well weir. The seal well weir is a dam that maintains a constant lower limit for the hydraulic grade line to ensure that water siphons through the condenser properly. If the hydraulic grade line is too steep (e.g., during extreme low tides), the siphoning effect of the circulating water on the discharge side of the condenser is excessive and causes a break in the siphon in the condenser. When the siphon breaks, air enters the condenser tubes and the efficiency of the heat exchange process declines.

Downstream from the weir, a crossover box conduit branches off the main discharge conduit. Normally, the gate at the entrance to the crossover conduit is closed, but during heat treatments it is opened to allow recirculation of heated water.

There is an open slot in the top of the discharge conduit for a stop-gate just upstream from the seawall. At this point, the discharge conduit is right next to the intake conduit. A stop-gate, like the one for the intake, can be lowered from the plant yard into the opening, to close the conduit and prevent the flow of water out of or into the plant through the discharge pipe.

At the shoreline, the box conduit joins to a 5.5 m (18 ft) diameter discharge pipe that transports the water to the diffuser. The discharge pipes for Unit 2 and Unit 3 extend 1950 m and 1150 m offshore, respectively; both are buried 1.4 m under the substrate surface. At the end of each discharge pipe is a diffuser. Each diffuser is 762 m long and has 63 ports, spaced 12.2 m apart. Each port was designed to rise 2.7 m above the bottom with a flared opening that is positioned so that water is discharged at a 20° angle from the horizontal. The ports are alternately aligned at angles of 25° to each side of the pipe pointing offshore. The maximum discharge velocity is 4 m/s. At intervals of 254 m along the diffuser, the diameter of the diffuser pipe decreases by 1.2 m (4 ft) from an initial diameter of 5.5 m (18 ft) to a final diameter of 3.1 m (10 ft). The decrease in pipe diameter maintains a relatively constant backpressure in the diffuser so the discharge velocity is relatively constant for all 63 ports.

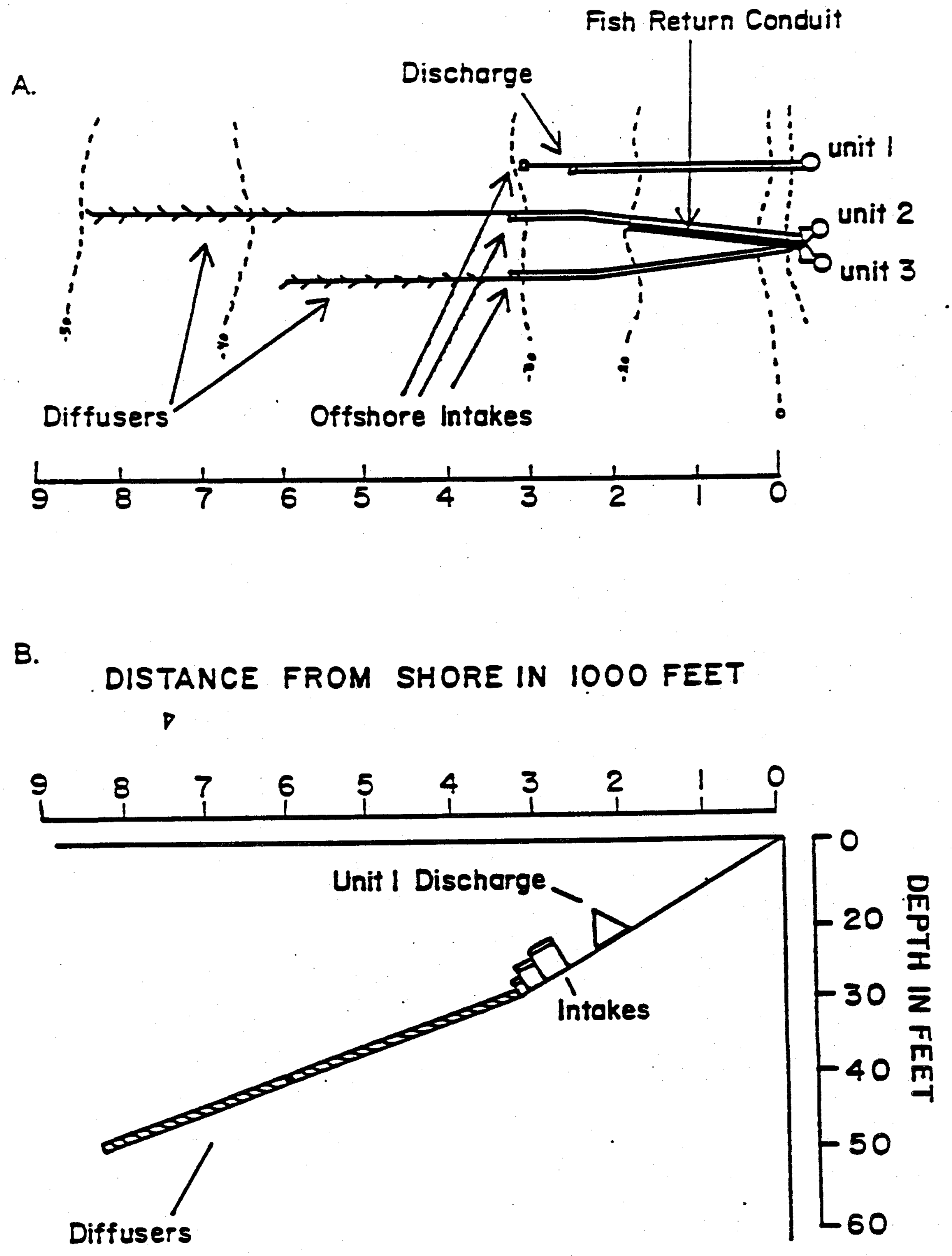

Figure A-1. Schematic of offshore cooling system structures at SONGS.

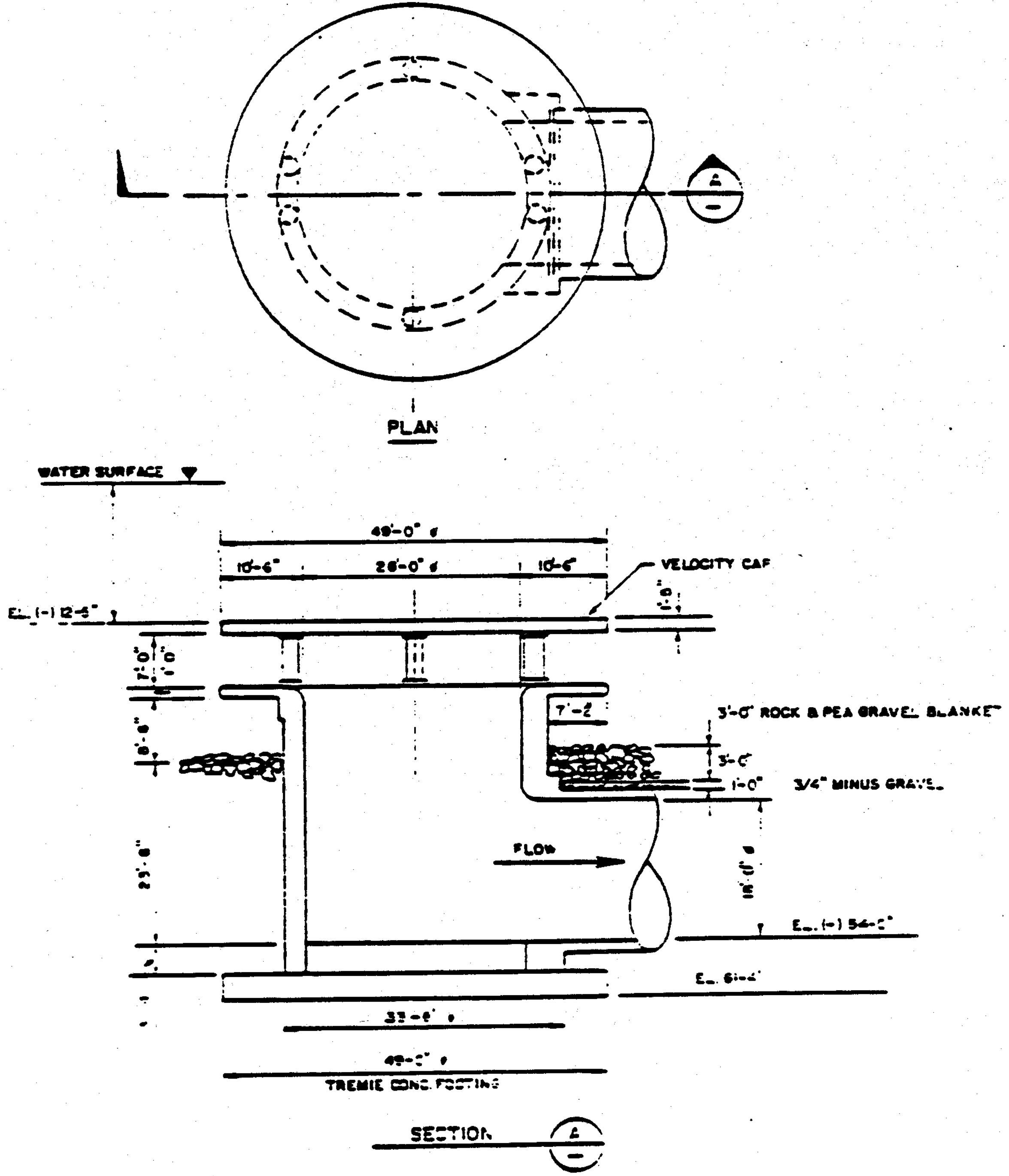

Figure A-2. Offshore intake structure for SONGS Units 2 and 3. Velocity cap serves to reduce the entrapment of fish.

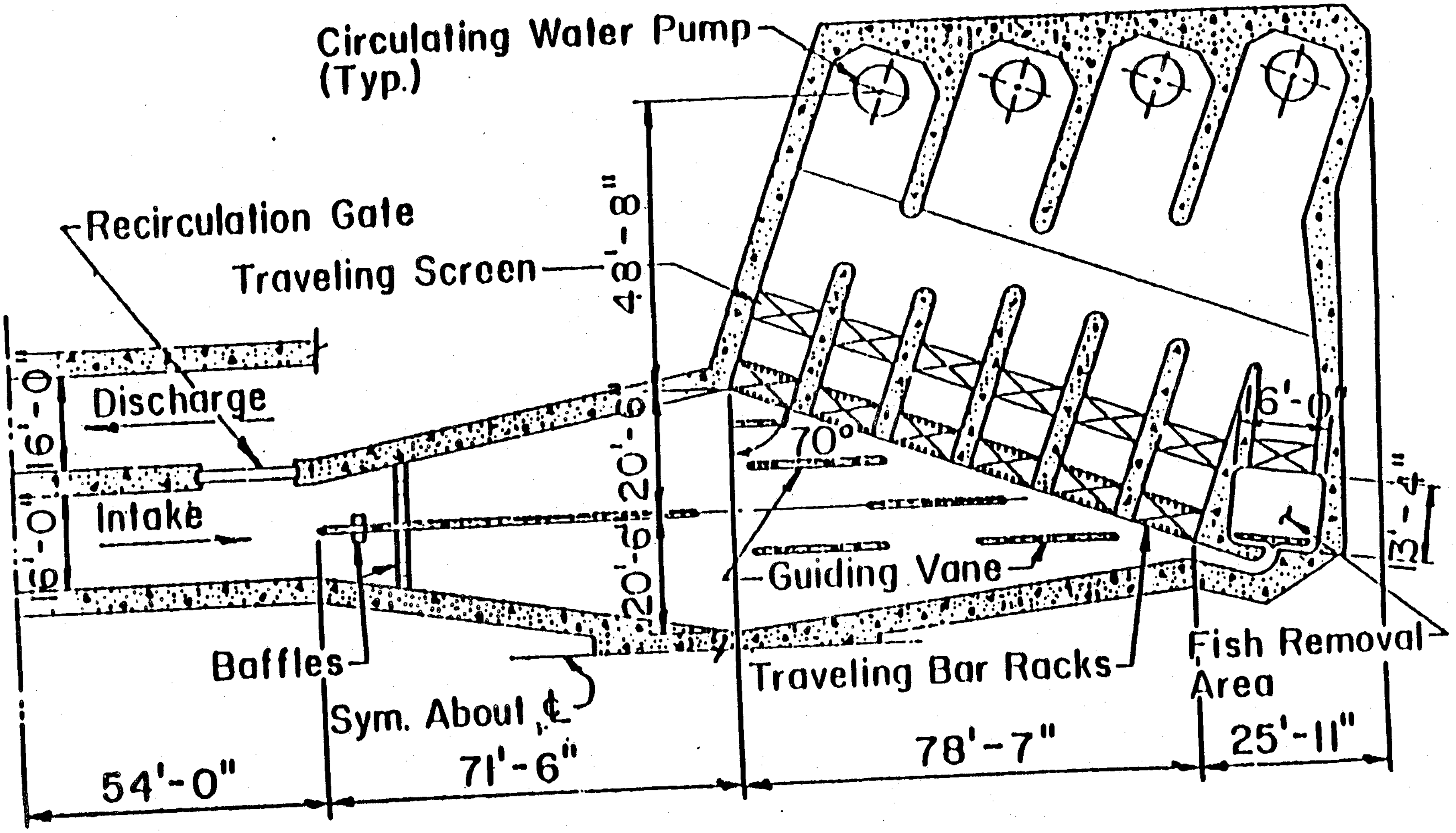

Figure A-3. Screenwell structure at SONGS Units 2 and 3. Shown is the arrangement for Unit 2; Unit 3 screenwell is a mirror image.

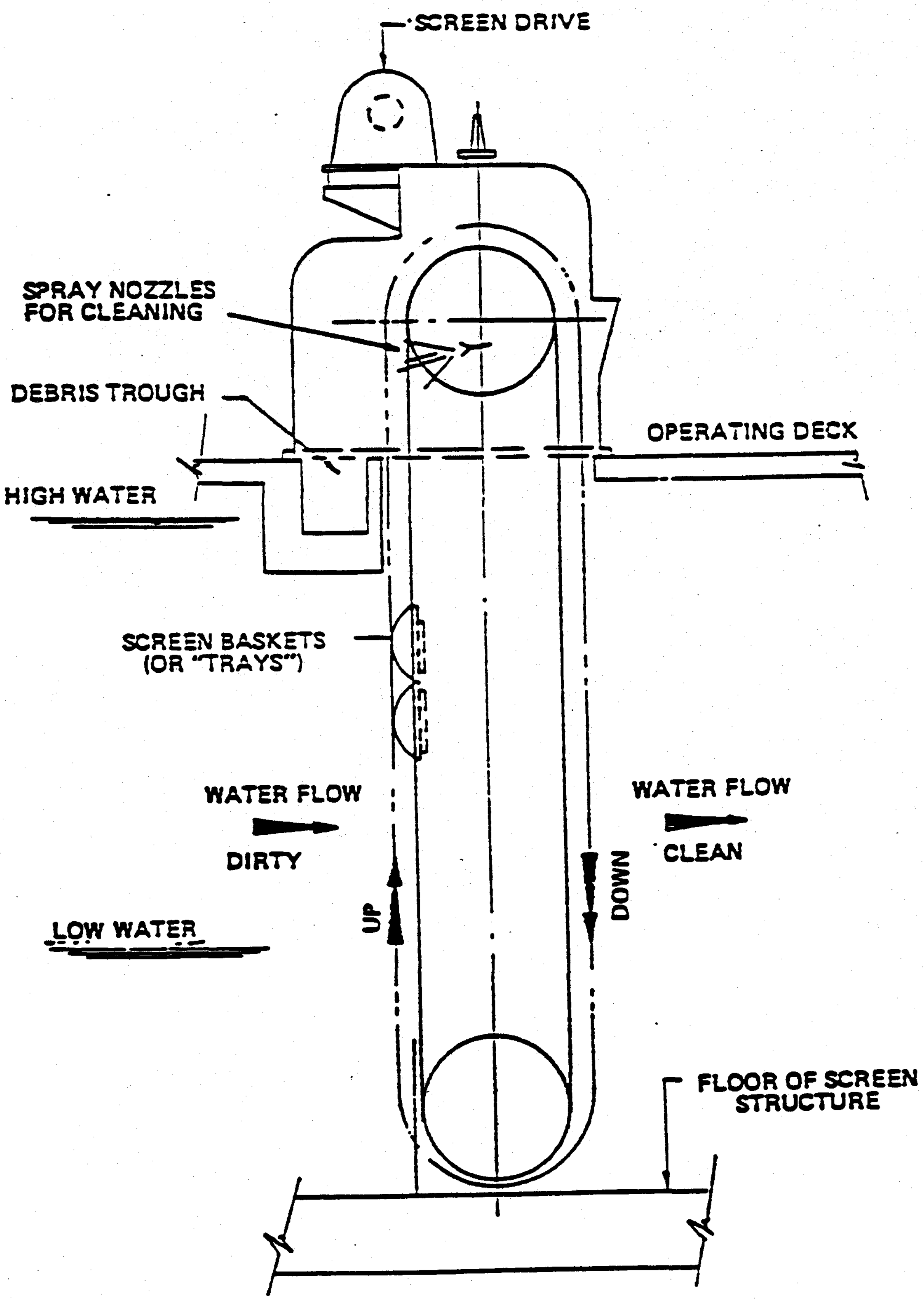

Figure A-4. Diagram of vertical traveling screen used at SONGS Units 2 and 3.

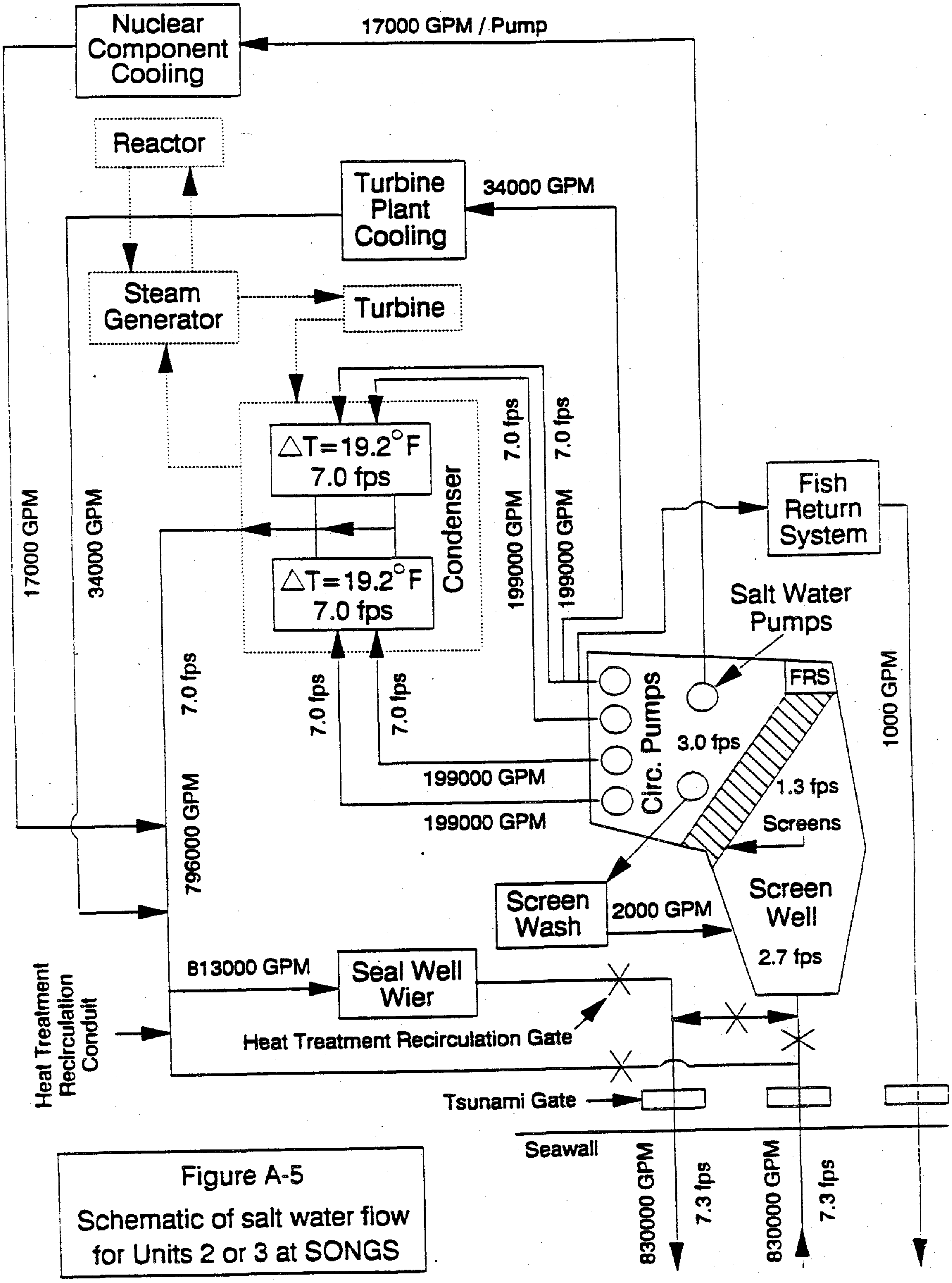

Figure A-5
Schematic of salt water flow for Units 2 or 3 at SONGS

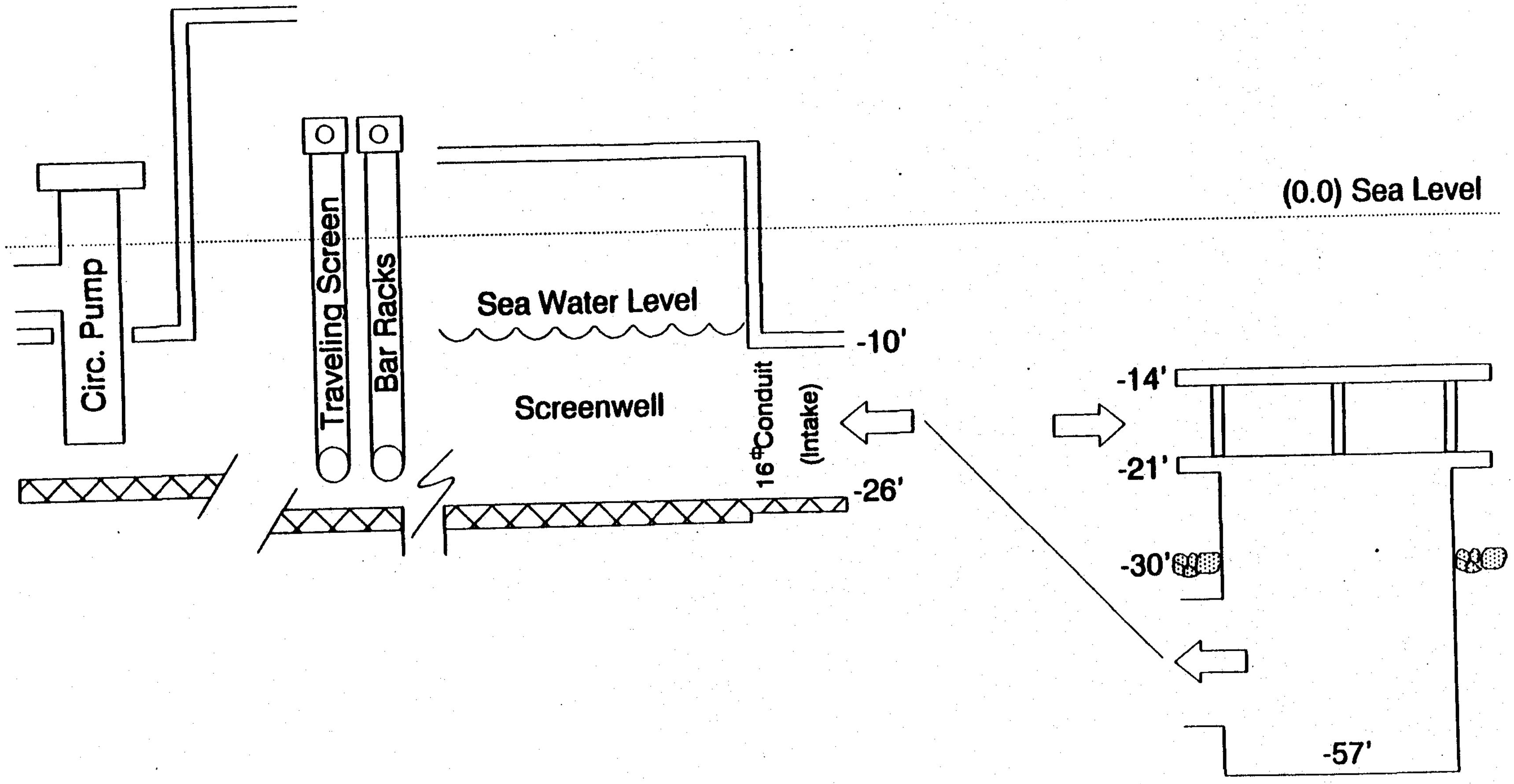

Figure A-6. Elevations of offshore intake and screenwell for SONGS Units 2 & 3.

APPENDIX B

ENTRAINMENT LOSSES OF FISH LARVAE

The most certain technique for reducing the entrainment losses of fish larvae (ichthyoplankton) is to restrict the operations of SONGS. Because entrainment losses are directly related to flow rate, reducing the flow rate will result in a proportionate reduction in entrainment losses; this possibility is discussed in Section 6.2. Rescheduling SONGS' operations to avoid periods of high larval abundances might also substantially reduce entrainment; this possibility is examined in Section 6.3 and this Appendix.

Densities of fish larvae in the field have been used to estimate the entrainment losses due to SONGS. A similar approach was employed to estimate the adult-equivalent loss due to SONGS (Technical Report D). The calculations presented here are not as detailed as those required for the adult-equivalent analysis; only the temporal pattern of larval abundances is needed in order to determine whether a particular period of reduced intake flow could result in a substantial reduction in entrainment losses.

Ichthyoplankton data were collected over a period of eight years and in different areas, as outlined below. In the first part of this Appendix, I compare the temporal abundance patterns of different sample combinations in order to determine the appropriate densities to be used in the analysis. In the second part, I estimate the larval losses that could be prevented by scheduling the operation of SONGS to avoid critical periods (times of particularly high ichthyoplankton abundances).

B1.0 Data Collection

Marine Ecological Consultants Inc. (MEC) estimated the densities of eggs and fish larvae near SONGS from 1978 through 1986. Data were collected at two sites: the Impact site was 1-3 km downcoast from SONGS, and the Control site was 18.5 km downcoast from SONGS. Each site was divided into five cross-shelf blocks (A-, B-, C-, D-, and E-blocks) extending to about 7 km from shore. Three depth strata (bottom 0.5 m, top 0.16 m, and the water in between) were sampled within each block. The two blocks of greatest interest for this analysis are A- and B-blocks; A-block extends to about 1 km offshore, and B-block extends from 1 km to about 2 km. A detailed description of the sampling locations and methods is given in the Interim Technical Report 5 on Fish Larvae and Eggs (MRC 1988). Technical Report D on Adult-Equivalent Loss is also relevant (MRC 1989).

B2.0 Choice of sample densities

Ichthyoplankton were sampled in five different nearshore blocks at two different sites over a period of seven years; it is not clear *a priori* whether it would be most appropriate to combine all the data or to analyze some subset. In this section, I consider: (1) whether to use data from A & B blocks only, or to average across all five cross-shelf blocks; (2) whether to use data for the impact site only, control site only, or combined data; and (3) what years to include, and whether or not to distinguish between preoperational (before July 1983) and operational periods.

B2.1 A and B Block versus Cross-shelf Densities

The intake risers for Units 2 and 3 are located near the boundary of the A- and B-blocks, so the intake water is withdrawn from both of these blocks. Of course, the proportion of water withdrawn from either block probably depends on prevailing oceanographic conditions. It seems most reasonable to assume the number of fish larvae withdrawn into the plant would be best estimated by the densities in A & B blocks. However, it might be better to use the cross-shelf data if its temporal pattern is the same as the pattern in A- and B-block, since it constitutes a larger dataset. Furthermore, some B-block samples were taken as far as 3 km south of the intakes. For these reasons, I have compared the densities in A & B blocks with the densities average across A through E blocks.

When all years and all species are combined, the seasonal pattern of ichthyoplankton abundances in A & B blocks is quite similar to the cross-shelf abundance pattern (Figure B-1). In both cases, ichthyoplankton were most abundant in February, March and April. However, the relative importance of these three months differed. In the cross-shelf pattern, March was had a much higher abundance than either February or April, whereas the abundances were much more even in A & B blocks.

Differences in the abundance patterns between cross-shelf and A- & B-block samples can also be seen for individual species. For example, the pattern for northern anchovy larvae (Figure B-2) is nearly identical to the pattern for all species combined; this is not surprising, since anchovies comprise a majority of the larvae. For queenfish larvae (Figure B-3), the cross-shelf and A- & B-block abundance patterns were not the same. Queenfish larvae were relatively more abundant in the summer months in A & B blocks; the highest abundance in A & B blocks occurred in August, whereas abundances were higher in May when densities are averaged across all blocks.

Because the abundance patterns were somewhat different for A & B blocks compared to cross-shelf and the intake water comes from A & B blocks, I have chosen to use only the data from A & B blocks.

B2.2 Impact versus Control Densities

The analysis of adult-equivalent losses assumes that the average contemporaneous densities at the Impact and Control sites were equal. Parker and DeMartini (Technical Report D) reviewed the data for A- and B-block densities at the two sites during the preoperational period; the operational period data were not reviewed because the ichthyoplankton densities may have been influenced by SONGS. No consistent differences were found between the Impact and Control sites. In this section, I compare the Impact and Control sites over all years sampled.

The temporal patterns of larval densities for all years combined at the Control and Impact sites are presented in Figures B-1, B-2 and B-3; I have chosen to use only data from A & B blocks, so the comparison focuses on these data. For total species and northern anchovy there were slight differences in absolute densities, but the seasonal patterns were very similar at the Control and Impact sites. For queenfish larvae, there was a bimodal abundance pattern at the Impact site that was not present at the Control site.

Differences between the Control and Impact sites can also be seen in Figures B-4 through B-10. These figures present densities at each of the two sampling sites over all of the years sampled for the seven species with densities that exceeded 20 larvae/400 m^3. In all cases, some differences between the two sites can be distinguished, and these differences are frequently substantial. Many species were not consistently more abundant at one site or the other. For example, northern anchovy (Figure B-4) were more abundant at the Impact site in 1980 and at the Control site in 1986. On the other hand, some species, such as jacksmelt (Figure B-10), were generally more abundant at the Impact site, whereas other species, such as arrow goby and shadow goby (Figures B-7 and B-8), were more abundant at the Control site. Note that higher densities at the Control site could be due to SONGS' impact, and for these two species the differences between Impact and Control were most notable after SONGS began operations.

From these data, it is clear that there were no consistent differences between the Control and Impact sites: the relative importance of a site depended on the species and year in question. These variations may or may not be random; it is possible that one site was consistently better for a particular species. Nonetheless, the lack of a consistent difference between the sites suggests that combining the data from the two sites would provide the best estimate of general ichthyoplankton abundance.

B2.3 Interannual Variation in Densities

To evaluate the importance of interannual variation in larval fish densities, the abundance patterns for the nine years between 1978 and 1986 are presented in

Figures B-11 through B-15. Note that relatively few months were sampled in some years, no samples were taken in 1982, and SONGS began operations in July 1983.

There clearly were substantial differences between years. The total ichthyoplankton achieved high densities in 1980 and 1986, apparently with much lower densities in intervening years (Figure B-11); however, the period of highest abundance when all years are combined, March and April, was not sampled in most years. Northern anchovies (Figure B-12), which constitute the largest component of the ichthyoplankton, and white croaker (Figure B-13) followed the same pattern. When northern anchovy is excluded, the abundance of all other species is somewhat lower in February and somewhat higher in August, but otherwise the pattern is similar (Figure B-14). The overall abundance pattern for queenfish was produced almost entirely by the pattern in 1980, when queenfish appeared to be most abundant (Figure B-15). Note that arrow goby and shadow goby (Figures B-7 and B-8) appeared to have increased between 1979 and 1986.

As with the comparison between Impact and Control sites, there were no consistent differences among years. In addition, sampling was not intense enough in each year to choose a subset of years. It seems that combining all years sampled would provide the best estimate of <u>general</u> ichthyoplankton abundance. However, it is important to realize that some months were only sampled in one or a few years, so the data are not based on a very large sample size. (On the other hand, it is worth noting that this is perhaps the best ichthyoplankton dataset ever collected for a segment of Southern California coastline.)

B3.0 Calculation of potential savings

This section considers how the number of fish larvae that are entrained by SONGS could be reduced by restricting the operation of SONGS during periods of high ichthyoplankton abundances. Current estimates of losses of fish larvae (about $5x10^9$ larvae/year; see Technical Report D and Interim Technical Report 5) are based on the operating history of SONGS, that is, the past flow rates. The flow rates used in calculations of ichthyoplankton losses included all periods of reduced operations, including scheduled outages.

In this section, I evaluate how scheduling outages during the period of maximum ichthyoplankton abundance could reduce overall larval losses. First, I consider the past operating history of SONGS in order to provide a basis against which proposed changes can be compared. Next, I consider how the timing of outages could affect the number of fish larvae entrained at SONGS. I calculate how many larvae would be spared by stopping the flow of water through SONGS during a particular period of time. Of course, larvae are not entrained during outages under the current operating schedule; we are interested in the difference in larval entrainment between the current schedule and an alternative schedule. Therefore, the number of larvae not entrained under a proposed operating schedule is adjusted by the number that would not be entrained under the current operating schedule.

One final concern is also discussed. When SONGS does not operate, power production must be increased at other Southern California Edison facilities. I consider whether an alternative operating schedule would result in higher larval entrainment at these other facilities.

B3.1 Operating history of SONGS

Larval losses will be reduced any time SONGS operates at a lower than normal flow rate. Operating SONGS at a sustained reduced flow rate is considered in Section 6.2. This Appendix considers the resource savings that can be achieved by scheduling SONGS' operations to avoid periods of high larval abundances, so I focus on periods when there is no flow through SONGS, and hence no loss of ichthyoplankton.

Figure B-16 shows the total number of days Units 2 and 3 did not operate between the period January 1, 1984 and July 31, 1988 (1674 days). During this period, Units 2 and 3 did not produce power an average of 32% of the days, or about 116 days/year. Some of these periods of no power were caused by unscheduled outages (see Table 6-3). Periods of no flow occur during scheduled outages at fairly regular intervals of about 14 months (Figure B-17). On average, Units 2 and 3 had no flow 12.5% of the days, or about 46 days/year. Most scheduled refueling periods lasted for about two months (Figure B-17, Table 6-3), but of course the annual average was less than two months because the scheduled outages did not occur at 12-month intervals.

In the future, Units 2 and 3 may operate at a somewhat different rate. Future fuel cycles are scheduled to be 525 Effective Full Power Days (EFPDs) long, or about 18 months. Unscheduled outages might also be less frequent now that SONGS has been through several fuel cycles. Future refueling periods are scheduled to be 70 days long (D. Pilmer, *personal communication*). In spite of these possible future changes, the data presented in this section are indicative of the type of operating schedule expected and are therefore used as the baseline against which a proposed new schedule can be compared.

B3.2 Larvae entrained by SONGS

In this section, I calculate the number of fish larvae that would be entrained if SONGS were to operate at 100% flow during the period of highest ichthyoplankton abundance. I have targeted 13 species with high estimated adult equivalent losses (see Table B-1; unidentified kelpfish, which has an estimated adult-equivalent loss of 4.97%, is the only species with >1% AEL that was not analyzed), as well as total ichthyoplankton, northern anchovy, and total minus anchovy. Several different periods of time are considered, ranging from two to three months long.

Fish larvae were most abundant during February through April (Table B-2; Figures 6-3 and B-1). For all species combined, 31% of the annual abundance occurred in March, 24% in April and 17% in February (Table B-3); thus, 55% of the ichthyoplankton occurred in 2 months and 72% of the ichthyoplankton occurred in 3 months. This pattern is strongly influenced by northern anchovy because it is by far the most abundant species. However, the general pattern exists when anchovies are excluded (Figure 6-3), and 53% of the total ichthyoplankton minus anchovies occurred in March and April (Table B-3). The main contribution of anchovies to the abundance pattern is to increase the importance of February; when anchovies are excluded, only 7% of the ichthyoplankton occurred in February.

Data on the combined ichthyoplankton taxa demonstrate that a disproportionate number of larvae occur during a few months, so that restricting the operation of SONGS during those months could result in a substantial reduction in losses. Of course, individual taxa have different abundance patterns. Table B-3 presents the larval abundance of 13 species with estimated adult equivalent losses (AELs) exceeding 1% (Technical Report D). Many of the species with high AELs were abundant in March and April. Nine species (queenfish, giant kelpfish, white croaker, black croaker, cheekspot goby, arrow goby, jacksmelt, shadow goby and diamond turbot) had more than 10% of their larvae in March, while seven species (queenfish, giant kelpfish, white croaker, California grunion, arrow goby, jacksmelt and California clingfish) had more than 10% of their larvae in April. Only three species (giant kelpfish, shadow goby and diamond turbot) had more than 10% of their larvae in February.

The estimated number of larvae that would be entrained (and, hence, the losses that would be prevented if SONGS didn't operate) are presented in Table B-4 for three periods: March and April, February through April, and March, April and August. Based on the general pattern of ichthyoplankton abundance and the abundances of the 13 species with high AELs, March and April would be the two best months to eliminate the flow of water through SONGS. Nearly 3.3 billion larvae would be entrained in March and April if SONGS operates at full flow; more than 2 billion of these larvae would be northern anchovies. In addition, more than 1 billion larvae of the 13 species with AELs >1% would be entrained during March and April. However, few of the species with high AELs are common, and only queenfish and white croaker would have more than 100,000 larvae entrained during March and April.

Restricting the operation of SONGS during February would also disproportionately reduce the total loss of ichthyoplankton (Table B-4), since about 1 million larvae are entrained in February, but the reduction would consist primarily of anchovies, which have an estimated adult equivalent loss of less than 0.1%. Giant kelpfish, with an estimated adult equivalent loss of 6.88%, were much more abundant in February than other months (Table B-2). However, relatively few giant kelpfish larvae are entrained ($6.98x10^6$ per year; of the 13 target species, only black croaker had fewer larvae entrained), and losses to this species could be compensated in-kind by building an artificial reef with kelp. As in March and April, white croaker is the AEL species with by far the greatest number of larvae entrained.

A number of ichthyoplankton species were most abundant in summer (Table B-3), as reflected in the small peak in abundance in August (Figure 6-3). Species with high AELs and high larval abundances in summer include queenfish, California grunion, black croaker, California corbina, reef finspot and California clingfish. Compared to the nine species with high AELs and >10% abundance in March, six species had >10% abundance in August. Furthermore, four of these species (black croaker, California corbina, reef finspot and California clingfish) were much more abundant in August than in March.

Substantial losses in some of the most-impacted species could be avoided by scheduling the plant for no flow in August as well as in March and April. The number of queenfish larvae entrained in August is equal to the number entrained in March and April combined (Table B-4). Although black croaker and California corbina were not common, they were very abundant in August, with 1.5 and 6 million larvae entrained in that month, respectively (Table B-4).

Finally, note that very few species were abundant in September through January (Table B-3); only 11% of the ichthyoplankton occurred during this four-month period. Coincidentally, this is the period when SONGS most frequently had no-flow conditions (Figure B-16). In addition, SONGS has had relatively few no-flow days in March and April, when the ichthyoplankton were most abundant, or even in July and August, when some of the species with high AELs were most common. The past operating history of SONGS has by chance been almost the opposite of the optimal schedule for reducing ichthyoplankton losses.

B3.3 Larvae spared under present schedule

The number of days offline/year was used to estimate the number of larvae that are spared under the present operating schedule. (Under actual conditions, SONGS also sometimes operates at less than full flow, but this has been ignored for the sake of simplicity in this analysis.) Note that SONGS is not offline at the same time each year (Figure B-17), but rather can be offline in any month. Over a long period of time, each month would be expected to have the same number of no-flow days. (Figure B-16 demonstrates that this has not been the case over the past few years, but eventually it should be.) Therefore, the total number of larvae that are spared under the present schedule is estimated by using the average entrainment rate over all months, as follows:

$$\text{Number of Larvae Spared Per Year} = \text{Mean Density of Larvae} \times \text{Flow Volume Per Month} \times \text{No. Months With No Flow Per Year}$$

For example:

$$\text{Total No. of Larvae Spared Per Year} = 1.78/\text{m}^3 \times 2.76\text{x}10^8\ \text{m}^3/\text{mo} \times 1.5\ \text{mo}$$

$$= 7.37\text{x}10^8\ \text{larvae}$$

A similar procedure was used to calculate the number of larvae of individual species that are spared under the present schedule.

Under the present operating schedule, 737 million larvae are spared during the 1.5 months of the year when SONGS has no flow (Table B-5). Most of these larvae (62%) are northern anchovies, but 245 million of the larvae belong to the 13 species with high AELs.

B3.4 Potential reduction in entrainment of fish larvae

To estimate roughly the number of larvae that can be saved by rescheduling the operation of SONGS, the number of larvae that would be spared using the present schedule (Table B-5) has been subtracted from the number entrained during the critical months (Table B-4). The ichthyoplankton losses that might be prevented by rescheduling SONGS over three different periods are presented in Table B-5. For example, if the flow of cooling water through SONGS was stopped during March and April, roughly 2.5 billion *fewer* larvae would be killed than under the present operating schedule. This would cut the current estimated losses in half.

The savings could be increased to 68% of the current losses by also eliminating the cooling system flow in February.

When only the 13 species with high AELs are considered, 827 million fewer larvae would be killed by not operating SONGS in March and April; this savings could be increased to more than 1 billion larvae by also not operating SONGS in August. The additional benefit of not operating SONGS in August is not obvious when the numbers of all high-AEL species are combined because white croaker, which are not abundant in August, are by far the most abundant species. However, the importance of August is clear when the average reduction is calculated. The mean reduction in entrainment for the 13 high-AEL species is 18% in March & April, 25% in February, March & April, and 37% in March, April and August.

The savings that could be obtained by rescheduling SONGS' operations would vary from species to species. With SONGS offline in March and April, the loss of white croaker, which has one of the highest AELs, could be reduced from 875 million larvae to 210 million larvae, a reduction of 76%. Having no flow during March and April would cut the losses of northern anchovies and jacksmelt in half.

On the other hand, not all species would necessarily benefit from rescheduling SONGS. Although March and April may be overall the best months for scheduling SONGS to be offline, some species may experience somewhat higher losses as a result. Of the 13 species with high AELs, 1.1 million more California corbina and 1.06 million more reef finspot would be entrained if SONGS is offline in March and April (Table B-5); for both species, this would be an increase of about 14% in the number of larvae killed. However, including August in the time period

SONGS is scheduled to be offline would result in a substantial reduction in losses to these two species. In fact, none of the 13 high-AEL species would experience less than a 12% reduction in losses if SONGS is scheduled to have no flow in March, April & August, and jacksmelt, California corbina, white croaker, queenfish and northern anchovy would experience a 50-75% reduction in losses.

The savings calculated in this section were based on SONGS' recent operating history, i.e., 46 days per year with no flow through the plant. The savings would be lower if SONGS operates in the future with fewer days with no flow. The savings would be only half as great if only one unit was offline each year, as would be the case if SONGS operated on a 24-month fuel cycle.

B3.5 Larvae entrained at other power stations

If rescheduling SONGS means that more larvae will be impinged at other power stations, the savings attributed to the the rescheduling must by adjusted by the increased losses elsewhere. In order to evaluate this possibility, we need to know the seasonal pattern of entrainment at the stations that would be used to generate power when SONGS is offline.

One approach to making this adjustment would be to compare the daily entrainment rate at SONGS by month with the daily entrainment rate at other stations by month. The comparison would be based on the absolute number of larvae entrained or, better still, the number of larvae entrained per megawatt of electricity (MW_e) generated, since that is what will determine how much water is pumped through the other plants. (Note that nuclear power plants use more water per MW_e than fossil fuel plants.) The analysis for each plant would parallel the analysis performed for SONGS, with the larval entrainment under the mitigation schedule compared to the entrainment under the present operating schedule. Unfortunately, this approach is complicated by the fact that we don't know which station is likely to be used as an alternative to SONGS (SCE chooses the alternative based on a complex set of factors, including cost of fuel and emissions) and we don't have their operating histories.

A simpler approach to this problem would be to ask whether increased operations at other SCE generating stations in February, March, April or August would result in disproportionate losses. I have used SCE data to examine the seasonal entrainment patterns of ichthyoplankton at other SCE stations. SCE does not collect ichthyoplankton abundance data near all of its offshore intakes. Instead, Schlotterbeck *et al.* (1979) categorized the physical and biological characteristics of the several intake types in the SCE system. Data from Ormond Beach Generating Station (OBGS), identified as representative of offshore velocity cap intakes, were used to estimate entrainment at El Segundo and Huntington Beach Generating Stations. Data from Haynes Generating Station (actually run by Los Angeles Water and Power), representative of canal/embayment harbor intakes, were used to estimate entrainment at Mandalay, Long Beach and Alamitos Generating Stations. Data were also collected at both the offshore (Units 7 & 8, near the mouth of King Harbor) and harbor (Units 1-6, within King Harbor) intakes at the Redondo Beach Generating Station (RBGS). In all cases, ichthyoplankton were sampled over about one year, so it is not possible to consider year-to-year variations, and it is possible that the year sampled (1979-1980) was not representative of the long-term average.

There were two distinct temporal patterns of entrainment for these stations (Figure B-18). Ormond Beach and Redondo Beach Units 7 & 8, which have offshore intakes, had temporal patterns that were fairly similar to SONGS: the greatest entrainment occurred in March. At OBGS, the high entrainment in March was due to both northern anchovies (20.7% of the total annual entrainment) and white croaker (14.6%); 14% of the larvae were entrained in April, and no other month contributed >10%. The pattern was somewhat different at RBGS Units 7 and 8, which entrained a great many white croaker larvae in January as well as March; no other month contributed >10%.

A different pattern occurred at HGS and RBGS Units 1-6, where highest entrainment occurred during the summer months. At HGS, entrainment was dominated by *Hypsoblennius* and gobies, and May, June and August each contributed >10% of the total annual entrainment. RBGS 1-6 entrained many cheekspot gobies and reef finspots, especially in June and September, although July also contributed >10% of the total annual entrainment.

The entrainment at HGS and RBGS 1-6 was relatively low during February through April, so that increasing power production at these plants (and presumably Mandalay, Long Beach and Alamitos Generating Stations) if SONGS is scheduled down during this time would not result in higher total entrainment. Although entrainment was highest in the summer at HGS and RBGS 1-6, it was only 11% and 9%, respectively, during August, so that increasing power production during this time would not result in high additional losses. The entrainment at RBGS 7 & 8 and OBGS was more similar to SONGS, although white croaker was more important at RBGS than at SONGS. Increasing pumping at RBGS 7 & 8 during

March and OBGS (and presumably Huntington Beach and El Segundo Generating Stations) during March and April would result in somewhat higher total larval losses at those stations, so if these stations operate at a higher level because SONGS is offline during March and April, the savings calculated above would need to be adjusted downward somewhat.

I have not attempted a quantified adjustment because SCE's entrainment data were collected during only one year, while the MRC's data from the Impact and Control sites clearly show large interannual differences.

APPENDIX B

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Table B-1

Common and scientific names of fish species.

Northern anchovy and 13 species with estimated adult equivalent losses >1% were targeted. Adult equivalent losses from Technical Report D. AEL = Adult equivalent loss.

SPECIES/GROUP	SCIENTIFIC NAME	% AEL
Queenfish	*Seriphus politus*	12.70
Giant kelpfish	*Heterostichus rostratus*	6.88
White croaker	*Genyonemus lineatus*	7.50
California grunion	*Leuresthes tenuis*	4.59[1]
Black croaker	*Cheilotrema saturnum*	3.89[1]
California corbina	*Menticirrhus undulatus*	3.55[1]
Cheekspot goby	*Ilypnus gilberti*	3.04
Reef finspot	*Paraclinus integripinnis*	2.86
Arrow goby	*Clevelandia ios*	2.60
Jacksmelt	*Atherinopsis californiensis*	2.45[1]
Shadow goby	*Quietula y-cauda*	2.14
Diamond turbot	*Hypsopsetta guttulata*	2.06
California clingfish	*Gobiesox rhessodon*	1.43
Northern anchovy	*Engraulis mordax*	<0.10

[1] Loss through juvenile stage inestimable (see Technical Report D)

Table B-2

Monthly densities of fish larvae near SONGS.

Data are densities (number of larvae/400 m^3) for total species, northern anchovy (the most abundant species), total species minus anchovy, and 13 species with estimated adult equivalent losses >1%. Densities based on A- and B-blocks, Impact and Control, all years combined.

SPECIES/ GROUP	TOTAL	DENSITY (#/400 M^3)											
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Total	8542	146	1484	2651	2090	513	218	190	418	245	55	129	400
Northern Anchovy	5282	89	1261	1762	1259	230	50	43	96	122	14	29	329
Total minus anchovy	3260	57	224	888	834	284	168	145	322	126	41	101	71
Queenfish	789	0	7	92	134	84	90	83	224	656	8	0.2	0.04
Giant kelpfish	10.1	0	3.3	1.2	1.1	1.3	0.6	0.5	0.4	0.7	0.4	0	0.6
White croaker	1449	7	144	576	578	65	8	2	3	1	2	49	14
California grunion	29.4	0	0	0.3	5.8	10.5	9.1	2.6	0.9	0.1	0	0	0
Black croaker	5.8	0	0	0.8	0	0.6	1.5	0.6	2.1	0.3	0	0	0
California corbina	13.0	0	0	0	0	0.5	0.2	0.6	9	2.5	0.1	0	0
Cheekspot goby	238	13	10	29	10	29	14	14	15	22	12	34	37
Reef finspot	13.0	0	0	0.1	0	0	0.7	6.5	4.6	0.5	0.5	0	0
Arrow goby	89	2	5	25	12	14	7	10	3	5	3	5	1
Jacksmelt	136	16.1	10.4	54.7	23.2	24.3	1.0	0.02	0	0.03	0.4	0.4	5.5
Shadow goby	36.9	1.5	5.0	5.7	1.8	4.1	1.1	3.7	3.9	3.2	1.6	1.7	3.7
Diamond turbot	18.5	0	3.2	5.5	1.3	0.8	0.2	0	0.2	1.7	0.5	4.9	0.1
California clingfish	16.9	0	0	0.6	4.4	1.4	3.3	3.1	2.2	1.6	0.2	0	0
Total AEL species	2844	39	187	790	771	235	136	127	269	104	29	95	62

Table B-3

Temporal patterns of ichthyoplankton abundance near SONGS.

Data are presented for total species, northern anchovy (the most abundant species), total species minus anchovy, and 13 species with estimated adult equivalent losses >1%. Densities based on A- and B-blocks, Impact and Control, all years combined. Months with >10% of the total abundance are shown in boldface type.

SPECIES/ GROUP	PERCENT OF TOTAL ABUNDANCE											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Total	1.7	**17.4**	**31.0**	**24.5**	6.0	2.6	2.2	4.9	2.9	0.6	1.5	4.7
Northern Anchovy	1.7	**23.9**	**33.4**	**23.8**	4.4	0.9	0.8	1.8	2.3	0.3	0.5	6.2
Total minus anchovy	1.7	6.9	**27.3**	**25.5**	8.7	5.1	4.5	9.9	3.9	1.3	3.1	2.2
Queenfish	0	0.9	**11.7**	**17.0**	**10.6**	**11.5**	**10.6**	**28.4**	8.3	1.1	0.03	0.004
Giant kelpfish	0	**32.1**	**12.1**	**10.9**	**12.8**	5.7	5.0	3.9	7.2	3.9	0	6.4
White croaker	0.5	9.9	**39.7**	**39.9**	4.5	0.6	0.2	0.2	0.1	0.1	3.4	0.9
California grunion	0	0	1.1	**19.8**	**35.7**	**30.8**	8.9	3.2	0.5	0.04	0	0.006
Black croaker	0	0	**13.3**	0.06	**10.3**	**25.0**	**10.3**	**35.9**	5.2	0	0	0
California corbina	0	0	0	0	3.8	1.2	5.0	**69.8**	**19.2**	1.1	0	0
Cheekspot goby	5.4	4.4	**12.2**	4.1	**12.0**	5.7	5.8	6.4	9.2	5.1	**14.3**	**15.6**
Reef finspot	0	0	0.4	0	0	5.5	**50.5**	**35.3**	4.1	4.2	0	0
Arrow goby	1.8	5.4	**27.6**	**13.0**	**15.6**	7.3	**10.7**	3.6	5.1	2.9	5.4	1.6
Jacksmelt	**11.8**	7.7	**40.2**	**17.1**	**17.9**	0.7	0.02	0	0.02	0.3	0.3	4.0
Shadow goby	4.0	**13.5**	**15.4**	4.8	**11.1**	2.9	**10.0**	**10.6**	8.7	4.4	4.7	9.9
Diamond turbot	0	**17.1**	**29.9**	7.1	4.4	1.1	0.09	1.3	9.3	2.6	**26.6**	0.5
California clingfish	0	0	3.5	**26.0**	8.4	**19.7**	**18.6**	**13.2**	9.2	1.4	0	0
Total AEL species	1.4	6.6	**27.8**	**27.1**	8.3	4.8	4.5	9.5	3.7	1.0	3.3	2.2

Table B-4

Anticipated ichthyoplankton entrainment at SONGS.

Data are presented for total species, northern anchovy (the most abundant species), total species minus anchovy, and 13 species with estimated adult equivalent losses >1%. Number of larvae entrained is estimated by multiplying ichthyoplankton density times the flow rate at SONGS (9.07×10^6 m^3/day for Units 2 and 3 combined) times the number of days in the period being considered.

SPECIES/ GROUP	NUMBER ENTRAINED (X 10^9) MARCH & APRIL	FEBRUARY, MARCH & APRIL	MARCH, APRIL & AUGUST
Total	3.28	4.22	3.57
Northern anchovy	2.1	2.9	2.17
Total minus anchovy	1.19	1.33	1.42
Queenfish	0.156	0.1603	0.316
Giant kelpfish	0.0017	0.0038	0.002
White croaker	0.79	0.881	0.792
California grunion	0.0042	0.0042	0.0049
Black croaker	0.0005	0.0005	0.002
California corbina	0	0	0.006
Cheekspot goby	0.0276	0.0342	0.0386
Reef finspot	0.00004	0.00004	0.00304
Arrow goby	0.0249	0.0279	0.0272
Jacksmelt	0.054	0.061	0.054
Shadow goby	0.0052	0.0084	0.0079
Diamond turbot	0.0049	0.0069	0.0051
California clingfish	0.0034	0.0034	0.005
Total AEL species	1.0724	1.1916	1.2637

Table B-5

Possible reduction in entrainment of fish larvae from rescheduling.

Data are presented for total species, northern anchovy (the most abundant species), total species minus anchovy, and 13 species with estimated adult equivalent losses >1%. Loss prevented was calculated as the number of larvae that would be entrained in the months noted (see Table B2) minus the number that would not be entrained under the present operating schedule.

Species/ Group	No. spared per year at present	Annual Loss Prevented by Eliminating Flow During:					
		March & April		February, March & April		March, April & August	
	x 10^9	x 10^9	%	x 10^9	%	x 10^9	%
Total	0.7368	2.5432	49	3.4832	68	2.8322	55
Northern anchovy	0.4556	1.6444	52	2.4444	77	1.7414	54
Total minus anchovy	0.2812	0.9088	46	1.0488	53	1.1388	58
Queenfish	0.0681	0.0879	18	0.0922	19	0.2479	52
Giant kelpfish	0.0009	0.0008	13	0.0029	48	0.0011	18
White croaker	0.1250	0.6650	76	0.7560	86	0.6670	76
California grunion	0.0025	0.0017	10	0.0017	10	0.0024	13
Black croaker	0.0005	0.000002	0.06	0.000002	0.06	0.0015	43
California corbina	0.0011	-0.0011	-14	-0.0011	-14	0.0049	63
Cheekspot goby	0.0206	0.0070	5	0.0136	9	0.0180	12
Reef finspot	0.0011	-0.00106	-14	-0.00106	-14	0.0019	24
Arrow goby	0.0077	0.0172	32	0.0202	37	0.0195	36
Jacksmelt	0.0117	0.0423	52	0.0493	60	0.0423	52
Shadow goby	0.0032	0.0020	9	0.0052	23	0.0047	21
Diamond turbot	0.0016	0.0033	30	0.0053	48	0.0035	32
California clingfish	0.0015	0.0019	19	0.0019	19	0.0035	34
Total AEL species	0.2455	0.826942	48	0.946142	55	1.018242	59

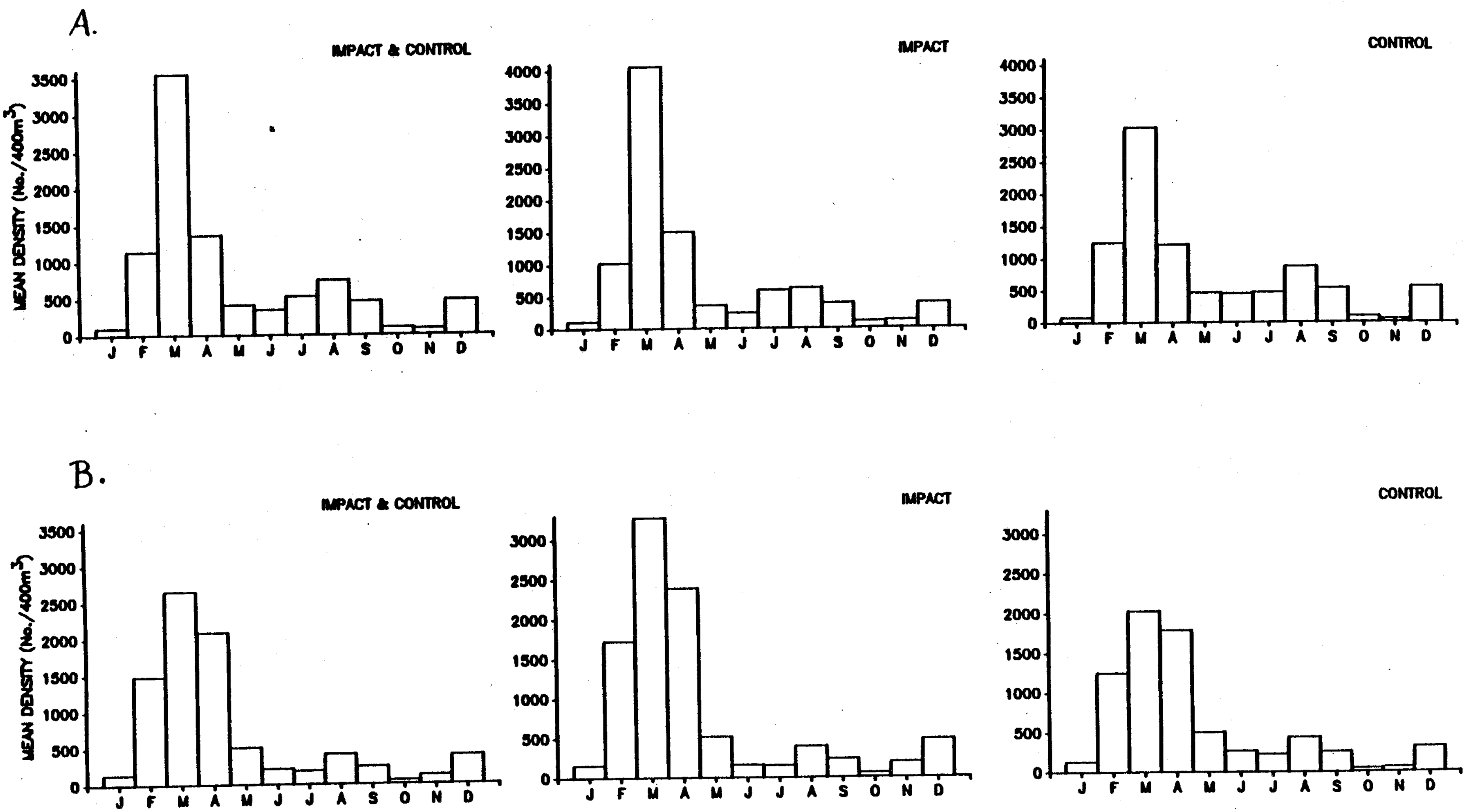


Figure B-1 Seasonal pattern of total ichthyoplankton abundances, all years combined. (A) Cross-shelf (A through E blocks). (B) A & B blocks. Seasonal patterns are presented for the Impact (SONGS) and Control sites combined and for each site separately.

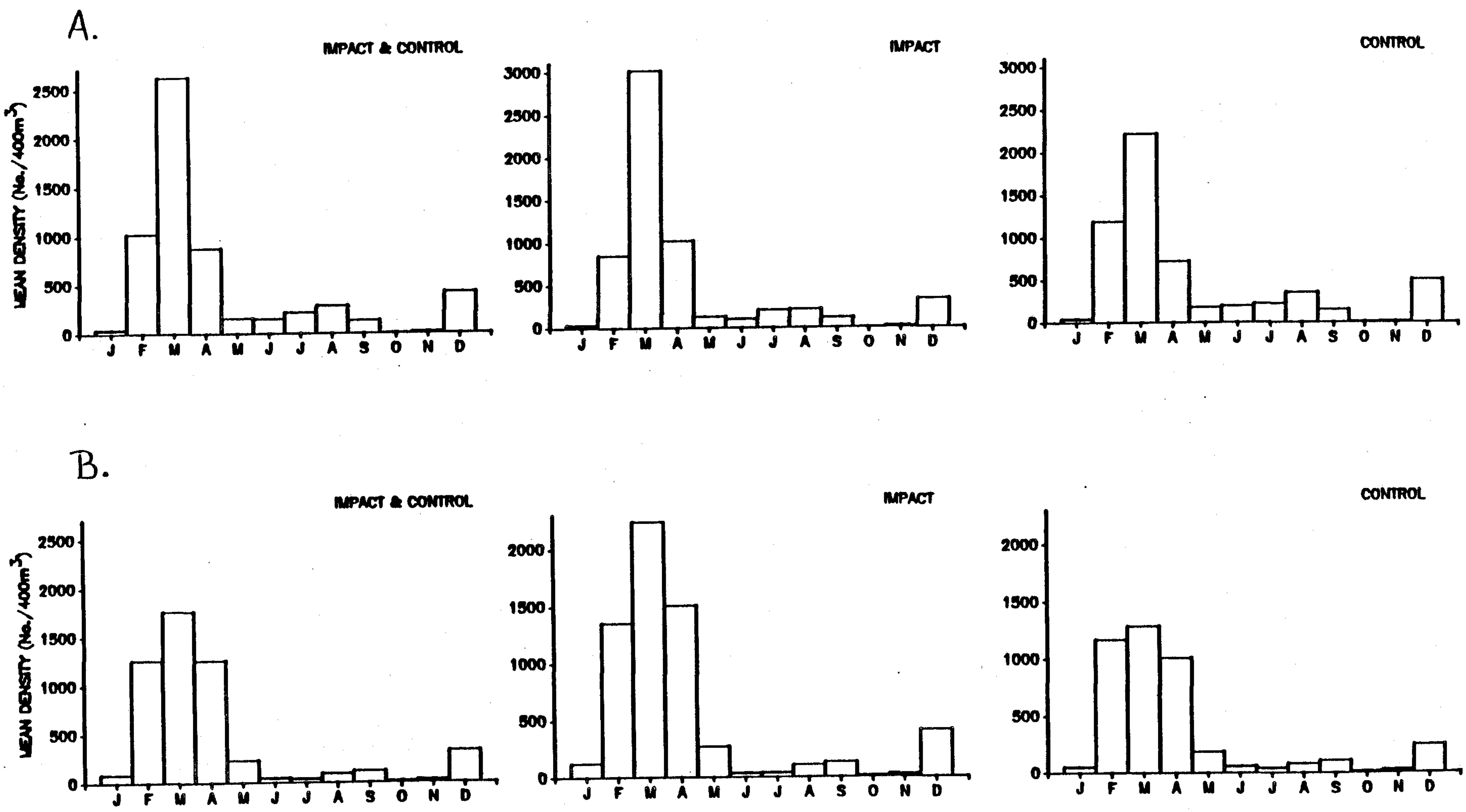


Figure B-2 Seasonal pattern of larval northern anchovy densities, all years combined. (A) Cross-shelf (A through E blocks). (B) A & B blocks. Seasonal patterns are presented for the Impact (SONGS) and Control sites combined and for each site separately.

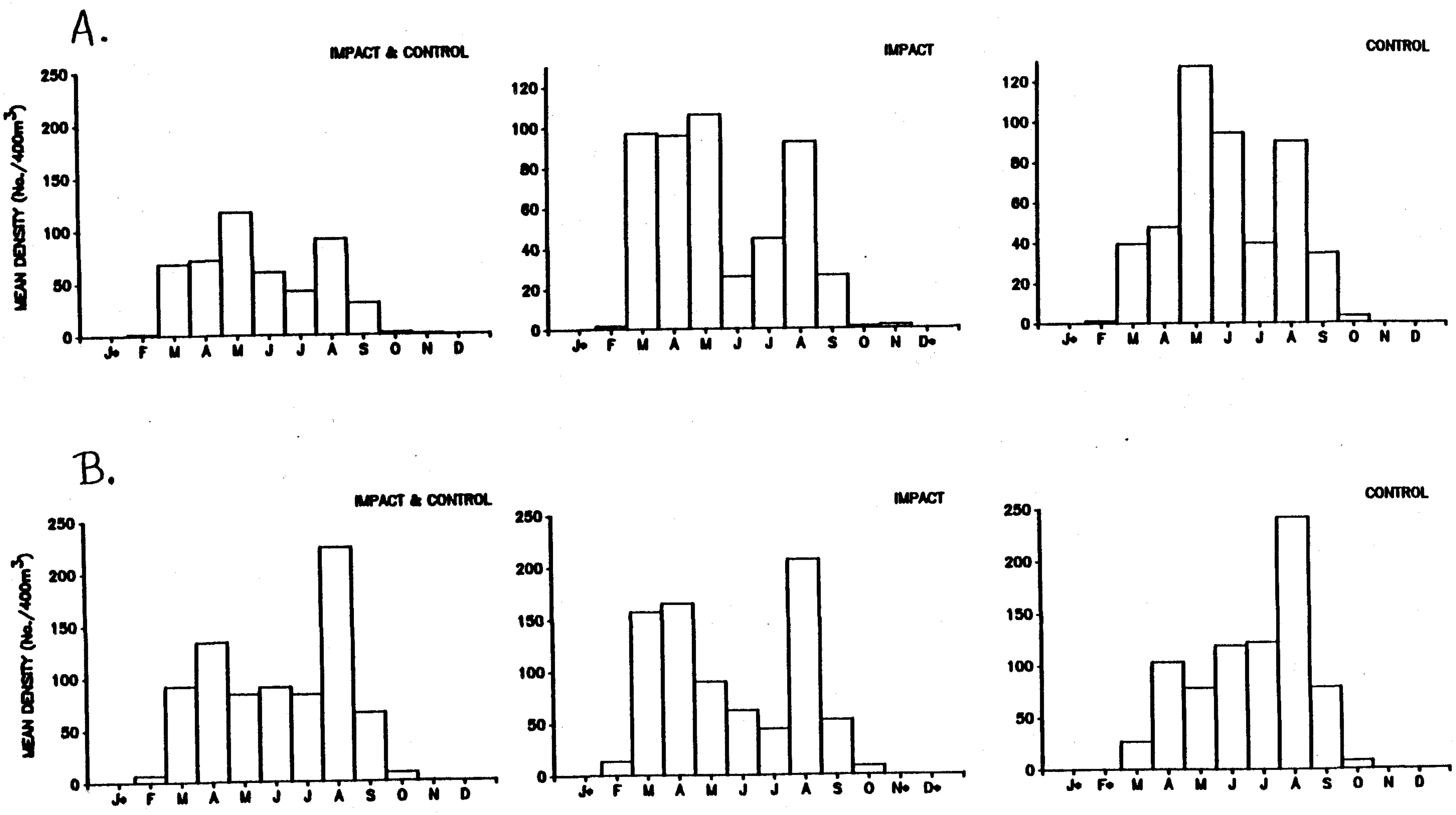


Figure B-3 Seasonal pattern of larval queenfish densities, all years combined. (A) Cross-shelf (A through E blocks). (B) A & B blocks. Seasonal patterns are presented for the Impact (SONGS) and Control sites combined and for each site separately. * indicates zero density.

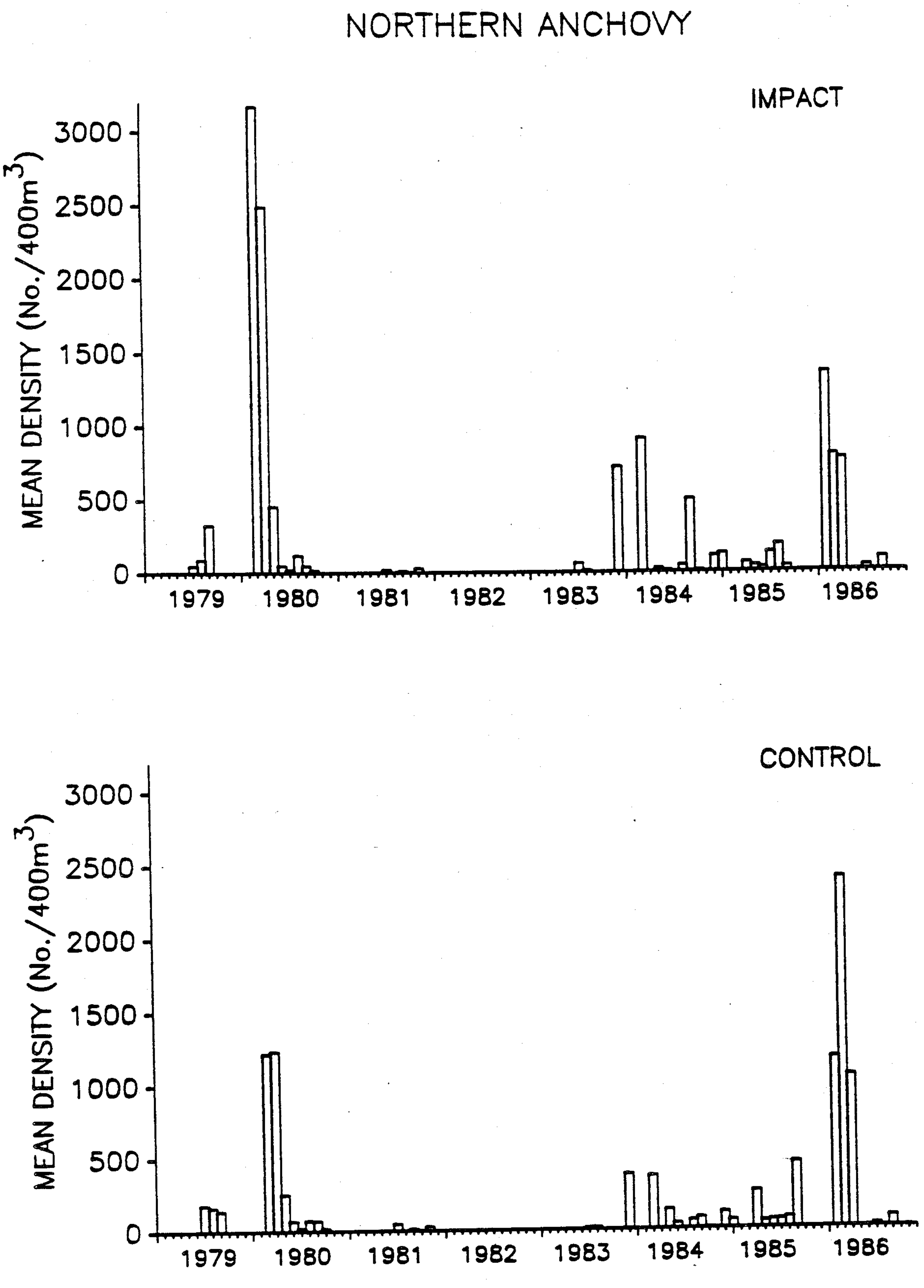


Figure B-4 Densities of northern anchovy larvae at Impact and Control sites from 1979 to 1986.

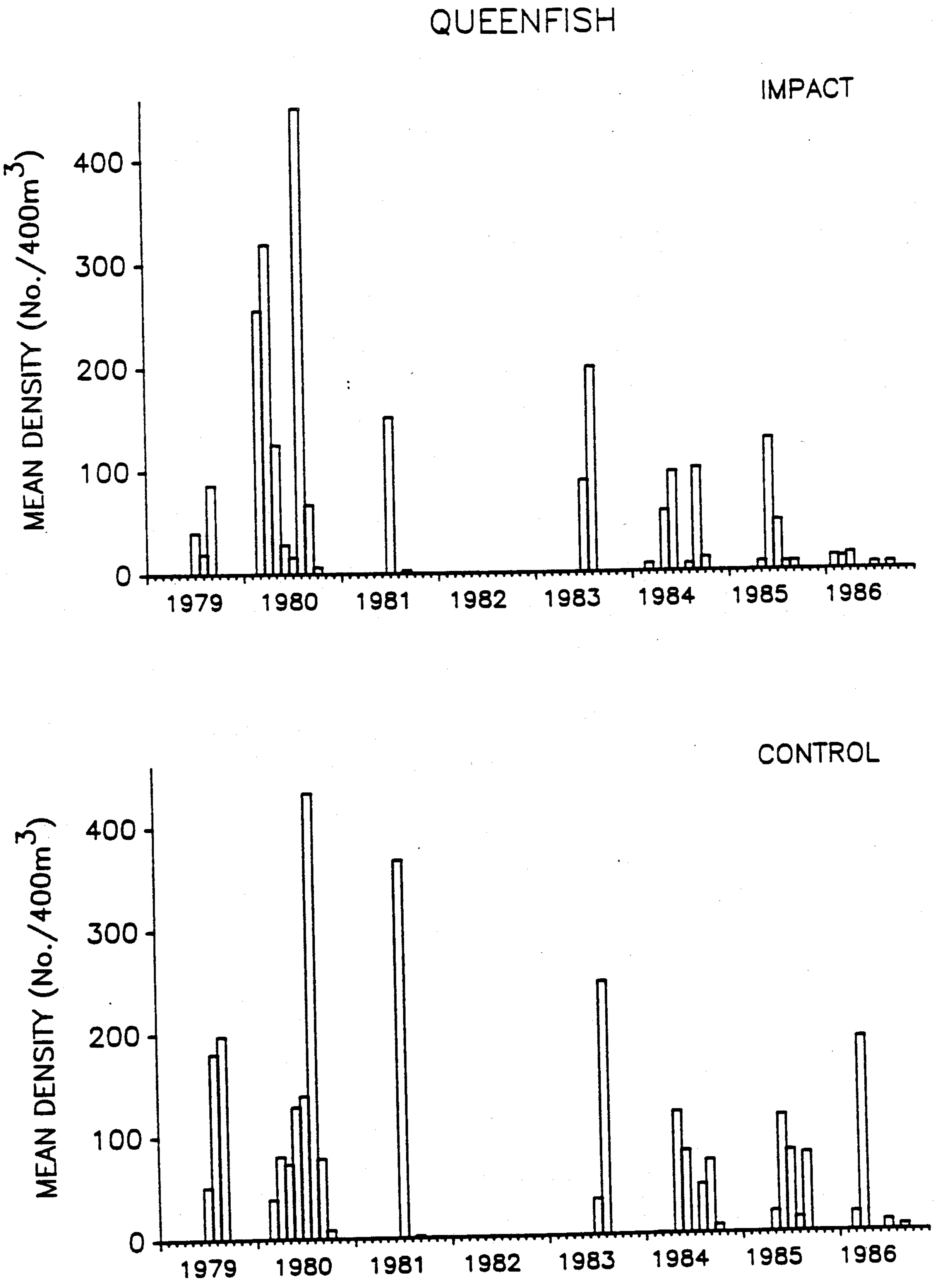


Figure B-5 Densities of queenfish larvae at Impact and Control sites from 1979 to 1986.

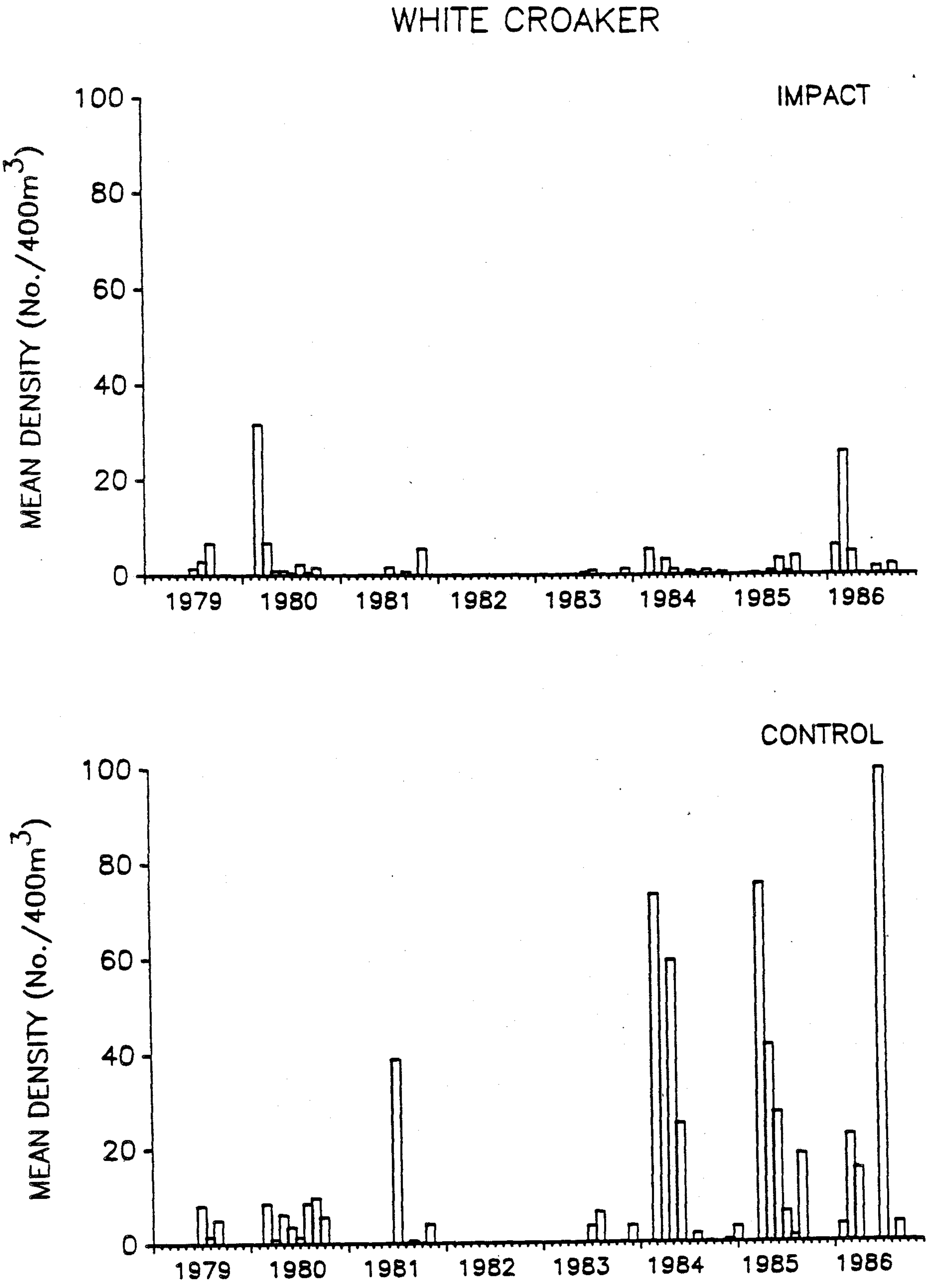
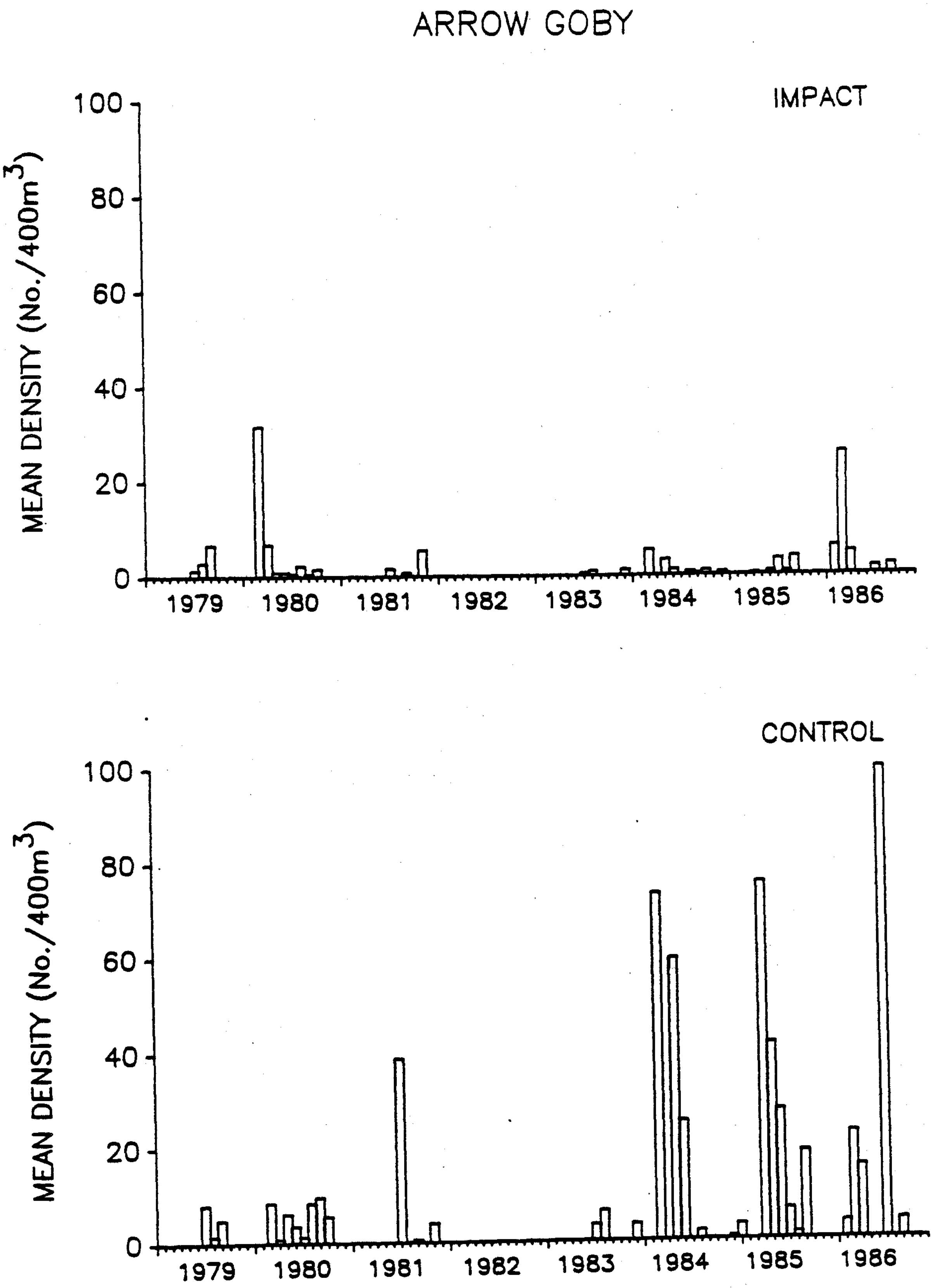


Figure B-6 Densities of white croaker larvae at Impact and Control sites from 1979 to 1986.


ARROW GOBY

IMPACT

CONTROL

Figure B-7 Densities of arrow goby larvae at Impact and Control sites from 1979 to 1986.

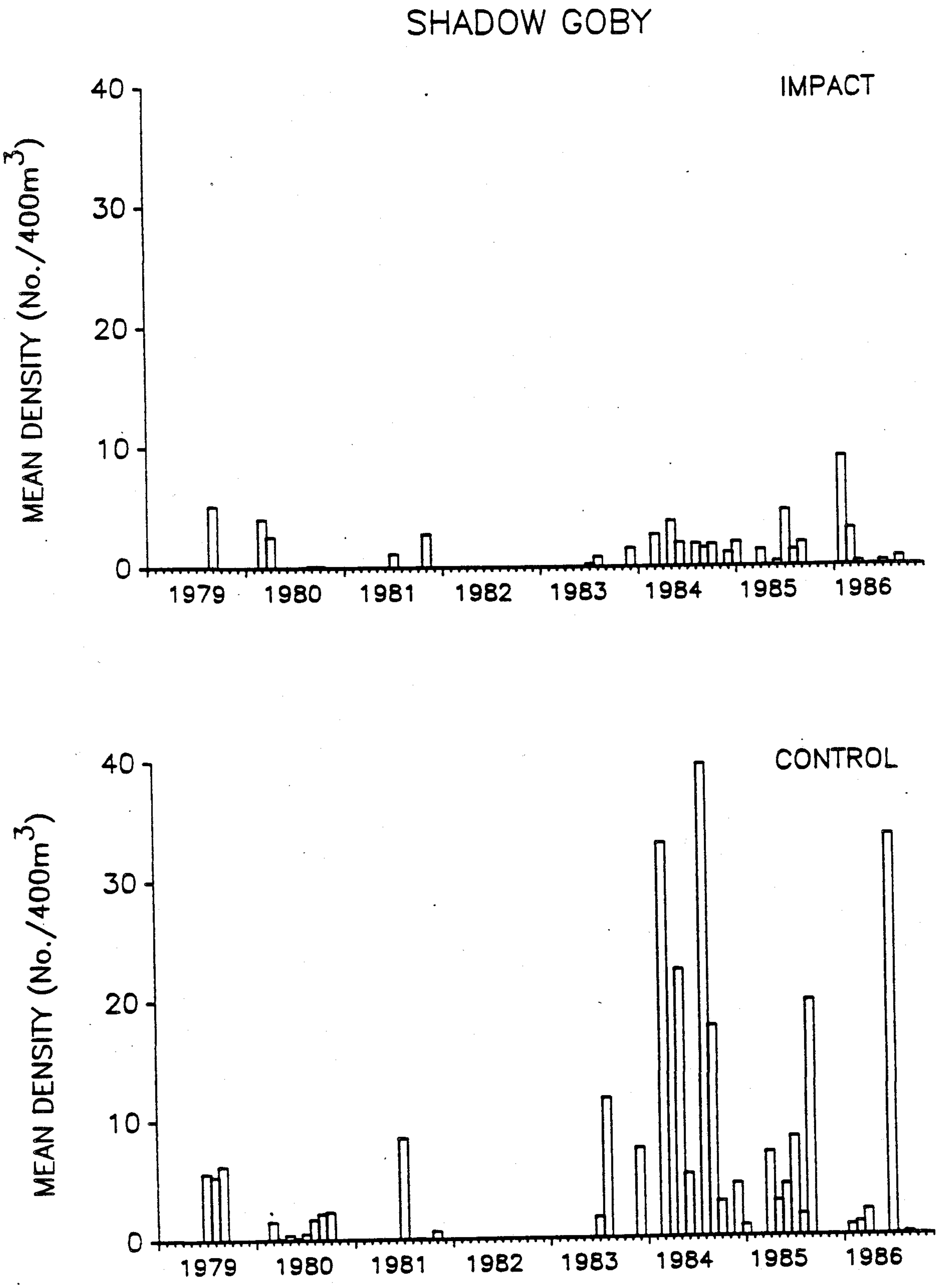


Figure B-8 Densities of shadow goby larvae at Impact and Control sites from 1979 to 1986.

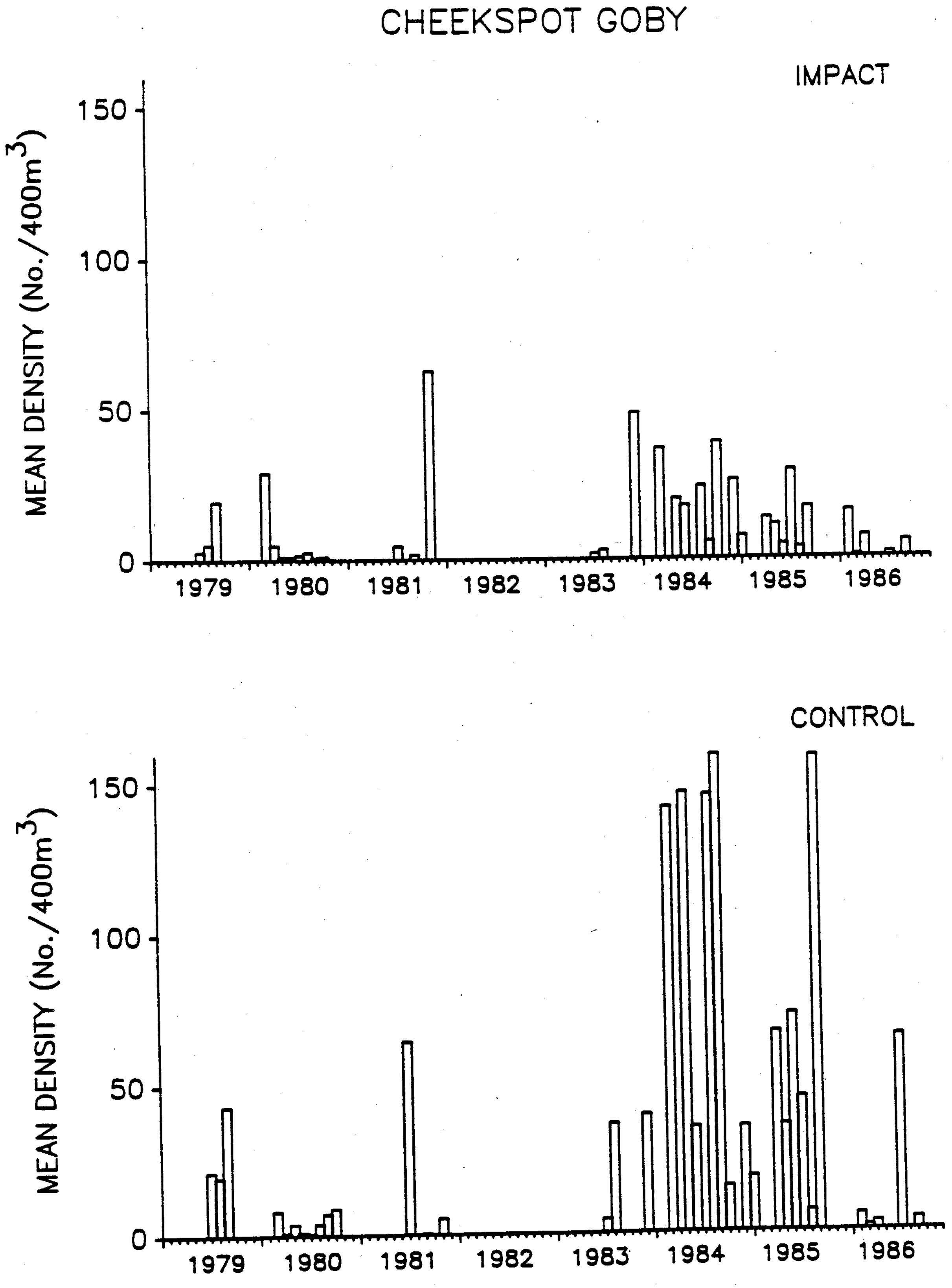


Figure B-9 Densities of cheekspot goby larvae at Impact and Control sites from 1979 to 1986.

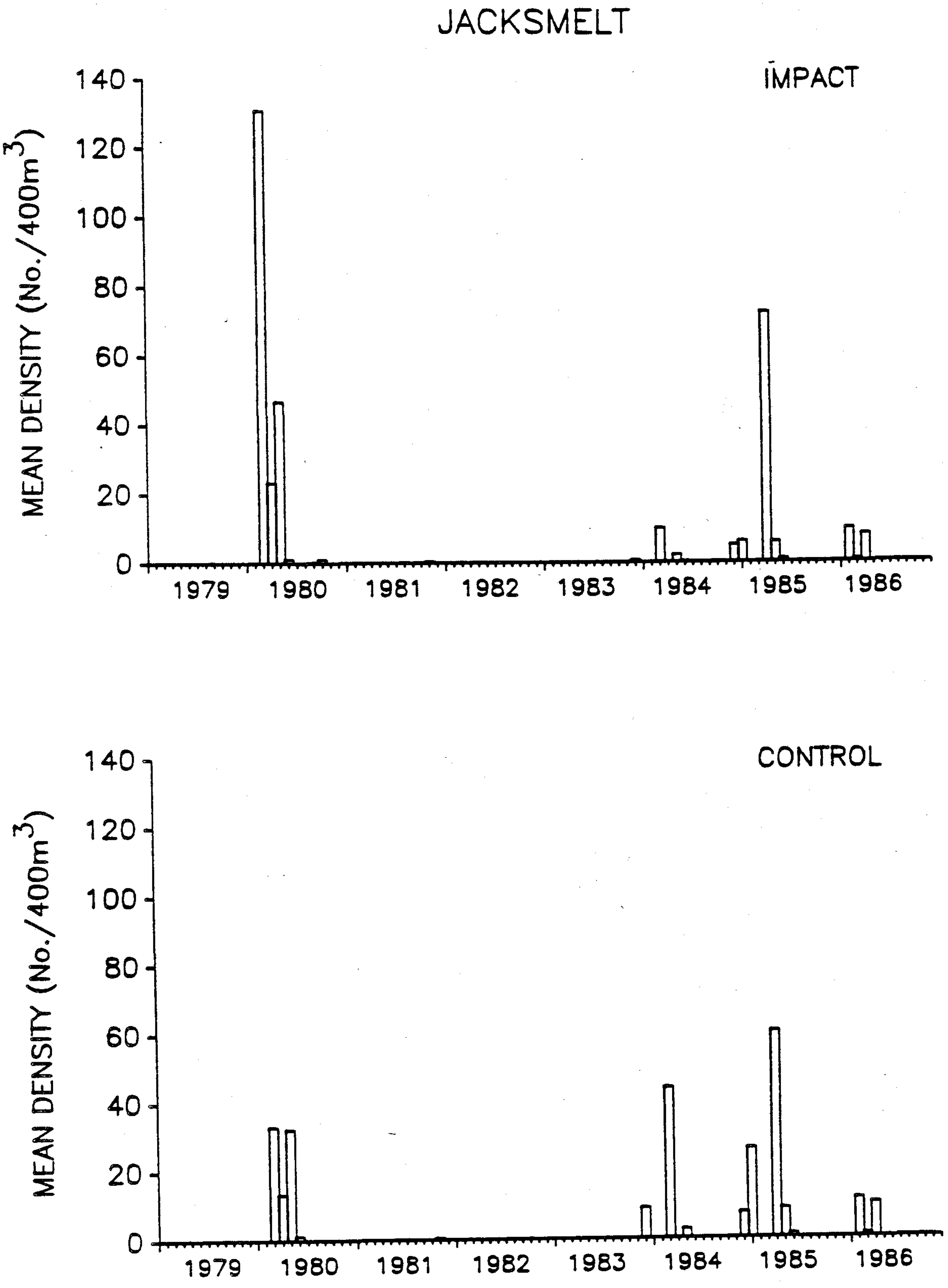


Figure B-10 Densities of jacksmelt larvae at Impact and Control sites from 1979 to 1986.

Figure B-11 Densities of total fish larvae at Impact & Control sites combined for each of the years sampled from 1979 to 1986 and for all years combined. Only months in which samples were taken are labelled. * indicates zero density.

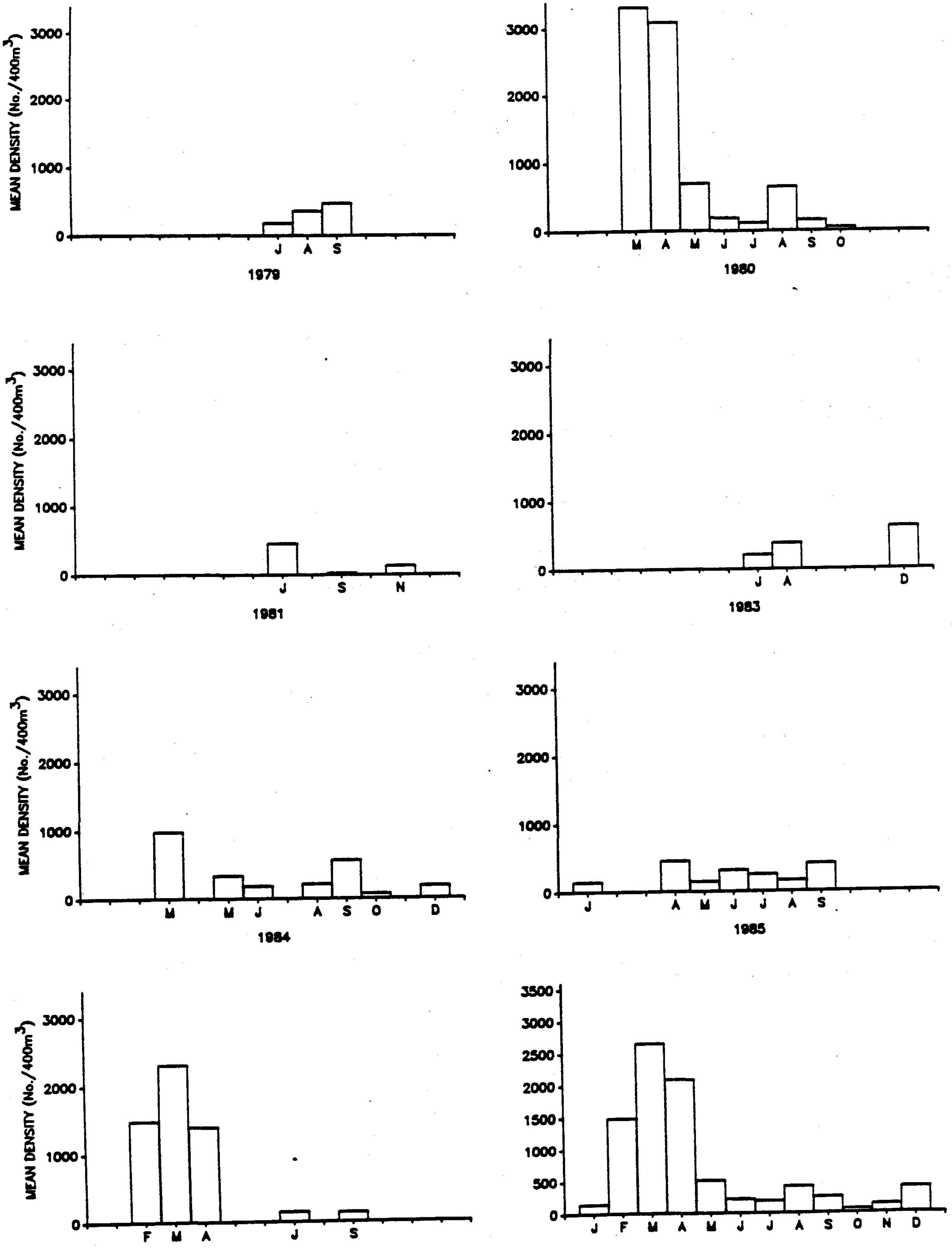


Figure B-12 Densities of northern anchovy larvae at impact & Control sites combined for each of the years sampled from 1979 to 1986 and for all years combined. Only months in which samples were taken are labelled. * indicates zero density.

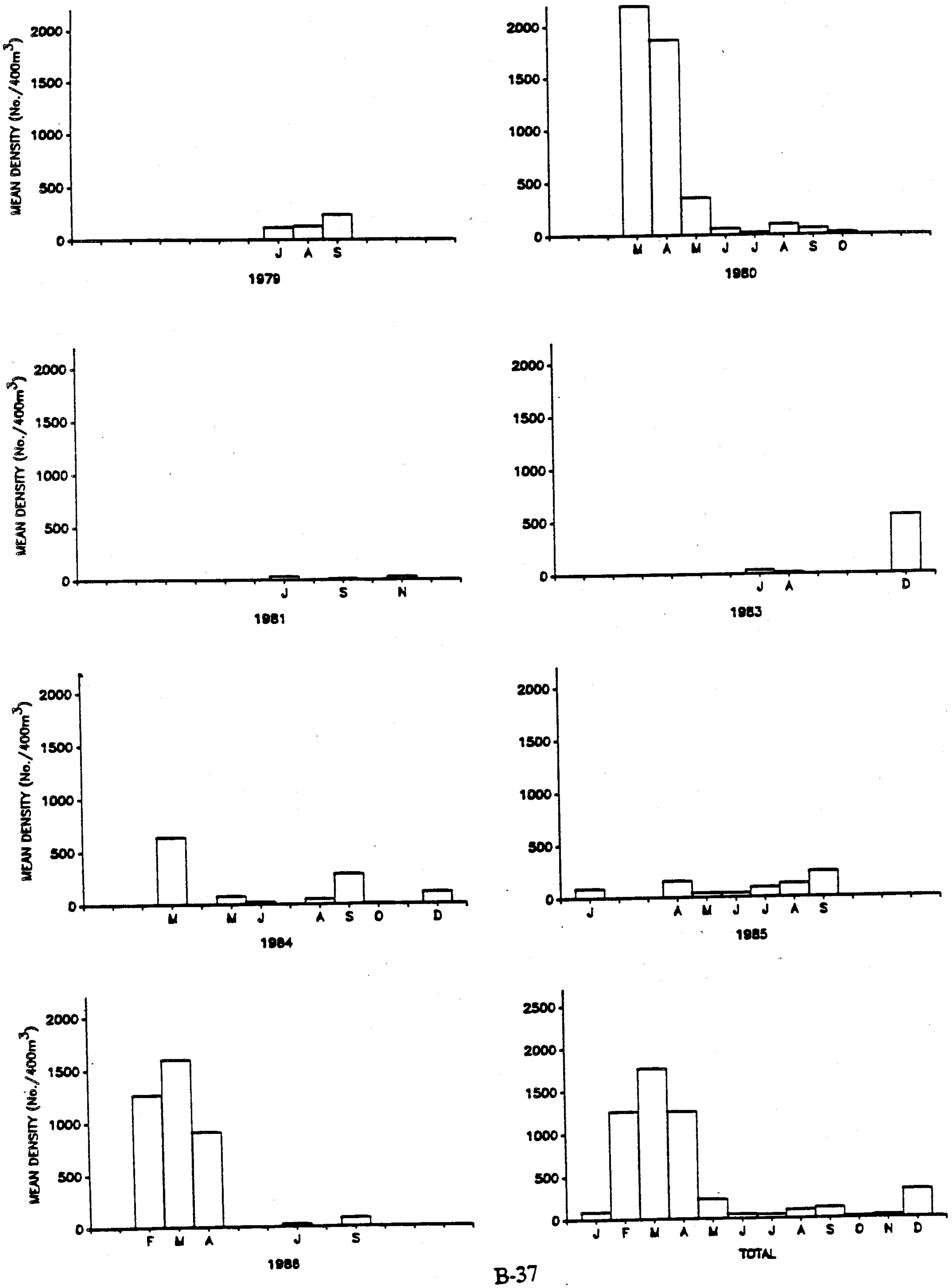


Figure B-13 Densities of white croaker larvae at Impact & Control sites combined for each of the years sampled from 1979 to 1986 and for all years combined. Only months in which samples were taken are labelled. * indicates zero density.

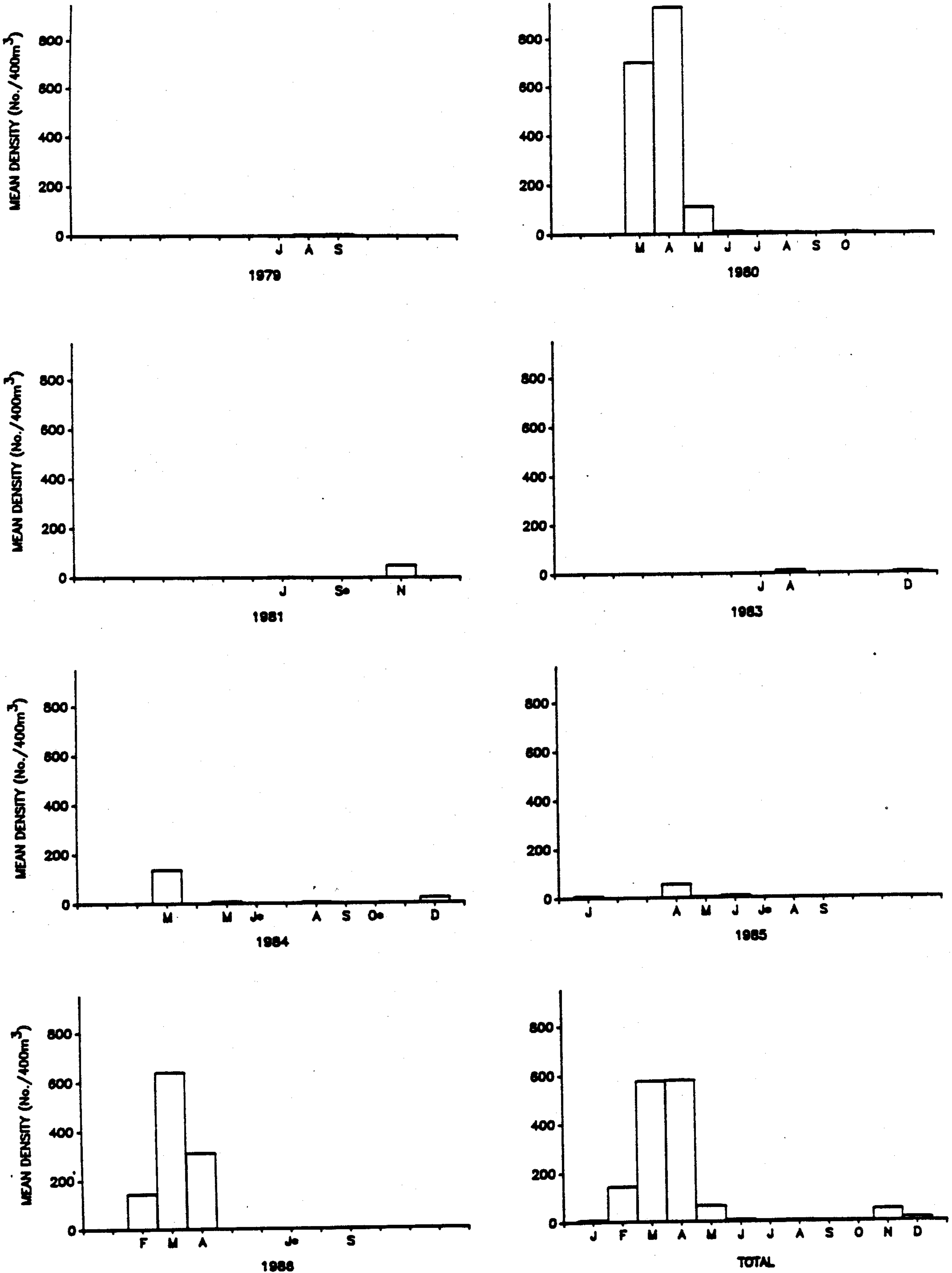


Figure B-14 Densities of total fish larvae minus anchovy at Impact & Control sites combined for each of the years sampled from 1979 to 1986 and for all years combined. Only months in which samples were taken are labelled. * indicates zero density.

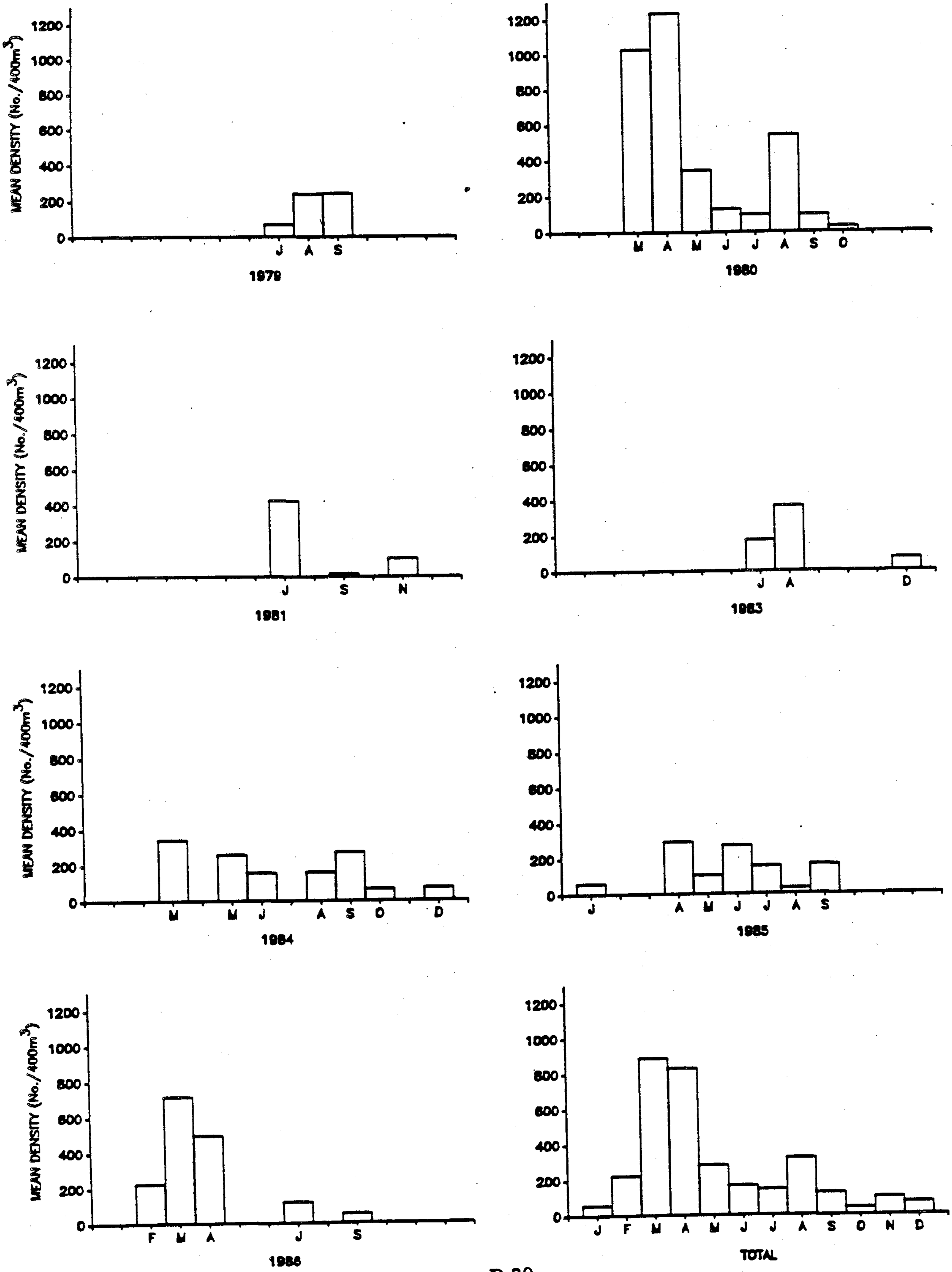
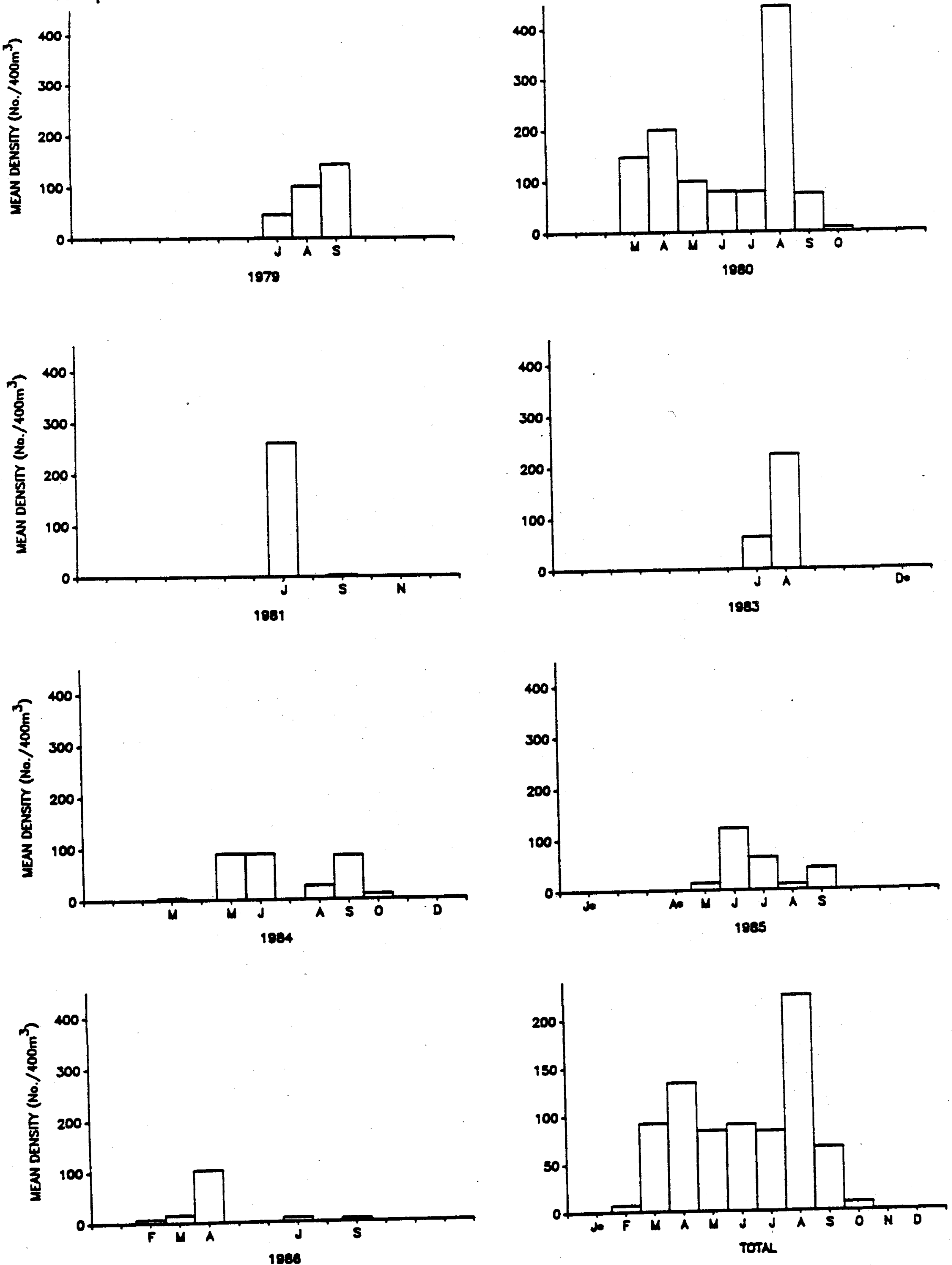


Figure B-15 Densities of queenfish larvae at Impact & Control sites combined for each of the years sampled from 1979 to 1986 and for all years combined. Only months in which samples were taken are labelled. * indicates zero density.



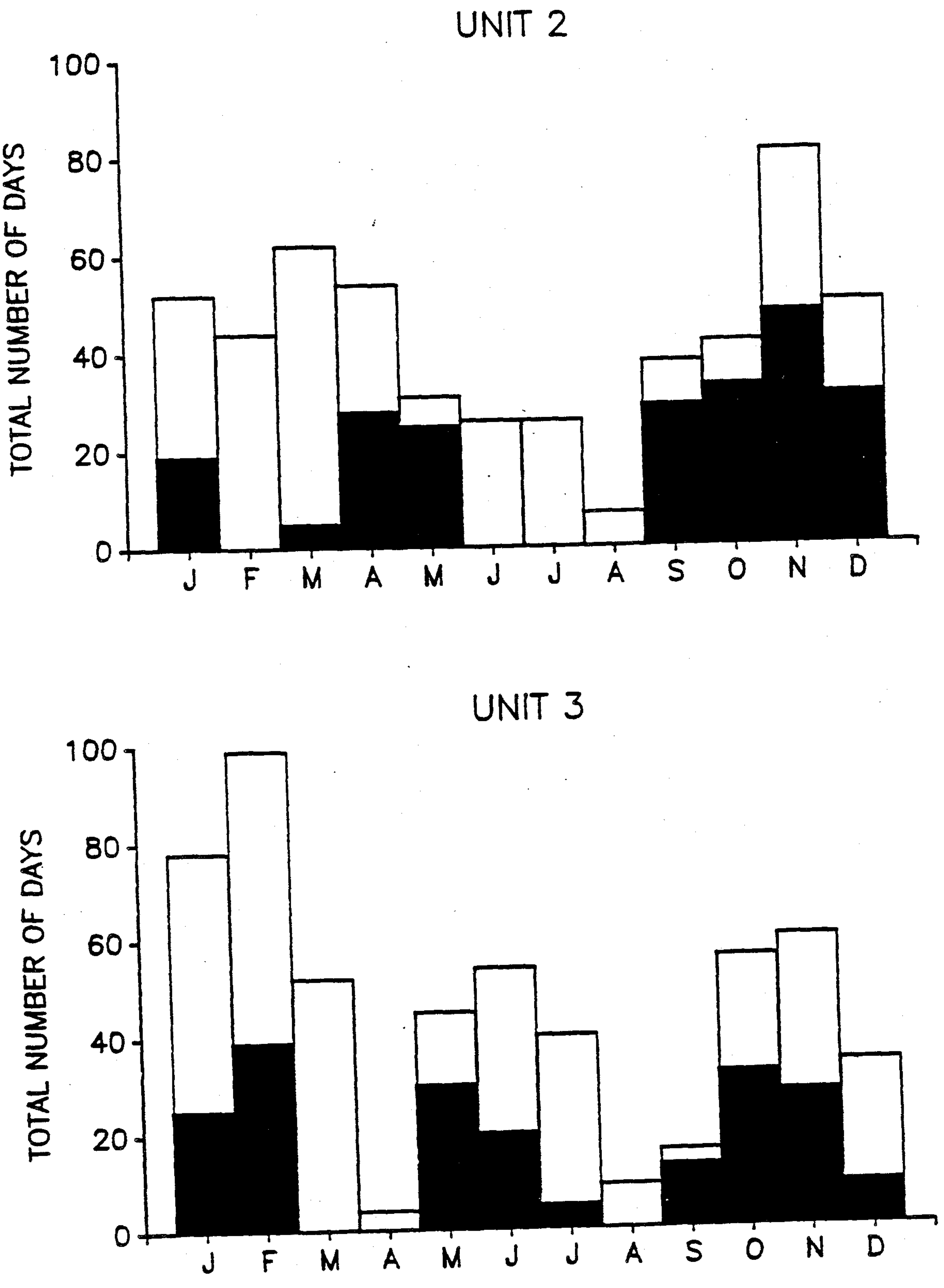


Figure B-16 Annual pattern of operations at SONGS Units 2 and 3 between January 1, 1984 and July 31, 1988. Open bars indicate number of days a Unit did not produce power during a particular month; solid bars indicate number of days with no water flow through a Unit. There were 1674 days during the sample period.

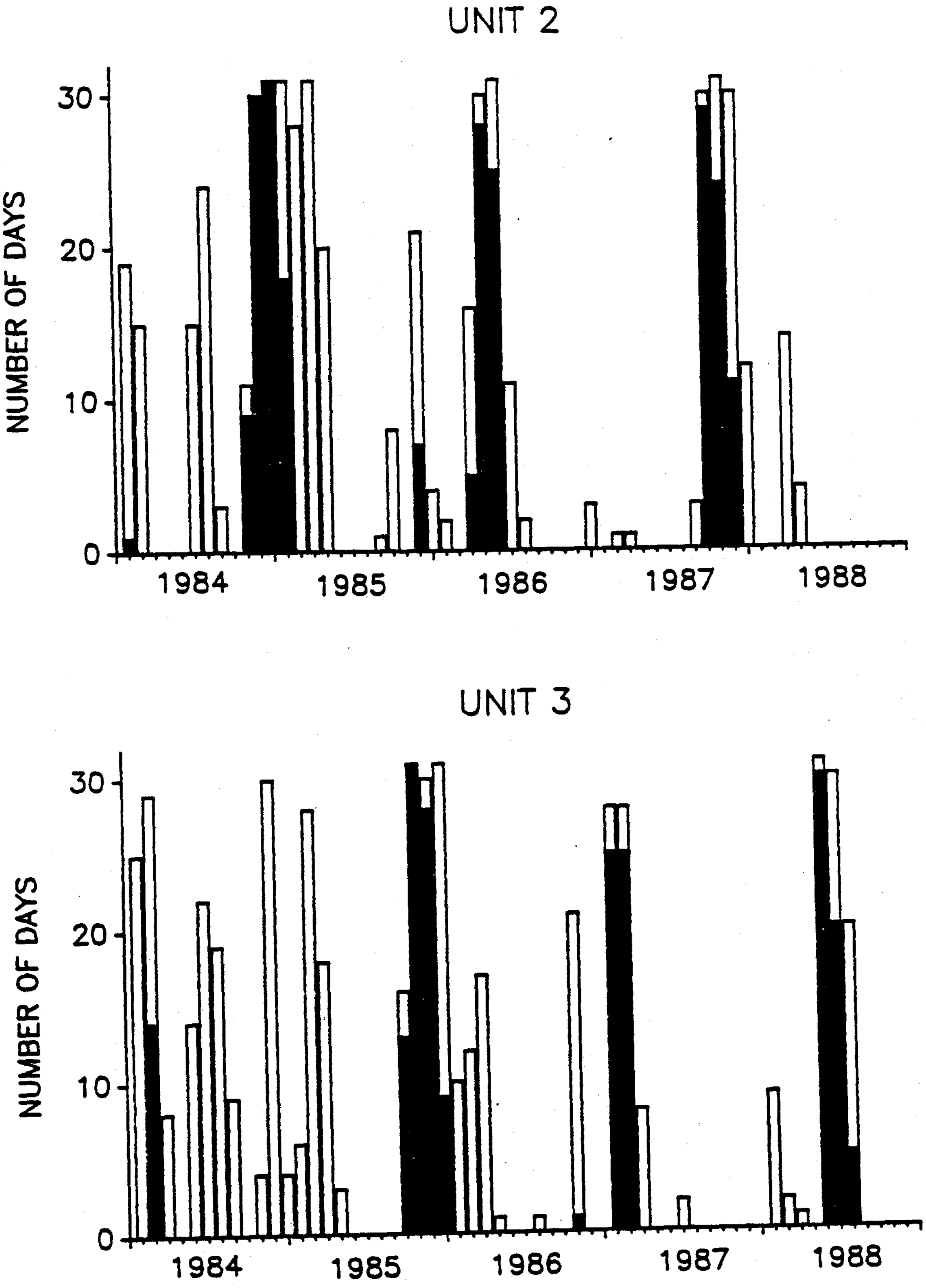


Figure B-17 Operations at SONGS Units 2 and 3 by month between January 1, 1984 and July 31, 1988. Open bars indicate number of days a Unit did not produce power during a particular month; solid bars indicate number of days with no water flow through a Unit.

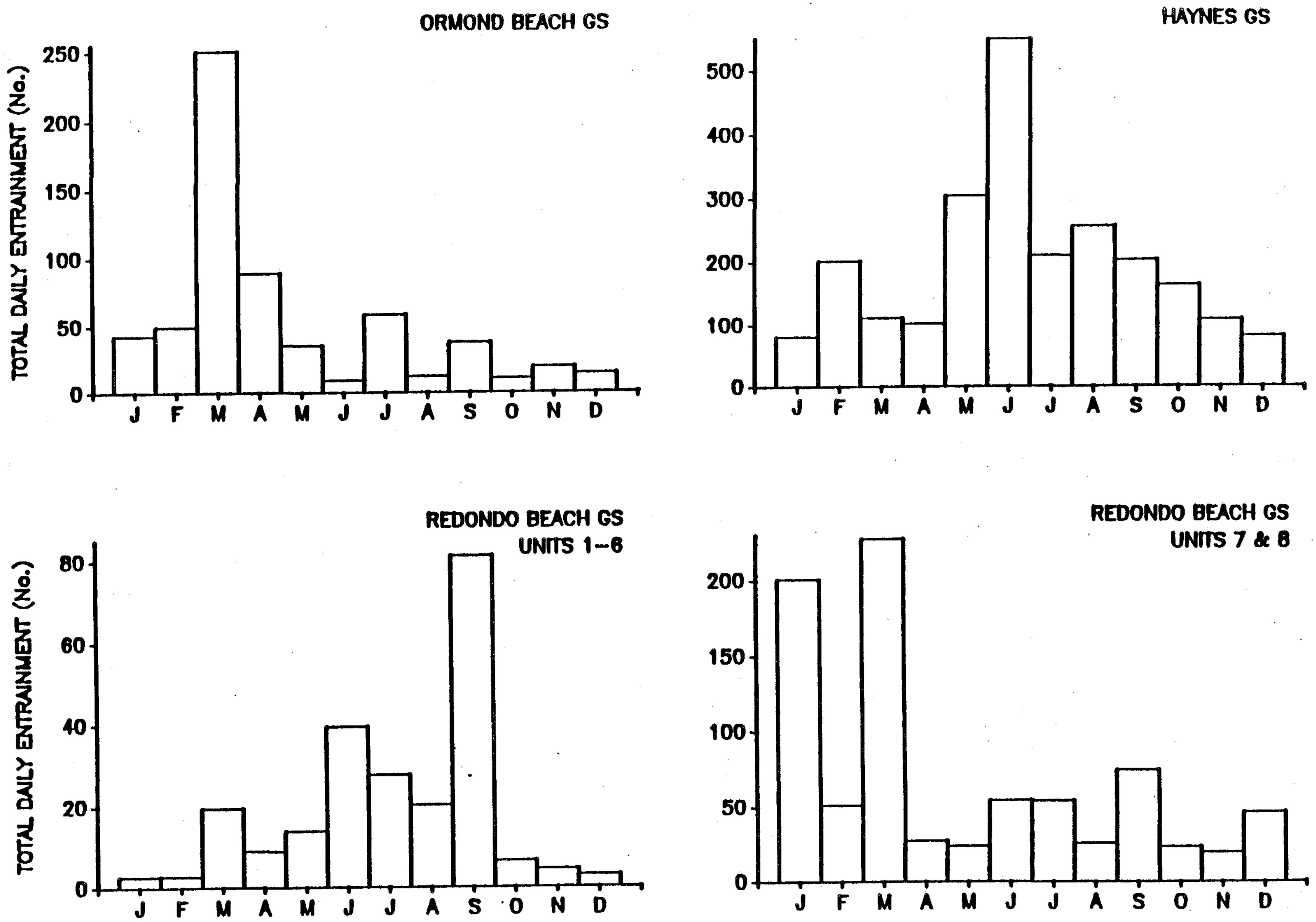


Figure B-18 Temporal pattern of Ichthyoplankton entrainment at SCE generating stations. Data are from SCE (1982, 1983a, 1983b). Ormond Beach Generating Station is used as representative of El Segundo and Huntington Beach; data were collected Aug 79 - Sept 80. Haynes Generating Station is used as representative of Mandalay, Long Beach and Alamitos; data were collected Oct 79 - Sept 80 by IRC (1981). Redondo Beach Generating Station data were collected Aug 79 - July 80.

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APPENDIX C

METHODS USED IN FALL 1986 SURVEY OF ARTIFICIAL AND NATURAL REEFS

The methods used in the survey of artificial and natural reefs in Southern California conducted in Fall 1986 are summarized in this Appendix. A more detailed description of the methods and analyses used is presented in Ambrose (1987).

Ten artificial reefs, including three breakwater sites and one artificial island, were chosen for this study. For comparison, 16 natural reefs were sampled. The 26 reefs sampled range from San Diego to Ventura (Figure C-1, Table C-1). Eleven natural reefs and four artificial reefs had a giant kelp (*Macrocystis pyrifera*) canopy at the time of sampling.

Sampling methodology was the same on natural and artificial reefs. Visual transects were used to estimate the densities of fish. A diver swam at a constant rate along a transect to minimize counting fish attracted to him or counting fish twice, and recorded all fish encountered within a corridor of specific dimensions; fish were placed in life-stage categories according to length (Ambrose 1987). Two types of transects were employed: "adult" transects, in which adult and subadult fish were counted, and "young-of-year" transects, in which young-of-year and juvenile fish were counted. On each reef, the transects were located in two habitat types: near the benthos, and in the water column.

Eight benthic transects, 30-m long and spaced at least 5 m apart, were sampled on each reef. In the "adult" transects, adult and subadult fish were counted within a 3-m wide by 1.5-m high corridor. Young-of-year and juvenile fish were sampled along the same benthic transects as the adults and subadults, but after at least one-half hour had elapsed to allow the fish to recover from the disturbance of the initial sampling of adult fishes. The "young-of-year" corridor was only 1-m wide to allow a more detailed search of the substrate, but was 2-m high to ensure that young occurring off the substrate (such as *Chromis punctipinnis*) were included.

Adult and sub-adult fish occurring in the water column were sampled by underwater video camera at a depth of about 3 m. Eight transects, approximately 30-m long, were sampled at each site. Horizontal visibility was measured and used to determine the width and height of each transect based on a previous calibration of the video camera. Young-of-year and juveniles were sampled in eight visual transects (2-m high x 1-m wide x 30-m long) in the same area as the adult video survey.

To determine the size frequency distribution of fish, divers estimated the lengths of all fish seen during a 10-min swim around the reef.

Literature cited

Ambrose, R.F. 1987. Comparison of communities on artificial and natural reefs in Southern California, with emphasis on fish assemblages. Final Report submitted to the Marine Review Committee. December 1987.

Table C-1

Physical Characteristics of Reefs surveyed in Fall 1986

Reefs are numbered within the two type of reefs in order of occurrence from South to North (see Figure A1-1). * indicates breakwaters or man-made islands that reach the surface of the water.

No.	REEF	REEF CODE	AREA (ha)	DEPTH (m)	HEIGHT (m)	SLOPE	SUBSTRATE
	ARTIFICIAL REEFS						
A1	Torrey Pines AR	TPAR	0.18	16	5	21.3°	large rock, boulders
A2	Pendleton AR	PAR	1.40	15	4	27.5°	medium & large rock, boulders
A3	Newport Beach AR	NBAR	2.50	24	3	21.3°	concrete pilings, sand
A4	L.A. Harbor Breakwater - outside	LOAR	5.81	11	11*	33.8°	boulders
A5	L.A. Harbor Breakwater - inside	LIAR	4.75	9	9*	38.1°	large rock, boulders
A6	King Harbor Breakwater	KHAR	3.86	9	9*	39.8°	large rock, boulders
A7	Hermosa Beach AR	HBAR	0.24	21	2	1.3°	concrete pilings, sand
A8	Marina Del Rey AR	MDAR	0.32	21	4	41.7°	large rock, boulders
A9	Pitas Point AR	PPAR	0.45	11	3	11.3°	medium & large rock, sand
A10	Rincon Oil Island	RIAR	2.81	16	16*	47.5°	large rock, boulders
	MEAN		2.23	15.3	6.6	28.3°	
	(SE)		(0.649)	(1.69)	(1.42)	(4.63)	
	NATURAL REEFS						
N1	Marine Street Reef	MSR	220.00[1]	22	13	0.3°	bedrock
N2	La Jolla Cove Reef	LJCR	220.00[1]	18	3	0°	large rock, boulders, sand
N3	Del Mar Reef	DMR	214.00	16	1	0°	bedrock
N4	Barn Kelp	BK	80.00	15	1	1.8°	small & med. rock, bedrock
N5	Las Pulgas Reef	LPR	53.00	12	5	18.8°	large rock, bedrock
N6	Box Canyon	BC	16.00	17	1	0°	sand, cobble, med. rock
N7	San Onofre Kelp - Main (4-1)	SOKM	104.00[2]	16	1	0°	small & med. rock, sand
N8	San Onofre Kelp - North (002)	SOKN	104.00[2]	15	1	1.3°	cobble, small & med. rock
N9	San Mateo Kelp	SMK	114.00[3]	16	2	0°	medium rock, sand
N10	Two Man Rock	TMR	114.00[3]	18	5	17.5°	med. & large rock, bedrock, sand, boulder
N11	Laguna Beach North	LBN	23.00	18	5	0°	sand, cobble, rocks, bedrock
N12	Pelican Point	PP	31.00	15	4	35.0°	small rock, bedrock
N13	Point Vicente	PV	551.00[4]	24	13	33.8°	boulders, bedrock
N14	Don't Dive There	DDT	551.00[4]	15	8	39.6°	boulders, bedrock
N15	Flat Rock	FR	551.00[4]	16	5	18.8°	medium & large rock, bedrock, boulders
N16	Rincon Kelp	RK	6.80	11	2	10.9°	medium & large rock, sand
	MEAN		184.55	16.5	4.4	11.1°	
	(SE)		(48.609)	(0.80)	(0.99)	(3.59)	

[1] Both reefs are part of the La Jolla reef complex.
[2] Both reefs are part of the San Onofre Kelp Bed
[3] Both reefs are part of the San Mateo Kelp Bed
[4] All three reefs are part of the Palos Verdes Peninsula reef complex

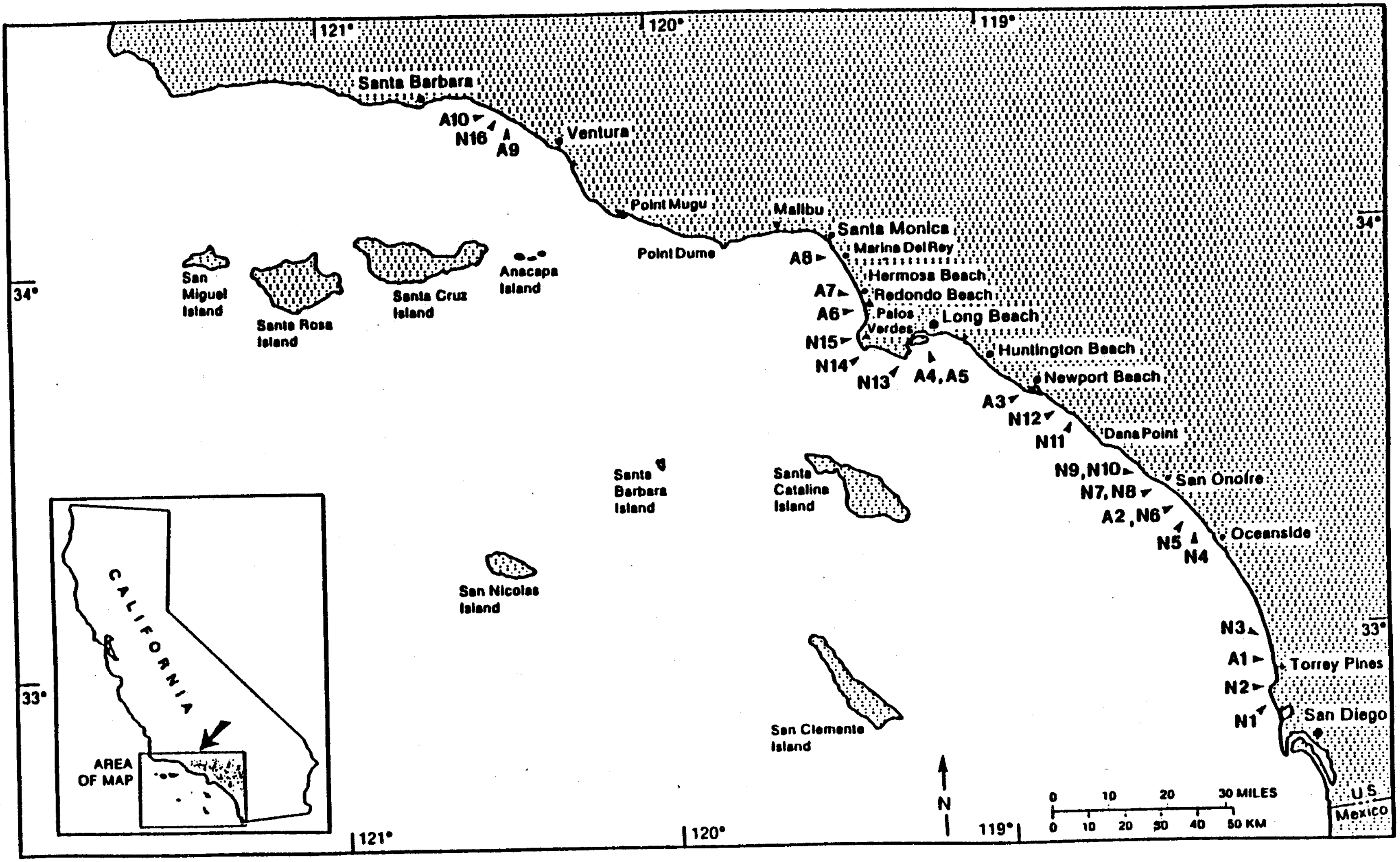

Figure C-1: Map of Fall 1986 survey sites. "A" indicates artificial reef. "N" indicates natural reef. See Table C-1 for the names of reefs corresponding to numbers.

APPENDIX D

CALCULATING THE SIZE OF ARTIFICIAL REEF NEEDED FOR MITIGATION

The MRC has proposed that artificial reefs be used to mitigate two types of impacts. First, an artificial reef could serve as in-kind replacement of San Onofre Kelp Bed resources. Second, an artificial reef could provide out-of-kind mitigation for midwater fish losses, such as those caused by SONGS' killing of fish larvae and eggs. As noted in Chapter 8, a critical aspect of using artificial reefs as mitigation is determining the size of reef needed. Different procedures are needed for the two different applications of artificial reefs, in-kind and out-of-kind mitigation; the processes used by the MRC in developing their recommendations on size are described below.

D1.1 Size needed for in-kind mitigation

As noted in Section 8.3.3, there is insufficient evidence to warrant constructing a reef that is smaller than the area of natural reef impacted; in fact, the general uncertainty about the processes operating on artificial reefs argues that the artificial reef should be larger than the impacted area.

There are no established policies that could be used to determine the appropriate "compensation ratio" that should be used. Other mitigation projects have used ratios that range from 1:1 to 4:1 or 5:1 or more. The MRC decided that a 1.5:1 ratio of artificial reef to area of kelp lost would be appropriate for SONGS.

The actual size of reef recommended is based on the area of kelp estimated to be lost from the San Onofre Kelp Bed (SOK) due to the operation of SONGS: 80 ha. Using the 1.5:1 ratio, the size of artificial reef needed to mitigate the impacts of SONGS on the San Onofre Kelp Bed was estimated to be 120 ha, or 300 acres.

In addition to the impacts to kelp, SONGS has reduced the abundances of kelp forest invertebrates and fish. Because the kelp forest invertebrates are closely tied to the hard substrate at SOK, a 120-ha artificial reef would probably provide a 1.5:1 replacement of invertebrates. However, this might not be the case for kelp forest fish.

As noted in Chapter 8, the fact that no large artificial reefs similar to the proposed reef have been built means that it is not possible to predict the density (much less the production) of fish that will occur on such a reef. However, I have used the Fall 1986 survey of artificial and natural reefs (Ambrose 1987) to estimate the biomass densities that might occur on a large artificial reef.

Existing artificial reefs had a mean biomass density of nearly 0.5 MT/ha (Table D-1). Although fish density was higher on artificial reefs than natural reefs during this and other surveys comparing the reef types (see Ambrose 1987 and Chapter 8), this will not necessarily be the case for a very large artificial reef. All of the artificial reefs sampled (including Pendleton Artificial Reef) and all other artificial reefs constructed so far in California are much smaller than most natural reefs, and consist of isolated piles of rock in the midst of a sand plain. (Although some recent reefs spread reef modules over a large area, the actual area covered by rock is still quite small.) The characteristics of existing artificial reefs probably increase the number of fish attracted to the reefs, thereby artificially enhancing the density of fish (see Chapter 8 and Ambrose and Swarbrick 1989). A large artificial reef, such as the proposed mitigation reef, would not attract such a high proportion of fish, so that the fish biomass densities would probably be lower than on existing artificial reefs.

The best estimate of the density that would occur on the proposed mitigation reef is perhaps the average density found on the natural reefs surveyed in Fall 1986, 0.29 MT/ha. At this density, a 120-ha reef would just replace the biomass of fish lost, and 180-190 ha would be needed for 1.5:1 replacement (Table D-1).

Of course, since the artificial reef would be designed to mimic the physical structure of SOK, biomass density on the artificial reef might be as low as it was in the main portion of SOK, 0.19 MT/ha, in which case a 282-ha artificial reef would be required for 1.5:1 replacement (based on these estimates). Since SOK had already been impacted by SONGS when it was surveyed in 1986, 0.19 MT/ha might be too low an estimate; however, the 214-ha Del Mar Reef had a biomass density of only 0.17 MT/ha, so this value is not unreasonably low. On the other hand, the San Mateo Kelp Bed, which served as the control for SOK, had a biomass density of 0.36 MT/ha. Overall, it simply is not possible to predict the density that would occur on the proposed mitigation reef.

D1.2 Size needed for out-of-kind mitigation

There is no clear, simple, quantitative link between the Bight-wide losses of fish and the size of reef needed to completely mitigate those losses. Likewise, there are few guidelines for developing such a link. (The most common approach to this type of problem, the Habitat Evaluation Procedures [HEP] developed by USFWS, focuses on habitat values; since SONGS does not degrade the midwater fish habitat, HEP cannot be used here.) In the absence of a quantitative method, one frequently used approach is to rely on "best professional judgement", deciding by consensus on a size that seems reasonable to some panel of experts. We have chosen instead to try to calculate a value. The method I describe in this section has the advantage of being explicit about the steps taken to arrive at a value (which is one of the principal advantages of HEP as well), but we recognize that our assumptions cannot be verified and that our estimate depends in part on a subjective judgement. Nonetheless, it is the best estimate we can make.

Our approach relies on rough estimates because virtually none of the necessary information is accurately known. We have dealt with this problem by presenting minimum and maximum estimates.

D1.2.1 Minimum estimate

The minimum size of artificial reef needed to mitigate for the Bight-wide effects of SONGS on fish is 0 ha (Table D-2). This minimum size is based on complete biological compensation of the losses of fish larvae; that is, there would be no loss in standing stock in spite of SONGS killing 4 to 5 billion fish larvae. Although complete biological compensation is not likely, in principle it is possible.

D1.2.2 Maximum estimate

The maximum size of artificial reef needed to mitigate for the Bight-wide effects on SONGS on fish is estimated to be 240 ha (Table D-2).

Our estimate of the size of reef needed to mitigate the Bight-wide effects of SONGS is based on two steps (Figure D-1). First, we estimate the biomass of adult fish expected to be lost as a result of SONGS' entrainment of fish larvae. This estimate is derived from the analyses of adult-equivalent losses (Technical Report D) and Bight-wide effects (Technical Report M) and estimates of the Bight-wide standing stocks of the affected fishes. Second, we convert the estimated loss, in tons, to area of rocky reef based on a judgement about the relative values of the lost midwater fish versus the community of organisms living on a rock reef (including the tonnage of fish on a hectare of reef).

The estimates of biomass lost due to SONGS are given in Table D-3. The combined standing stock of white croaker and queenfish is estimated to be almost 10,000 MT (Appendix B in Technical Report D); with an estimated adult equivalent loss of about 10% for these two species (Technical Report D), and assuming that this adult equivalent loss leads to a 10% decrease in standing stock (i.e., no biological compensation; Technical Report M), we estimate that SONGS causes a loss of 1000 MT of these two species. The other species killed by SONGS had lower estimated adult equivalent losses, which we approximate as about 1% for the group as a whole. Although we cannot estimate the standing stocks of these species, it seems safe to assume that the combined stock does not exceed 20,000 MT, so the loss of these species is estimated to be 200 MT (Table D-3). [This excludes northern anchovy, which has an estimated standing stock of 500,000 MT but an adult equivalent loss of <0.1%; Technical Report D.] Thus, the maximum reduction in the standing stocks of fish in the Bight is estimated to be about 1200 MT.

In order to determine the size of artificial reef needed to mitigate these losses, we need to convert the 1200 MT of mostly midwater fishes to area of rocky reef; this out-of-kind conversion requires a judgement about the relative values of midwater fish and rocky reef communities. One possibility would be to judge that midwater fish and rocky reef fish have the same value; this would require an artificial reef of 1200 ha or larger (based on fish biomass densities in Ambrose 1987). However, we do not believe this is a reasonable estimate because we believe rocky reef communities are generally conceded to be more valuable that midwater fish such as queenfish and white croaker.

The rocky reef community created by constructing an artificial reef might be considered more valuable than the midwater fish killed by SONGS for several reasons: (1) <u>The type of fish</u>. Rocky reefs support a number of species that have been given a special protected status, such as garibaldi and black croaker; in contrast, none of the species substantially impacted by SONGS are protected. (2) <u>The number of economically valuable fish</u>. Rocky reefs support a high density of economically valuable fish, including kelp bass, sand bass, surfperches and rockfish. Although some midwater fish, such as barracuda and yellowtail, are economically valuable, these are not impacted by SONGS. However, both white croaker and queenfish have a limited commercial and/or sport value: they are commonly caught by sportfishermen, but they are not highly valued species. (3) <u>The permanence of</u>

the rocky reef. A properly designed and located rocky reef should continue to produce resources indefinitely, and in any case long after Units 2 and 3 have been decommissioned and cease impacting midwater fish. (4) The relative rarity of rocky reef versus sandy bottom in the Southern California Bight. For example, only 14% of the shoreline consists of rocky areas in San Diego County, while in Orange County rocky areas comprise only 7% of the shoreline, and relatively few subtidal reefs are found along the mainland in Southern California (Ambrose *et al.* 1989). (5) Recreational and aesthetic values. Because rocky reefs in Southern California support a diverse biological community containing macroalgae, multicolored invertebrates such as sponges, tunicates, gorgonians and nudibranchs, and a variety of fish species, they provide significant recreational and aesthetic values to scuba divers that are not provided by the assemblage of midwater fish. (6) The diversity and abundance of organisms on the reef, including invertebrates and algae (perhaps including giant kelp). In place of a single assemblage of fish, a rocky reef would produce a full, complex community of organisms. Thousands of different species belonging to many different taxonomic groups live on rocky reefs. The rocky substrate is typically covered with algae (20% to 30% cover) and invertebrates (40% to 55% cover)(Ambrose 1987). Larger invertebrates (such as gorgonians, snails, sea urchins and sea stars) are also common; large invertebrates (all species) had an average of density of 25-30/m^2 during the Fall 1986 survey of artificial and natural reefs throughout Southern California (Ambrose 1987). And of course, there are many reef fish on rocky reefs; during the Fall 1986 survey the biomass density of fish near the bottom was estimated to be 0.3-0.5 MT per ha (Ambrose 1987). [Note: This survey only sampled the conspicuous fish on reefs; the estimates would be somewhat higher if the cryptic species had been included. In addition, the biomass density of fish in the water column could be substantial (more than 0.2-0.4 MT/ha) for reefs that supported giant kelp. A reasonable rough estimate of the total fish biomass on a reef would be 1 MT/ha.]

In spite of the many reasons for judging a rocky reef more valuable than the midwater fish impacted by SONGS, there is no accepted procedure for quantifying the relative values of these two dissimilar resources. At this point, judging the relative worth of these two resources must be a societal or policy decision rather than a scientific one. We believe that it could reasonably be determined that one ha of rocky reef supports a community that is worth 5 MT of white croaker, queenfish, and the other species impacted by SONGS' entrainment of their larvae.

Using the conversion factor of 5 MT impacted fish per ha of rocky reef, the estimated loss of 1200 MT of fish translates into 240 ha of rocky reef (Table D-2).

We think it is unlikely that the losses are large enough to require a 240-ha artificial reef. To arrive at this estimate, we used maximum values, we assumed that biological compensation did not occur (although some biomass compensation seems likely; Technical Report M), and we judged a ha of artificial reef to be worth only 5 MT of impacted fish.

D1.2.3 Best estimate

The MRC's best estimate of the size of artificial reef needed to mitigate Bight-wide fish losses moderates both the estimate of biomass lost due to SONGS and the relative values of midwater fish and rocky reef communities.

We think that the estimate of 1200 MT of fish lost might be too high. While we think that it is unlikely that there is perfect compensation of larval losses, some biomass compensation seems likely. In addition, we have assumed that late larval stages cannot avoid entrainment and that all larvae entrained into SONGS are killed in the plant; if these assumptions are not correct, the number of larvae killed by SONGS will have been overestimated. Therefore, the biomass lost seems likely to be between several hundred tons to more than one thousand tons, and an estimate of 600 MT lost seems most reasonable (Table D-3).

In addition, the conversion rate of 5 MT of impacted fish per ha of rocky reef may undervalue rocky reefs. We perceive a consensus among marine scientists (and the general public) that rocky reefs are far more valuable than sandy habitats. More importantly, the rocky reef will continue to have value long after SONGS has stopped killing larvae. It seems fair to consider 1 ha of rocky reef to be worth 10 MT of impacted fish.

These more moderate estimates suggest that a 60-ha artificial reef would mitigate the losses caused by the entrainment of fish (Table D-2).

D2.0 Literature Cited

Ambrose, R.F. 1987. Comparison of communities on artificial and natural reefs in Southern California, with emphasis on fish assemblages. Final Report submitted to the Marine Review Committee. December 1987.

Ambrose, R.F. and S.L. Swarbrick. 1989. Comparison of fish assemblages on artificial and natural reefs off the coast of Southern California. Bulletin of Marine Science 44: 718-733.

Ambrose, R.F., D.C. Reed, J.M. Engle and M.F. Caswell. 1989. California Comprehensive Offshore Resource Study: Summary of Biological Resources. Report to the California State Lands Commission. 146 pp.

Table D-1

Size of artificial reef needed for in-kind replacement of kelp forest fish losses (36 MT).

Biomass estimates are based on survey of artificial and natural reefs conducted in Fall 1986 by Ambrose (1987) and refer only to the biomass of fish near the bottom; on most reefs, biomass density was much lower in the water column. The proposed mitigation reef would serve to replace resources lost at the San Onofre Kelp Bed (SOK), particularly the Main portion of the bed downcoast from the diffusers.

BIOMASS ESTIMATE		SIZE NEEDED	
SOURCE	(MT/HA)	1:1 REPLACEMENT	1.5:1 REPLACEMENT
Mean of all artificial reefs	0.452	80 ha	120 ha
Density on Pendleton Artificial Reef	0.359	100 ha	150 ha
Mean of all natural reefs	0.286	125 ha	187 ha
Mean at SOK Main Bed	0.191	188 ha	282 ha
Mean at Del Mar Reef	0.174	207 ha	310 ha

Table D-2

Calculation of artificial reef area needed for out-of-kind mitigation

The minimum estimate is based on the assumption that there is complete biological compensation, so there is actually no biomass lost due to the operation of SONGS. The maximum estimate assumes no biological compensation (see Table D-3) and judges that 5 MT of midwater fish is worth 1 ha of rocky reef. The best estimate assumes there is some biomass compensation and that rocky reef communities are relatively more valuable.

	BIOMASS LOST	RELATIVE VALUES	AREA OF ROCKY REEF
Minimum	0	--	0
Maximum	1200 MT	5 MT fish = 1 ha reef	240 ha
Best estimate	**600 MT**	**10 MT fish = 1 ha reef**	**60 ha**

Table D-3

Estimates of biomass lost

The <u>maximum</u> estimate is based on the assumption that there is no biomass compensation, i.e., a 10% Adult Equivalent Loss would lead to a 10% reduction in standing stock. The <u>best</u> estimate considers that there may be some biomass compensation, later larval stages may be able to avoid entrainment, and all fish larvae may not be killed after being entrained.

SPECIES	STANDING STOCK	ADULT EQUIVALENT LOSS	BIOMASS LOST
Maximum estimate			
Queenfish & white croaker	10,000 MT	10%	1000 MT
All other species[1]	20,000 MT	1%	200 MT
			1200 MT
Best estimate			
Queenfish & white croaker	10,000 MT	10%	500 MT
All other species[1]	20,000 MT	1%	100 MT
			600 MT

[1] Excluding northern anchovy, which had an adult equivalent loss <0.1%.

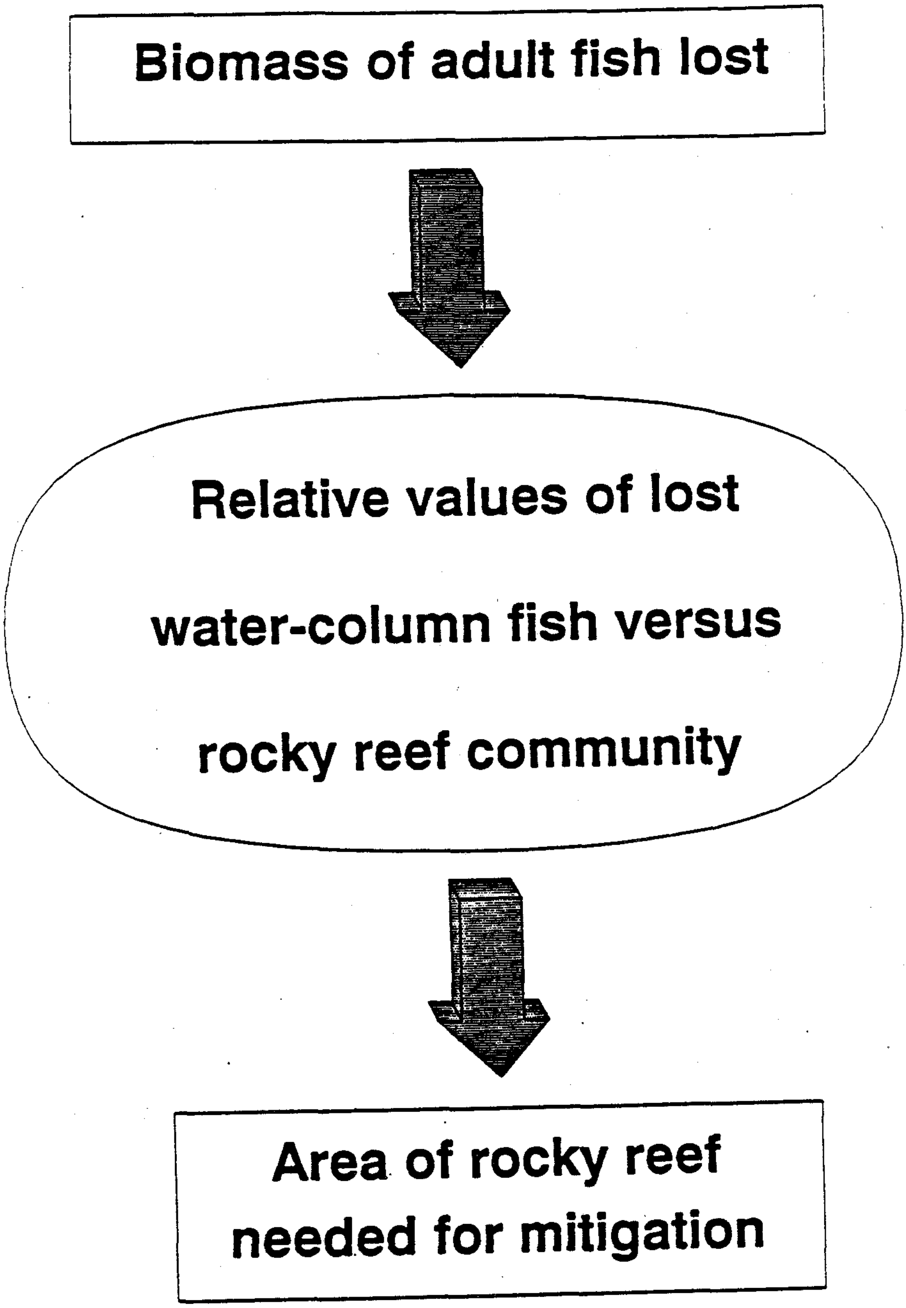

Figure D-1: Process used to estimate area of rocky reef needed to replace midwater fish impacts caused by SONGS.