# TECHNICAL REPORT TO THE CALIFORNIA COASTAL COMMISSION

## C. Entrapment of Juvenile and Adult Fish at SONGS

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This report analyzes and presents the results of studies of the UCSB Fish Program, which were done on behalf of the MRC over the period 1980-1988, under the direction of Dr Edward E. DeMartini. Dr. DeMartini's Final Report to the MRC "The Effects of Operations of the San Onofre Nuclear Generating Station on Fish" (December 1987) provided the starting point for the analyses in the present report.

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# SUMMARY

SONGS withdraws cooling water from the ocean through intake pipes situated in 9 m of water about 1 km offshore. When all pumps are operating, 10.8 x $10^6$ $m^3$ of water passes through the three units daily. Juvenile and adult fish are drawn into the plant with the cooling water.

All the fish that enter Unit 1 are killed; they are either impinged on travelling screens, pass through the screens, or remain in the screenwells until they are killed by periodic heat treatments that are used to control the accumulation of biofoulers. Unlike Unit 1, the new units have a Fish Return System (FRS) designed to divert fish past the travelling screens and return them to the ocean. Thus, fish that enter Units 2 and 3 are impinged on screens, extruded through the screens, killed in heat treatments or diverted through the FRS. In this report we have estimated entrapment of fish at SONGS and evaluated the efficiency of the Fish Return System in reducing the loss of fish at Units 2 and 3.

Annual entrapment was estimated from samples collected at the three SONGS units during the 39-month period from May 1983 to August 1986. Almost six million fish weighing 41.1 metric tons (MT) were entrapped annually at SONGS. Only 5% of the total number and 10% (4.2 MT) of the total biomass were entrapped at Unit 1. More than 98% of the 5.6 million fish entrapped at Units 2 and 3 were small species. Two of them, northern anchovy and queenfish, accounted for 75% and 20%, of the fish entrapped, but they were small and comprised only 13% and 39%, of the biomass. Less than 2% of the entrapped fish were medium and large species, but because of their size, they represented 13% and 31% of the biomass, respectively. These estimates of annual entrapment are too low because

some small fish passed through the travelling screens in all three units and could not be sampled. While the abundance of fish may be substantially underestimated by the loss of these individuals, the effect on estimates of biomass is smaller because the fish are small.

At Units 2 and 3, most entrapped fish were diverted through the FRS and returned to the ocean. About 794,000 fish (7.2 MT) were impinged on travelling screens, 66,000 fish (3.0 MT) were killed in heat treatments and 4.7 million fish (26.6 MT) were diverted through the FRS. In general, medium and large species were more likely to be diverted than small ones. For most species, individuals that were diverted were, on average, larger than those that were impinged. However, for many of the abundant species, including white croaker, yellowfin croaker, sargo and zebra perch, the largest individuals were killed in heat treatments.

The efficiency of the FRS at SONGS Units 2 and 3 is defined as the percent of the fish entrapped in the plant that are returned to the ocean alive. Efficiency is the product of the percentage of entrapped fish that are diverted to the FRS return conduit (percent diversion) and the percent survivorship of diverted fish. Estimates of the probability of surviving transport through the FRS include mortality up to 4 days after discharge. Mortality resulted from physiological damage incurred while fish were in the FRS and was estimated from experimental data. Estimates for most species are unreliable due to poor replication and lack of controls, but we include them because they are the only estimates available.

Percent diversion estimates for individual species ranged from 41% to 94% of the number and from 49% to 91% of the biomass of fish entrapped in Units 2 and 3. Overall, 68% of the number and 76% of the biomass of small species were diverted to the FRS. Percent diversion of medium species was 68% for number and 66% for biomass, and diversion of large species was 74% for number and 67% for biomass.

There were too few data to estimate survivorship of diverted fish for most species. However, we have more confidence in the estimates for the two most abundant species, northern anchovy and queenfish, and for the small and large size classes of species. About 97% of the northern anchovy and 68% of the queenfish that were diverted to the FRS survived. These two species accounted for 98% of the fish in the small size class. Survivorship for large species was almost 100%. Survivorship for medium species could not be estimated accurately; it could range from 77% to 95%. These are estimates of maximum survivorship; because they do not include mortality from FRS effects that are lethal more than 4 days (the duration of each experiment) after fish were discharged from the plant.

Estimates of the efficiency of the FRS are also maximum estimates since they depend on percent survival of fish discharged from the FRS. Efficiency of the FRS ranged from a low of about 25% for white croaker to a high of about 90% for walleye surfperch and salema. Efficiency for northern anchovy was relatively high; 87% of the number and 76% of the biomass of entrapped fish were returned to the ocean and survived for the four days that they were observed in the FRS study. Efficiency for queenfish was only 48% for number and 53% for biomass of entrapped fish. The FRS seemed most efficient for large species; efficiency was 74% for number and 67% for biomass. On average, about 50% of fish in the medium and small (excluding anchovy) size classes were returned and survived. Small species were such a dominant component of the fish entrapped at Units 2 and 3 that they accounted for almost 98% of the fish that survived even though they had the lowest probability of surviving FRS transport. Small species represented 54% of the biomass successfully returned while medium and large species comprised 11% and 35%, respectively. Overall, the FRS successfully returned 4.33 million fish (21.9 MT) representing 77% of the fish (59% of the biomass) entrapped at Units 2 and 3.

During May 1983 to August 1986, about 272,000 juvenile and adult fish (4.2 MT) were entrapped each year at Unit 1; they all died. Approximately 1.27 million (15.0 MT) of the 5.6 million juvenile and adult fish entrapped annually at Units 2 and 3 were killed. Therefore, total annual losses at SONGS during this period were 1.54 million fish (19.2 MT). This represents 26% of the number and 47% of the biomass of fish entrapped annually at SONGS during this period.

Annual estimates of entrapment were based on samples taken over a period when there was an unusual broadscale reduction in the abundance of nearshore fish induced by El Nino. Entrapment at SONGS depends on the nearshore abundance of fish. To estimate future entrapment during periods of higher abundance of nearshore fish, entrapment during 1983-1986 was compared with entrapment during 1976-1979, before the El Nino period. If the nearshore abundance of fish were at 1976-1979 levels, then SONGS Units 1, 2, and 3 together might entrap more than 110 MT of fish each year (assuming SONGS operated at 75% of the maximum pumping level). If overall efficiency of the FRS remained at the same level as 1983-1986 (47% for biomass), then 52 MT of fish would be killed each year.

# 1. INTRODUCTION

An electric generating station that uses water for cooling entrains planktonic fish eggs and larvae and entraps juvenile and adult fish along with the water that is drawn into the plant (Sharma 1978). Power plants currently operating in the United States withdraw cooling water from many sources, including lakes, rivers, estuaries and the ocean. San Onofre Nuclear Generating Station (SONGS), which is located on the coast of Southern California (Figure 1), withdraws water from the ocean.

SONGS withdraws cooling water through intake pipes situated in 9 m of water about 1 km from shore (Figure 1). Unit 1, which has two circulating pumps, withdraws $1.7 \times 10^6$ $m^3$ /day when both pumps are operating. Each of the new units, Units 2 and 3, has four circulating pumps which take in about $4.5 \times 10^6$ $m^3$ /day at full flow. Thus, when SONGS is fully operational, about $10.7 \times 10^6$ $m^3$ of water /day passes through the plant.

Juvenile and adult fish are drawn into the plant with the cooling water. The structure of the intake system at Unit 1, which has operated since 1968, is different from Units 2 and 3, which began operation in May 1983 and April 1984, respectively. These differences affect the magnitude of entrapment and the fate of the fish entrapped.

The intake pipe for each unit is covered with a velocity cap which various studies have indicated reduces the entrapment rate of adult fish (Thomas *et al.* 1980, Lawler *et al.* 1982a, EPRI 1984). The cap covering the intake pipe for Unit 1 is rectangular. In contrast, circular caps were installed over intake pipes for Units 2 and 3 because a circular cap reduces the variance and vertical components of incurrent flow, two factors believed to influence fish entrapment (Weight 1958, Schuler and Larson 1975).

In Unit 1, most entrapped fish are impinged on travelling bar racks and screens which have a 5/8-inch mesh size. However, small fish can pass through the screens (Appendix A). Also, some fish are not immediately impinged on the screens but remain in the screenwells until they are killed by periodic heat treatments that are used to control the accumulation of biofoulers. After they die, they collect on the screens and are removed. All fish collected from the screens are taken to a landfill site.

Units 2 and 3 also have travelling bar racks and screens that collect entrapped fish, but the mesh size of these screens is only 3/8 inch. (The maximum size of fish that can pass through these screens is much smaller than at Unit 1 [Appendix A].) Unlike Unit 1, the two new units have a fish return system (FRS) designed to reduce losses of fish by diverting them past the travelling screens and eventually returning them to the ocean. Thus, of the fish that enter Units 2 or 3, some fish are impinged on (or pass through) the travelling screens, some remain in the screenwells and are eventually killed during periodic heat treatments, and the rest are diverted into the FRS holding bay.

The successful operation of the FRS depends on the behavioral responses of fish to changes in water velocity and pressure. The FRS consists of a series of guiding vanes and louvers that direct fish into a bay of quiet water, where they are held until they are returned to the ocean (Figure 2). The louvers (travelling bar racks), which are located to one side of the incoming water flow in front of the travelling screens, are vertical bars that are about 0.5 cm wide and 6 cm deep, and are spaced about 3 cm apart. As water enters the screenwell, the guiding vanes help direct some fish towards the collection bay; they also ensure that the flow across the louvers is uniform so that fish are less likely to be trapped against the louvers in areas of high velocity. Fish that contact the louvers theoretically swim along the bars and into the collection bay. The collection bay is a large concrete lined basin (about 5 m long x 4 m wide x 9 m deep) with a travelling screen at the back. Water flows through the basin but the flow is much slower than in the screenwell area.

A large rectangular elevator bucket, 4 m long and 1 m deep, sits within the basin and is used to remove the fish from the collection bay. The bottom and lower portion of the sides of the bucket are solid and the top 30 cm on all sides is mesh. When the elevator is activated, most of the fish are trapped in the bucket as it is slowly raised out of the water. The fish are then dumped from the bucket into the return sluice channel as water is flushed into the channel. The front edge of the bucket is at an angle to the bottom to facilitate the even flow of water and fish over the lip and into the sluice channel (Figure 3). The bucket is repeatedly raised and lowered until at least 90% of the fish are removed from the collection bay as judged by the diminishing number in each successive bucket load. Normally, fish are removed from the collection bay once a day but they may be removed more frequently during periods of heavy entrapment. The return conduit discharges the fish in 6 m of water about 400 m offshore (Figure 1).

### 1.1 Objectives

The goals of this report are: (1) to provide a comprehensive summary of the number and biomass of fish entrapped in all 3 SONGS units from May 1983 to August 1986, (2) to estimate the annual magnitude of entrapment for the period, (3) to evaluate the efficiency of the Fish Return System in reducing the loss of fish at Units 2 and 3, and (4) to estimate the potential inplant loss of fish at SONGS in the future.

This report is a summary of the work done by DeMartini *et al.* (1987) for the MRC. We have reviewed their results and included new analyses when warranted. DeMartini *et al.* used the data collected by contractors employed by Southern California Edison to carry out the monitoring studies of fish entrapment required by the National Pollutant Discharge Elimination System (NPDES) permits for SONGS Units 2 and 3. The mortality of fish that were discharged from the power plant through the Fish Return System was estimated from a study by researchers at Occidental College (Love *et al.* 1987).

# 2. METHODS

The following is a summary of the methods used to estimate entrapment of fish at SONGS during the first 39 months (May 1983 - August 1986) of operation of Units 2 and 3 and concurrent operation of Unit 1. In addition, the methods used to evaluate the efficiency of the Fish Return System (FRS) are summarized. A detailed description of methods used to collect samples, estimate entrapment, and evaluate the FRS can be found in DeMartini *et al.* (1986, 1987).

## 2.1. Estimates of entrapment at SONGS

Fish that enter Units 2 and 3 may : (1) pass through the travelling screens, (2) be impinged on the screens, (3) be diverted to the FRS, or (4) remain in the screenwells until they are killed during a heat treatment. At Unit 1, which has no FRS, fish may pass through the travelling screens or be impinged on them or die in heat treatments. The abundances of fish that were impinged, diverted, or killed in heat treatments were estimated separately. Small fish that pass through the screens in Units 2 and 3 could not be sampled and their abundance cannot be estimated. The abundances of small fish that passed through the 5/8"-mesh screens in Unit 1 but would have been collected on 3/8"-mesh screens like those in Units 2 and 3, was estimated for queenfish, northern anchovy and white croaker, by comparing the length frequency distributions of fish in Unit 1, and fish in Units 2 and 3 (Appendix A).

2.1.1. Impingement samples

Both number and biomass of fish impinged on the travelling screens in each of the three units were estimated from samples that spanned 24 (± 2) hrs of operation during full-flow conditions. Full-flow conditions occurred when all pumps operated for the entire sample period. The operational status of each SONGS unit was determined from a record of the volume of water pumped during the period and indicated in the Marine Review Committee (MRC) SAS data base DBFLOW. Table 1 lists the dates from May 1983 through August 1986 when quantitative impingement samples were taken at each unit. Samples were collected on 65 days at Unit 1 and on 88 and 103 days at Units 2 and 3, respectively. Samples were also taken during periods when some pumps were not operating; these samples were used in a separate analysis to determine the relationship between the magnitude of entrapment and the volume of water pumped through a unit.

Each unit 6 sets of bar racks and travelling screens arranged side by side. As the racks and screens rotate out of the water, fish and debris that have collected on the racks and screens are washed into a sluice channel and collect in large mesh lines. All fish in a 24 hr impingement sample were collected, identified and counted. Aggregate wet weights were determined for each species. The standard lengths of individuals of each of 10 select species, including queenfish, northern anchovy, white croaker, kelp bass, barred sand bass and black croaker, were usually measured in each 24 hr sample. At least 125 fish of each species were randomly selected and measured when present; after November 1983, up to 250 queenfish were measured.

2.1.2. Diversion samples

The number and biomass of fish diverted to the Fish Return System (FRS) in Units 2 and 3 were sampled during the same 24 ($\pm$ 2) hr periods that were sampled for impingement on travelling screens (Table 1). However, not all the fish that were removed from the FRS collection bay during the 24 hr period were counted. Instead, two subsamples were collected each time the elevator bucket was emptied, and used to estimate the number of fish diverted through the FRS. The sample was taken as the fish in the elevator bucket were poured into the return sluiceway. Two nets, each with circular openings 40 cm in diameter, were haphazardly position on the lip of the bucket, and captured the fish that spilled over that section of the lip as the bucket was emptied. Since the nets covered 20% of the 4 m length of the lip, the sum of all fish captured in nets as successive bucket-loads were emptied, represents 20% of the total fish removed from the FRS collection bay.

All fish in the subsamples were identified and counted and aggregate wet weights were determined by species in the same manner as for the impingement samples. The number and biomass of the subsamples were then scaled up to estimate total abundance and biomass. Standard lengths of individuals of the 10 select species (listed above in impingement samples) were also measured. At least 125 individuals of each species (250 for queenfish) were randomly chosen for measurement; if less than 125 individuals were collected, they were all measured.

A few very large species, such as rays and sharks, were not subsampled with nets as described above. Instead, they were counted, and lengths were estimated visually, while they remained in the elevator bucket, just before it emptied. The number and biomass of these very large fish were added to the scaled-up estimates of the other species to determine total abundance and biomass of diverted fish.

2.1.3. Heat treatment samples

The California Department of Fish and Game requires that all heat treatments at electrical generating stations in Southern California be monitored. Therefore, all fish killed during heat treatments at SONGS Units 1, 2 and 3 during May 1983 - August 1986 were collected from travelling screens, identified, counted and weighted in the same manner as impingement samples. The standard lengths of the select species were also measured. The dates when heat treatments occurred at Units 1, 2 and 3 are listed in Table 2; there were 8 heat treatments at Unit 1, 18 at Unit 2 and 13 at Unit 3.

**2.2. Comparison of entrapment at Units 2 and 3**

A comparison of abundance and biomass of fish entrapped in Units 2 and 3 showed that there were no statistically significant differences in the magnitude of entrapment at the two new units. The top 20 species caught in each unit were ranked by both number and biomass. The rankings for Units 2 and 3 were correlated which suggests that the species composition of the fish entrapped in the two new units is similar. Details of these analyses are presented in Appendix A. Therefore, estimates of the total number and biomass of fish impinged, diverted and killed in heat treatments are summed over Units 2 and 3 in all subsequent analyses.

### 2.3. Annual entrapment at SONGS

#### 2.3.1. Estimation of annual entrapment

Estimates of entrapment measured at the three SONGS units during full-flow operational conditions in the 39-month period from May 1983 to August 1986 were used to estimate the annual entrapment of fish (both number and biomass) by the power plant. Data from both impingement and heat treatment samples were used for Unit 1 and the combined data for impingement, diversion and heat treatment samples were used for Units 2 and 3.

The first step in estimating the annual impingement and diversion components of entrapment was to use the quantitative 24-hr entrapment samples to calculate the mean daily entrapment rate (i.e. the mean number and biomass impinged and diverted per day at full flow [all pumps operating] for each unit) for each of the 39 months. There were some months when no entrapment samples were taken for a unit, often because the unit was not operating at full flow during that month. At most, two quantitative samples were collected each week (Table 1).

The mean daily entrapment rate at full flow in a month was multiplied by the number of "full-flow" days in that month to estimate monthly entrapment. The number of "full-flow" days was calculated by summing the volume of water pumped during the month and dividing by the daily full-flow volume ($1.7 \times 10^6$ $m^3$ for Unit 1 and $4.5 \times 10^6$ $m^3$ for Unit 2 or 3). The number of "full-flow" days per month for Units 1, 2 and 3 are shown in Table 3.

This method of estimating monthly entrapment assumes that both the number and biomass of fish entrapped is positively and linearly related to the volume of water pumped over a range of 25% to 100% pump operation at a unit. This assumption was tested by comparing the number and biomass of fish entrapped at one new unit operating at full flow (4 pumps) to entrapment at the other new unit that was concurrently operating at less than full flow (fewer than 4 pumps). Results show that entrapment is a linear function of the volume of water pumped (Appendix A); for example, twice the volume pumped entraps twice as many fish, on average.

Estimates of monthly entrapment for the 39 months from May 1983 to August 1986 were averaged over years for each month (i.e. Jan., Feb., etc.) to determine the mean monthly entrapment for the sample period. The annual impingement and diversion components of entrapment were calculated by summing the estimates of mean monthly entrapment. Monthly entrapment was first averaged over years for each month and then summed over months to ensure that each month was represented equally in the estimated annual total. This was necessary because the summer months were overrepresented in the 39-month sample period. Estimates of annual entrapment are the same as those given in DeMartini *et al.* (1987). Variances of the estimated annual entrapment and a detailed description of the methods used to calculate the variances are also given in DeMartini *et al.* (1987) and will not be included here.

Heat treatments were not performed on a regular schedule; sometimes several months passed between treatments. Since heat treatments samples may have contained fish that had collected in screenwells over more than one month, "monthly" losses for the 39-month period could not be estimated. Annual estimates of heat treatment losses were calculated by summing losses over the 39-month sample period and taking $12/39^{ths}$ of the total. Annual heat treatment estimates were added to the annual impingement and diversion estimates to determine annual entrapment.

The method described above was used to calculate annual entrapment for all species at Units 2 and 3 and all species except queenfish, northern anchovy, and white croaker at Unit 1. The annual entrapment rates of queenfish, northern anchovy and white croaker at Unit 1 were calculated from entrapment estimates at Units 2 and 3 (see details below).

2.3.2. Estimating entrapment at Unit 1 from entrapment at Units 2 and 3

Since small fish were lost from impingement samples in all units because they passed through the travelling screens, entrapment of juvenile and small adult fish is underestimated. The absolute magnitude of the underestimate is larger for number than for biomass because small fish do not weigh much. Entrapment of small species at Units 2 and 3 is more representative of actual entrapment because more small fish are trapped on the small-mesh screens in the new units than on the larger-mesh screens in Unit 1. Therefore, entrapment at Unit 1 for queenfish, northern anchovy and white croaker, all abundant small species, was calculated from annual estimates at Units 2 and 3.

The first step in estimating entrapment at Unit 1 from entrapment at Units 2 and 3 was to determine the ratio of entrapment at Unit 1 to the new units. Since the volume of water drawn into Unit 1 is much less than the volume drawn into either of the new units, entrapment should also be lower at Unit 1. DeMartini and Larson (1980) predicted that, if mean sizes were equal, each new SONGS unit would entrap 2.5 times the amount of fish entrapped in Unit 1 because, when all pumps are operating, each new unit pumps about 2 1/2 times the amount of water that Unit 1 pumps. The number of fish entrapped at the different units cannot be compared directly because large numbers of small fish that are impinged on screens in Units 2 and 3 pass through the screens in Unit 1 and are not sampled. To avoid the bias caused by the difference in screen mesh size, only large ($\geq$ 100 mm SL) queenfish, which should be fully retained on the larger mesh screens in Unit 1, were used for the comparison. A two-tailed paired t-test was used to test the hypothesis that there was no difference between the number of fish entrapped in a new unit and 2.5 times the number of fish entrapped in Unit 1. Details of this analysis are presented in Appendix A.

Results show that the hypothesis that entrapment at either Unit 2 or Unit 3 is 2.5 times the entrapment at Unit 1 must be rejected for large queenfish. Instead, the number of fish entrapped in each new unit is about 7.7 times the number of fish entrapped in Unit 1 (Appendix A Table A-8) and this ratio is used in subsequent calculations. This relationship also seems to be a good approximation for the ratio of biomass entrapped at the new units and Unit 1 (Appendix A).

The ratio of entrapment at a new unit to entrapment at Unit 1 was estimated for full-flow conditions (all pumps operating) at all units. However, annual estimates of entrapment reflect the average pumping conditions over the 39-month sampling period. At Units 2 and 3, pumping levels averaged 76% of the full-flow level but Unit 1 operated at only 56% of full flow (Table 3). The difference in pumping must be taken into account when entrapment at Unit 1 is estimated from entrapment at Units 2 and 3. Therefore, annual entrapment at Unit 1 for queenfish, northern anchovy and white croaker was estimated as:

$$\text{(number or biomass at Unit 1)} = \frac{\text{(number or biomass at Units 2 and 3)} \times 0.737}{15.4}$$

where 0.737 is the ratio of the average pumping level at Unit 1 to the new units (56% / 76%) and 15.4 is 2 times the ratio of entrapment at a new unit to Unit 1.

## 2.4. Evaluation of the efficiency of the Fish Return System (FRS)

The efficiency of the FRS at SONGS Units 2 and 3 is defined as the percent of the fish entrapped in the plant that are returned to the ocean alive. There are at least two components that must be considered when evaluating efficiency. The first is percent diversion (i.e. the fraction of all fishes entrapped that are diverted to the FRS and ultimately discharged back into the ocean). The second is the percent survivorship of fishes that are diverted. Fish that are diverted to the FRS may die either before or shortly after discharge because of physiological stresses associated with transport through the FRS. The overall percent efficiency of the FRS is calculated as percent diversion times percent survivorship.

### 2.4.1 Percent Diversion

Estimates of percent diversion are based on the annual estimates of fish entrapped in Units 2 and 3. Percent diversion was calculated as the number or biomass of fish diverted divided by the total number or biomass of fish entrapped times 100. Annual estimates of total entrapment were used to calculate percent diversion rather than concurrent 24 hr samples of impingement and diversion because annual estimates include the heat treatment component of entrapment as well as impingement and diversion. Estimates of percent diversion differ slightly from those calculated by DeMartini *et al.* because they defined percent diversion as diversion divided by the sum of diversion plus impingement; they did not include heat treatment losses in the denominator of the equation. Many large fish are found in heat treatment samples and to exclude them from estimates of the total fish entrapped would result in an overestimate of percent diversion, particularly for biomass.

2.4.2. Percent Survivorship

Estimates of mortality from mechanical damage or physiological stress incurred during discharge through the FRS were based on the results of field experiments contracted directly by Southern California Edison and conducted by researchers at Occidental College. A summary of the methods is presented here; a more detailed description is given in Love *et al.* (1987).

Fishes discharged through the FRS were captured in octagonal (about 3.7 m x 3.7 m) pens that were attached to the discharge pipes. Pen frames were constructed of PVC pipe and walls were 1/4 in, knotless-mesh nylon netting. Before the pen was attached to the discharge pipe, any resident fish were flushed from the pipe. Once the net was attached, fish were dumped from the FRS elevator basket into the return sluice channel and flushed down the discharge pipe into the pen. The fish used in this experiment had been entrapped in the plant for 24 hr or less.

This is similar to normal operations since fish are removed from the FRS collecting bay at least once a day. After receiving fish, experimental pens were disconnected from the discharge pipe, moved a short distance away and anchored to the bottom.

To determine if mortality of fish in experimental pens was the result of containing fish inside pens rather than transport through the FRS, control pens were also established. Control pens were identical to experimental pens but had detachable fyke-net wings designed to herd fish into the pen without damage or stress. Control pens were set offshore in the vicinity of the discharge pipe 24 hrs before the start of a control trial to capture crepuscular and nocturnal cross-shelf migrators such as queenfish; therefore, some fish may have been in control pens up to 24 hrs longer than in experimental pens.

Only one pen was monitored during each experimental or control trial. The intent was to monitor one experimental and one control trial concurrently but trials were sometimes disrupted by storms and other factors so that experimental and control trials often alternated over periods of several days to several weeks. It is likely that variability in factors that vary with time (such as surge, temperature, temporal variability in size distribution of fishes, etc.) were randomly distributed among experimental and control trials and should not bias the results.

Fishes were held in pens and observed for 96 hours. Fish were held for only 4 days to minimize mortality from cage effects. Short-term effects resulting from the FRS (such as physiological stress from scale loss or osmotic damage) will be detected within 4 days, but long-term lethal effects will not be detected. Thus, it is likely that the results of this study overestimate percent survival. Dead fish were counted at the start of the experiment (fish that were dead when discharged) and daily thereafter. Although preliminary experiments began in May 1983, only data for the concurrent or alternating series of experimental and control trials completed at SONGS during October 1983 to August 1985 are included in the survivorship analyses presented here.

The number of species and of individuals of each species present in a pen varied among pens. Often, species that were present in experimental pens were either absent from or rare in control pens. This was not important for most species that were not found in control pens because these species did not die in experimental pens. However, it was a problem for a few species such as slough anchovy and topsmelt, that had relatively high mortality in experimental pens and no controls.

Species composition and abundance of fish in pens varied because of random fluctuations in the relative abundances of species over time and because the intakes and fyke nets differed in species selectivity. Species composition could be important if predatory species were trapped in pens with prey species because mortality could be the result of predation, not FRS or pen effects. There were high numbers of predators (at least 15 fish, mostly yellowfin croaker) in 6 of 18 experimental pens, and mortality in these six pens ranged from 22% to 100% for all species combined. There is no direct evidence to determine if predators killed the fish in these pens because the appropriate data (e.g. feeding observations or stomach contents of predators) were not collected. However, even if all the fish in these pens were killed by predators, they would only represent about 8% of the total fish that died in all experimental pens combined. There were many pens with high mortality and no predators. Thus, predators may have killed some fish but it seems unlikely that predation had an important impact on overall percent mortality.

To determine if mortality within experimental and control pens was a function of fish density, the observed 96 hr mortality was regressed against the initial abundance of fish in pens. Queenfish were used in this test because they occurred in all pens and had relatively high mortality. Mortality of queenfish was regressed against initial abundance of both queenfish and total fishes for experimental and control pens separately and both pen types combined. Results indicate that the number of queenfish that died in either experimental or control pens was not related to fish densities in the pens (Table 4).

Since there was no apparent relationship between mortality and fish density in pens, the data were summed over all pens within each pen type, either experimental or control. For each type of pen, total mortality was estimated as the initial number of fish minus the number alive after 4 days divided by the total number of fish initially present in the pens. The number of fish initially present in experimental pens included fish that were dead when discharged from the FRS.

Mortality in experimental pens was an estimate of FRS effects plus pen effects, while mortality in the control pens was an estimate of pen effects only. The percent mortality caused by transport through the FRS was estimated by subtracting control mortality from experimental mortality. Standard errors of the mean mortality were also calculated and used to determine 95% confidence intervals. Details of the methods used to estimate standard errors are presented in DeMartini *et al.* (1987).

Most species of fish entrapped at SONGS, did not occur in the survivorship experiments, because they were not entrapped on those days when experimental trials were conducted. To include these species in survivorship estimates, species were separated into size classes and the average percent mortality for species in different size classes was estimated. This assumes that there is a relationship between average size of individuals of a species and the probability of surviving the FRS. There are too few data to test this assumption for different species, although a comparison of percent mortality of large and small queenfish suggest that mortality of the smaller fish is higher (Table 15). A species of fish was classified as either small (<30 g), medium (30 - 199 g), or large (≥ 200 g) based on the average weight of all individuals collected in quantitative impingement and diversion samples at Units 2 and 3 (Table 8). These are the same size-classes used to combine species into larger groups for entrapment estimates (see Section 3.1.2).

For some species most of the individuals entrapped were juveniles. In the context of this report the size class of a species is based on the average weight of all individuals impinged or diverted, and does not necessarily reflect the sizes of adults in the population. For example, white croaker adults weight about 100 g (A. Ebeling, *personal communication*), but white croaker is classified as a small species because most individuals entrapped were juveniles. Thus, while estimates of mortality for size classes are appropriate for the average of individuals of species sizes entrapped at SONGS, the estimates can not necessarily be extrapolated to adults of the species.

Percent mortality for small species was calculated as the weighted mean of mortality estimates for white croaker, walleye surfperch, white seaperch and queenfish. Other small species were not included because they did not have adequate controls for pen effects. The controls were considered particularly important for small species because mortality in control pens was not trivial. Northern anchovy were also excluded from estimates for small species because mortality in control pens was much higher than in experimental pens.

The mortality estimate for medium species is the weighted average of all species. Species with no controls were included because, without them, we could not estimate mortality; the only medium species in control pens was blacksmith and only one blacksmith occurred in experimental pens. There was some mortality for medium species in experimental pens and, since it is impossible to determine whether some deaths were caused by pen effects rather than FRS effects, mortality for the size class may be overestimated.

The mortality estimate for large species is also the weighted average for all large species in experimental pens, even those that did not occur in control pens. The lack of controls for some large species is not a problem because very few of them died in the experimental pens.

# 3. RESULTS

Common names are used for species of fish throughout this report. Table 5 is a list of common and scientific names for species that were sampled.

## 3.1. Entrapment

### 3.1.1. Entrapment samples

Entrapment of juvenile and adult fishes at Units 2 and 3 is estimated as the sum of fish that are impinged on travelling screens, killed during periodic heat treatments, or diverted to the Fish Return System (FRS). At Unit 1, there is no FRS and entrapment is estimated as the number of fish impinged and killed in heat treatments. Most fishes are diverted to the FRS in the two new units, whereas in Unit 1, most are impinged on travelling screens.

The total number and biomass of fish impinged in samples collected from May 1983 to August 1986 at Units 2 and 3 are shown in Table 6; the total number and biomass of fish diverted to the FRS are listed in Table 7. Nearly 275,000 fish (2.9 MT) were collected in impingement samples and more than 1.2 million fish (10.8 MT) were collected in diversion samples during the 39 months. Overall, queenfish and northern anchovy were the most abundant fish in impingement and diversion samples. Queenfish alone contributed about 30% of the number and 48% of the biomass of fish in both types of samples.

For more than 75% of the species entrapped, individuals that were diverted to the FRS were larger, on average, than those impinged on travelling screens. For example, the mean weight of diverted queenfish was 50% greater than the mean weight of those impinged (Tables 6 and 7, Figure 4). One exception was northern anchovy, which was smaller, on average, in diversion samples than in either impingement or heat treatment samples (Tables 6 and 7, Figure 5). For northern anchovy, the size difference may have been due to the different methods used to collect the samples. Impingement and heat treatment samples were collected from the travelling screens. Many small anchovy were probably lost from the samples because they were extruded through the 3/8"-mesh screens under fast-flow conditions. Therefore, the mean weight of northern anchovy in impingement samples is undoubtedly overestimated. In contrast, diversion samples were taken with smaller mesh nets as the fish were dumped from the FRS elevator bucket and it is much less likely that small fish were lost from the samples.

Over the 39-month sampling period, about 215,000 fish (9.8 MT) were killed in heat treatments at Units 2 and 3 and an additional 11,000 fish (1.3 MT) were killed at Unit 1 (Tables 9 and 10). At Units 2 and 3, two species of small fish, queenfish and northern anchovy, were most abundant in heat treatment samples, but the species of large fish, including yellowfin croaker, sargo and zebra perch, accounted for most of the biomass. The latter 3 species and spotfin croaker, another large fish, also represented about 60% of the biomass in heat treatment samples in Unit 1.

The average weight per fish was greater in heat treatment samples than in impingement or diversion samples for some species, particularly those that were abundant (>100 individuals) in heat treatments (Tables 6, 7 and 9). The pattern was consistent for two-thirds of the abundant species. For example, the mean weight of white croaker in heat treatments was almost 3 times the mean weight in diversion samples and 5 times the mean in impingement samples (Tables 6, 7 and 9, Figure 6). The mean weights of the 3 most abundant large species, yellowfin croaker, sargo and zebra perch, were also greatest in heat treatments. Two of the exceptions were northern anchovy and queenfish, both small species, which were larger in impingement samples than in heat treatments; queenfish were also larger in diversion samples (Tables 6, 7 and 9). There is some indication that, in Unit 1, fish killed in heat treatments also tended to be larger that those impinged on travelling screens (Figure 7).

### 3.1.2. Annual estimates of entrapment

Annual entrapment at Unit 1 and the new units was estimated for 17 species, all other species combined, and total fish (Table 11). The 17 species were chosen because of their abundance in samples or importance as commercial or sport fish species; together they represent more than 99% of the fish entrapped at SONGS. Estimates for all species in Units 2 and 3, and all species except queenfish, northern anchovy and white croaker in Unit 1, were calculated from quantitative impingement, diversion and heat treatment samples collected from May 1983 through August 1986. Annual entrapment of queenfish, northern anchovy and white croaker in Unit 1 was estimated from annual estimates for Units 2 and 3 (described in detail in Section 2.3.2. and Appendix A).

Over the 39-month period from May 1983 to August 1986, SONGS Units 1, 2 and 3 together entrapped an average of almost 6 million fish (41.1 MT) per year (Table 11). Fish entrapped at Unit 1 comprised 5% of the total number and 10% of the biomass (4.2 MT) and fish at Units 2 and 3 comprised 95% and 90% (36.9 MT) of the number and biomass, respectively. Queenfish, northern anchovy and white croaker were the most abundant species entrapped (Table 11). At Units 2 and 3, queenfish represented 20% of the annual entrapment by number and 39% by weight. In contrast, northern anchovy accounted for 75% of the individuals but only 13% of the biomass entrapped. White croaker comprised about 2% of both number and biomass.

Species were classified as large, medium or small based on the average body weight of fishes collected in the impingement and diversion samples in Units 2 and 3 (Table 8). More than 90 species of fish were entrapped at SONGS (Table 5). Since we can not possibly discuss each species separately we use this size classification as a convenient method for combining species into larger groups.

Overall, most of the fish entrapped in Units 2 and 3 were small species; they represented 56% of the biomass entrapped. Medium and large species accounted for 13% and 31% of the biomass entrapped, respectively. The proportion of entrapment that was small species was even higher if calculations were based on abundance. Small species represented more than 98% of those entrapped; medium and large species each accounted for less than 1%.

Annual estimates of the three components of entrapment, heat treatment, impinged and diverted at Units 2 and 3 are shown in Tables 12 and 13. Estimates for number and biomass of small, medium and large species were calculated by first dividing the "all other species combined" group into the 3 size classes and then summing over all species within size classes.

About 66,000 fish (3 MT), were killed in heat treatments in Units 2 and 3 each year; this represents 1% by number and 8% by weight of the total entrapment (Tables 12 and 13). For most species, heat treatments killed a small percentage of the fish entrapped. However, for 3 large species, spotfin croaker, barred sand bass and yellowfin croaker, heat treatment losses represented 47%, 35% and 25% of the total biomass entrapped, respectively. Overall, large species represented 86% of the biomass but only 11% of the number killed in heat treatments each year. In contrast, small species accounted for 87% of the number but only 11% of the biomass.

Fish impinged on travelling screens comprised 14% (about 794,000) of the number and 20% (7.2 MT) of the biomass of fish entrapped in Units 2 and 3 (Tables 12 and 13). In general, individuals of small species were more likely to be impinged in travelling screens than individuals of medium or large species. Overall, small species comprised 62% of the biomass and 98% of the number of fish impinged annually. Medium species accounted for 22% by biomass and about 2% by number and large species represented only 16% by biomass and less than 1% by number.

Most fish entrapped in the new units were diverted to the Fish Return System (FRS) and returned to the ocean. The diversion component comprised 85% (about 4,740,000) of the number and 72% (26.6 MT) of the biomass entrapped. The FRS is discussed in more detail below.

### 3.2. Fish Return System

3.2.1. Percent diversion

Estimates of percent diversion were based on annual estimates of fish entrapped in Units 2 and 3. Since annual entrapment was estimated for only 17 species, percent diversion was also estimated for only these species.

Percent diversion estimates for individual species ranged from 41% to 94% of the number (Table 12) and from 49% to 91% of the biomass (Table 13) of fish entrapped in Units 2 and 3. At least 80% of the entrapped biomass was diverted for 7 of 17 species. For more than half of the species, percent diversion of biomass was greater than percent diversion for number because larger individuals, on average, were diverted through the FRS (Table 13). For example, percent diversion of queenfish, the second most abundant species, was 78% for biomass and 71% for number because the average weight of diverted fish was about one-third greater than the weight of those impinged or killed in heat treatments. In contrast, for 2 large species, yellowfin croaker and spotfin croaker, percent diversion was greater for number that for biomass because larger individuals were lost in heat treatments.

Percent diversion estimates for the size classes are shown in Tables 12 and 13. Overall, 85% of the number and 77% of the biomass of small species (including northern anchovy) were diverted to the FRS. Percent diversion of medium species was 68% for number and 66% for biomass and diversion of large species was 74% for number and 67% for biomass.

3.2.2. Percent survivorship

Survivorship of fish diverted to the FRS was estimated from results of field trials conducted off SONGS from October 1983 to August 1985. Eighteen experimental and nine control trials were completed during this period. Results of all trials are listed in Table 14; species are categorized by mean body weight (see Methods for details; size classes are shown in Table 8). A total of 28 species of fish occurred in experimental pens but only 12 of them were found in control pens. For 60% of the species, fewer than 10 individuals were found in all experimental pens combined. These sample sizes were too low to estimate percent mortality for the individual species with any confidence and the results were summed for each size class ("other species" in Table 14).

Some species that were relatively abundant in experimental pens were rare in control pens. Since control trials were used to factor out the effect of containing fish inside pens, mortality of species that died in experimental pens but had no control could be due to either transport or pen effects. Slough anchovy were absent from control pens, but high mortality could be attributed to the FRS since 97% of the individuals were already dead when discharged from the return pipe.

The percent survivorship estimates derived from this study must be viewed with caution. First, while more than 62 species of fish were diverted to the FRS (Table 7), only 28 species were observed during the study and only 11 of these occurred in number high enough to estimate species-specific mortality; in experimental pens the other species were grouped. In addition, the lack of adequate controls for pen effects for most species meant that percent mortality was estimated with confidence for only 4 species. Finally, since trials lasted only 4 days, long-term prospects of mortality due to FRS effects were not assessed. As a result survival may be overestimated. We include these estimates in this report because this was the only study of mortality effects of the FRS.

The three most abundant species entrapped at SONGS, queenfish, northern anchovy and white croaker, were well represented in experimental trials and also occurred in control trials (Table 14). Mortality of queenfish in experimental pens was 52%, but since 20% of the individuals in control pens also died, the estimated mortality due to stress associated with the FRS was 32%. Queenfish were in all experimental pens; although half of the total number occurred in only 2 pens, another 5 pens had at least 100 individuals. Queenfish were also in all the control pens. The number of queenfish in control pens was an order of magnitude lower than the number in experimental pens, but there were at least 15 individuals in more than half of the control pens. Fifty-two percent of the white croaker in experimental pens died (Table 14). White croaker occurred in 10 experimental pens but 80% of them were in only 2 pens. No fish died in control pens, but, because the sample size was small, this may not be an adequate test for pen effects, and mortality due to the FRS may be somewhat overestimated.

Only 3% of the northern anchovy in experimental pens died, but 85% died in the controls (Table 14). The control estimate was based on 108 fish in only one pen and the fish may have been killed by some random factor that was unrelated to the effects associated with holding fish inside a pen. Since the estimate for northern anchovy is based on more than 5,500 fish in 10 experimental pens, percent survivorship was, most likely, very high for this species.

Percent mortality of 4 other species, walleye surfperch, white seaperch, deepbody anchovy and Pacific pompano, was also very low. Estimates for the latter 3 species lacked adequate controls, but this was probably not important because few fish died. Slough anchovy had the highest mortality in experimental pens; all fish died (Table 14). Although there was no control, 93% of the fish were dead when discharged. Therefore, it is clear that slough anchovy do not survive transport through the FRS. This is not unexpected because slough anchovy are small, fragile fish that lose scales easily.

Only two medium species, salema and topsmelt, occurred in relatively high numbers in experimental pens, and neither was found in control pens (Table 14). None of the 122 salema died, so the lack of controls was not important. Mortality of topsmelt was 30%, but without a control, mortality cannot be unquestionably attributed to the effects of the FRS; mortality of topsmelt caused by FRS effects could range from a only few percent up to 30%.

The only large species that occurred in high numbers in experimental pens was yellowfin croaker and almost all of them survived. A total of 15 yellowfin croaker occurred in 3 control pens and none died.

The average percent survivorship for all small species was 68% (Table 16). It was estimated as the weighted average of all small species with controls (queenfish, white croaker, walleye surfperch, white seabass); northern anchovy were not included because the control was not adequate. Survivorship for small species is a reflection of survivorship of queenfish because it was by far the most abundant small species in the experiment. This is consistent with entrapment results; if northern anchovy are excluded, queenfish comprised more than 85% of the abundance of small species entrapped. Survivorship of medium species (calculated as the weighted average of all medium species in experimental pens) was 77% (Table 16). The estimate was based primarily on survivorship of topsmelt, which comprised more than 75% of the fish in the medium size class; it was also the only medium species that died. There were no topsmelt in control pens, so mortality due to pens effects could not be estimated, and survivorship may be underestimated. Therefore, 77% is probably an underestimate of survivorship for medium species; survivorship could actually be as high as 95%. Very few fish in the large size class died and survivorship for large species was close to 100% (Table 17).

It was not possible to estimate percent survivorship based on the biomass of fish that survive transport through the FRS because fish were not weighed. Therefore, the estimates based on number (described above) are also the only available estimates for biomass. Length data for two species suggest that larger fish have a higher probability of surviving than smaller fish. Mortality in experimental and control pens was 37% for small ($\leq$100 mm SL) queenfish and only 27% for large (> 100 mm SL) queenfish (Table 15). A comparison of the size distributions of white croaker that lived with those that died shows that a higher proportion of the larger individuals survived (Figure 5). Thus, estimates of percent survivorship based on number of fish probably underestimate percent survivorship based on biomass.

3.2.3. Efficiency of the Fish Return System

The efficiency of the Fish Return System (FRS) is defined as the percent of the fish entrapped in SONGS Units 2 and 3 that are returned to the ocean alive.

The efficiency of the FRS was estimated for 9 species and three size classes of fish. Species were included if percent survivorship estimates for FRS effects were based on at least 10 fish (Table 14) and if percent diversion had been estimated. The percent efficiency estimates reported here are maximum estimates because they do not include mortality from FRS effects which are lethal more than 4 days after fish are discharged.

Efficiency of the FRS ranged from a low of about 25% for white croaker to a high of about 90% for walleye surfperch and salema (Table 16). Efficiency for northern anchovy was relatively high: 87% of the number and 76% of the biomass of entrapped fish were return to the ocean and survived. Efficiency for queenfish was lower: 48% for number and 53% for biomass. The FRS was most efficient for large species; percent efficiency was 74% for number and 67% for biomass. On average, about 50% of fish in the medium and small (minus anchovy) size classes were returned and survived (Table 16).

### 3.3. Estimated losses at SONGS

A large proportion of the fish entrapped in Units 2 and 3 were diverted to the FRS. Estimates of the overall percent efficiency of the FRS, in conjunction with estimates of losses from impingement and heat treatments, can be used to estimate the number and biomass of fish that were killed each year at SONGS.

Overall, 5.6 million fish (36.9 MT) were entrapped each year at Units 2 and 3. Almost 860,000 fish (10.2 MT) were impinged or killed in heat treatments; the remaining 4.7 million fish (26.7 MT) were diverted to the FRS. Eight percent of the number (approximately 411,000) or about 18% of the biomass (4.8 MT) of diverted fish were killed during or shortly after discharge as a result of injuries incurred in the FRS. Therefore, the total number of fish killed each year at Units 2 and 3 was approximately 1.27 million (15 MT). The FRS successfully returned 4.33 million fish (21.9 MT) representing 77% of the fish (59% of the biomass) entrapped at Units 2 and 3.

More than 98% of the number of fish entrapped at Units 2 and 3 were small species; medium and large species accounted for about 1% and 0.5%, respectively. The two most abundant small species, northern anchovy and queenfish, accounted for 75% and 20% of the total fish entrapped, but since they were small, they comprised only 13% and 39%, respectively, of the biomass. Small, medium and large species comprised 56%, 13%, and 31% of the biomass entrapped, respectively. Small species were such a dominant component of the fish entrapped at Units 2 and 3 that they accounted for almost 98% of the fish that survived even though they had the lowest probability of surviving FRS transport. Small species represented 54% of the biomass successfully returned while medium and large species comprised 11% and 35%, respectively.

During May 1983 to August 1986, about 272,000 juvenile and adult fish (4.2 MT) were entrapped each year at Unit 1; they all died. Approximately 1.27 million (15 MT) of the 5.60 million juvenile and adult fish entrapped annually at Units 2 and 3 were killed. Therefore, total annual losses at SONGS were 1.54 million fish (19.2 MT). This represents 26% of the number and 47% of the biomass of fish entrapped annually at SONGS during this period.

# 4. DISCUSSION

## 4.1. Entrapment and Losses at SONGS

During the 39-month period from May 1983 to August 1986, almost six million fish weighing 41.1 MT were entrapped annually at SONGS Units 1, 2 and 3. The estimates of annual entrapment are too low because some small fish passed through the travelling screens in all three units and could not be sampled. While the abundance of fish may be substantially underestimated by the loss of these individuals, the effect on estimates of biomass is smaller because the fish are small.

Entrapment of small species at Units 2 and 3 is a better approximation of actual entrapment than estimates from Unit 1 because more small fish were trapped on the small-mesh screens in the new units. Consequently, entrapment at Unit 1 for northern anchovy, queenfish and white croaker, the 3 most abundant species, was estimated from entrapment at the new units. However, this method still underestimates entrapment at Unit 1 because many small fish are lost from Units 2 and 3 (for example, northern anchovy up to 90 mm can pass through the screens in the new units) and because of the uncertainty in the estimate of the ratio of entrapment at Unit 1 and the new units.

## 4.2. Temporal comparisons of the magnitude of entrapment

Annual estimates of entrapment were based on samples taken over a 39-month period and incorporated short-term (e.g. seasonal) fluctuations in the density of fish near SONGS. However, fish densities can fluctuate over much longer periods (e.g. years) due to factors such as successive years of poor recruitment or long-term changes in water temperature.

To predict entrapment in the future at SONGS, we must consider possible long-term changes in local fish densities. One method is to compare entrapment during an earlier period, March 1976 to December 1979, with entrapment during May 1983 to August 1986. Units 2 and 3 were not operational until 1983, but Unit 1 was operating during both periods. During 1976-1979, the average annual entrapment at Unit 1 was 445,000 fish, weighing 16.7 MT (DeMartini and Larson 1980). Unit 1 pumped at an average flow level of 83% during this period. During 1983-1986, Unit 1 entrapped 272,000 fish weighing 4.2 MT annually while operating at 56% of maximum flow. When the 1983-1986 biomass estimate is adjusted to the 1976-1979 pumping level (multiply 1983-1986 estimate by 0.83 / 0.56), the annual entrapment for 1983-1986 becomes 6.2 MT; this is only 37% of the 1976-1979 entrapment at Unit 1. One possible explanation for the much lower entrapment at Unit 1 in 1983-1986 is the broadscale reduction of nearshore fish during 1982-1985 induced by El Nino (DeMartini *et al.* 1987).

Since SONGS Units 2 and 3 were not operational until the early 1980's, entrapment cannot be estimated directly for a period of higher abundance of nearshore fish such as occurred in 1976-1979. Since entrapment at SONGS depends to a large extent on the nearshore abundance of fish, it is reasonable to estimate entrapment at Units 2 and 3 during periods of greater nearshore abundance based on the difference in entrapment at Unit 1 between 1976-1979 and 1983-1986. If the nearshore abundance of fish were at 1976-1979 levels, then SONGS Units 1, 2, and 3 together might entrap more than 110 MT of fish each year (41.2 MT / .37, at about 75% flow). If overall efficiency of the FRS remained at the same level as 1983-1986 (47% for biomass), then 52 MT of fish would be killed each year.

### 4.3. Fish Return System

#### 4.3.1. Percent diversion

The majority of fish entrapped at SONGS Units 2 and 3 are diverted to the FRS; average percent diversion for all species entrapped was 85% for number and 72% for biomass. There was, however, a great range in the percent diversion among species that reflects differences in morphological characteristics of species, particularly those characteristics that influence swimming speed. As an extreme example, pipefish are small, pencil-like fish that swim feebly and none of more than 100 entrapped individuals were diverted.

There was some influence of body size on successful diversion for the typically "fish-like" (subcarangiform and carangiform) swimmers that comprised the majority of fish entrapped. In general, for small species, smaller fish were impinged and larger ones, which were presumably stronger swimmers, were diverted. The major exception to this pattern was northern anchovy, but the observed larger size of impinged anchovy may be a sampling artifact. Northern anchovy up to about 90 mm in length can pass through the screens in Units 2 and 3 and, therefore, small individuals may be underrepresented in impingement estimates.

If body size is the most important factor influencing diversion for all species, then percent diversion should increase with body-size and diversion of large species should be highest. This pattern does occur if diversion estimates are based on the numbers of fish entrapped; large species are most successfully diverted (74%). When diversion is based on biomass, however, diversion of small species is greatest. This difference reflects the importance of heat treatment losses for some large species. Heat treatment losses accounted for 23% of the biomass of large species entrapped compared to only 2% for small and medium-bodies species. On average, larger individuals of large species tended to remain in screenwells and were killed during heat treatments. In particular, yellowfin croaker, which accounted for about 35% of the biomass of all large species, were 50% larger in heat treatments samples than in diversion samples.

### 4.3.2. Survivorship

Survivorship of fish diverted to the FRS was determined from the results of field experiments. Estimates of percent survivorship for most species are unreliable because of poor replication and lack of controls. However, estimates for one of the most abundant species, queenfish, is probably close to actual survivorship because it is based on large sample sizes and has an adequate control for pen effects. Although they lack controls, estimates for northern anchovy and the large species classification may also be close to actual survivorship since few fish died in experimental pens.

The estimate of survivorship for small species excluding northern anchovy was based almost entirely on survivorship of queenfish. This reflects the relative importance of queenfish in diversion samples; without northern anchovy, queenfish accounted for almost 90% of the total diversion of small species. We did not include northern anchovy in estimates for small species because of the problems with the control. If northern anchovy are included in the estimate of survivorship for small species, survivorship increases from 68% to 91%.

The estimate of survivorship for medium species is unreliable. There were no controls for mortality due to pen effects for any of the abundant medium species, so actual survivorship could range from 70% to 100%. The uncertainty about this estimate has little effect on the estimate of total losses of fish at SONGS because medium species comprised only 1% of the number and 13% of the biomass of fish entrapped. Estimated survivorship for large species is probably reliable because only 4 of more than 400 large fish died in the study.

Another source of mortality for discharged fish that has not been considered explicitly is an <u>increase</u> in the risk of predation. When fish are discharged from the FRS they may be weakened and disoriented. They may be more vulnerable to predators during the recovery period than they would be normally so that mortality from predation would be higher than normal. Predators such as halibut and kelp bass occur near the FRS exit, and they probably prey on fish as they are discharged from the pipe. However, predation by these species probably occurs at a relatively low rate. Predation by schools of predatory fish is likely to be more serious. For example, on several occasions, Chub mackerel were seen eating all of the anchovy discharged from a return conduit (J. Stein, formerly of Occidental College, *pers. comm.* to E. DeMartini), and K. Herbinson (*pers. comm.*) saw heavy predation be jack mackerel and barracuda on one of six dives at the FRS discharge pipe. In addition, the local abundance of predators could be higher than normal if they are attracted to the discharged fish or the pipe structures.

We have no data on predation rates near the discharge conduit at SONGS and any estimate of mortality due to predation would be highly subjective. Furthermore, we know of no studies of predation on fish discharged from other marine fish diversion systems. Only a few studies on the survival of fish have been published in the last ten years (as indicated by a computerized DIALOG search for the years 1977-1989). Edwards *et al.* (1983) showed that several species of fish reside within screenwells and studied predation in the intakes, but did not examine predation after fish were discharged. Other studies claiming low mortality of fish discharged from fish diversion systems (Taft and Mussalli 1978), along with studies that have found higher fish mortalities (Lawler *et al.* 1982b), give no information about mortality from predation once fish are discharged from the system.

Although there are no relevant data available, it seems likely that the probability of being killed by a predator shortly after discharge depends on size; small fish are probably at greater risk than large fish. Consequently, the effects of predation could potentially increase estimates of the number of fish lost at SONGS but would have a much smaller impact on biomass. For example, if 25% of the northern anchovy returned by the FRS were eaten by predators, the estimated number of fish killed at SONGS each year would increase by nearly one million fish (an increase of 78%), but the additional weight of the fish killed would be only 1.3 MT (an increase of only 7%).

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# 6.0 TABLES

## Table 1
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**List of dates (X) of quantitative entrapment collections at SONGS Unit 1, 2, or 3 during the 39-mo period from May 1983 through August 1986. Collections at Unit 1 are quantitative impingement samples and at Units 2 and 3 include both quantitative impingement and diversion samples.**

| DATE | UNIT 1 | UNIT 2 | UNIT 3 |
|---|---|---|---|
| 25 MAY 3 | | X | |
| 01 JUN 3 | | X | |
| 10 AUG 3 | X | | |
| 24 AUG 3 | | X | |
| 21 SEP 3 | | X | |
| 05 OCT 3 | | X | |
| 11 OCT 3 | | X | |
| 12 OCT 3 | | X | |
| 19 OCT 3 | | X | |
| 30 NOV 83 | X | | |
| 04 JAN 84 | X | X | |
| 05 JAN 84 | | X | |
| 11 JAN 84 | X | | |
| 18 JAN 84 | X | | |
| 14 FEB 84 | X | | |
| 15 FEB 84 | X | | |
| 21 FEB 84 | X | | |
| 22 FEB 84 | X | | |
| 29 FEB 84 | | X | |
| 06 MAR 84 | | X | |
| 07 MAR 84 | X | X | |
| 20 MAR 84 | | X | X |
| 28 MAR 84 | | | X |
| 17 APR 84 | | | X |
| 18 APR 84 | | X | X |
| 24 APR 84 | | X | X |
| 25 APR 84 | | X | X |
| 22 MAY 84 | | | X |
| 30 MAY 84 | | | X |
| 06 JUN 84 | | X | X |
| 12 JUN 84 | | X | |
| 13 JUN 84 | | X | |
| 18 JUL 84 | | | X |
| 01 AUG 84 | | | X |
| 14 AUG 84 | | X | X |
| 15 AUG 84 | | | X |
| 22 AUG 84 | | X | X |
| 05 SEP 84 | | X | X |

**Table 1**


| DATE | UNIT 1 | UNIT 2 | UNIT 3 |
|---|---|---|---|
| 19 SEP 84 | | X | |
| 03 OCT 84 | | | X |
| 09 OCT 84 | | X | X |
| 10 OCT 84 | | X | X |
| 16 OCT 84 | | X | |
| 17 OCT 84 | | X | X |
| 24 OCT 84 | | | X |
| 30 OCT 84 | X | | |
| 07 NOV 84 | X | | |
| 14 NOV 84 | X | | |
| 20 NOV 84 | X | | |
| 11 DEC 84 | X | | X |
| 18 DEC 84 | X | | |
| 19 DEC 84 | X | | |
| 26 DEC 84 | | | X |
| 27 DEC 84 | X | | X |
| 03 JAN 85 | | | X |
| 09 JAN 85 | X | | X |
| 16 JAN 85 | X | | X |
| 23 JAN 85 | X | | X |
| 29 JAN 85 | X | | |
| 30 JAN 85 | X | | X |
| 06 MAR 85 | X | | X |
| 13 MAR 85 | | | X |
| 20 MAR 85 | X | | X |
| 26 MAR 85 | X | | |
| 27 MAR 85 | X | | X |
| 02 APR 85 | X | | X |
| 03 APR 85 | X | | X |
| 09 APR 85 | X | | |
| 10 APR 85 | X | | X |
| 16 APR 85 | X | X | X |
| 17 APR 85 | X | X | X |
| 23 APR 85 | X | X | X |
| 24 APR 85 | X | X | X |
| 25 APR 85 | X | X | X |
| 07 MAY 85 | | X | X |
| 08 MAY 85 | | X | X |
| 15 MAY 85 | | X | X |
| 21 MAY 85 | | | X |
| 22 MAY 85 | | | X |
| 29 MAY 85 | X | | |
| 30 MAY 85 | | X | |
| 04 JUN 85 | X | X | X |
| 05 JUN 85 | | X | X |

**Table 1**
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| DATE | UNIT 1 | UNIT 2 | UNIT 3 |
|---|---|---|---|
| 11 JUN 85 | | | X |
| 18 JUN 85 | X | | |
| 25 JUN 85 | | X | X |
| 26 JUN 85 | X | X | X |
| 02 JUL 85 | X | | X |
| 03 JUL 85 | | | X |
| 09 JUL 85 | X | | |
| 10 JUL 85 | | | X |
| 16 JUL 85 | X | X | X |
| 17 JUL 85 | | X | X |
| 23 JUL 85 | | X | X |
| 24 JUL 85 | | X | X |
| 30 JUL 85 | | X | X |
| 31 JUL 85 | X | X | X |
| 06 AUG 85 | X | | |
| 14 AUG 85 | | X | X |
| 15 AUG 85 | X | | |
| 20 AUG 85 | X | X | |
| 21 AUG 85 | | X | X |
| 27 AUG 85 | | X | X |
| 28 AUG 85 | | X | X |
| 04 SEP 85 | X | X | X |
| 05 SEP 85 | | | X |
| 10 SEP 85 | X | | |
| 12 SEP 85 | | X | X |
| 17 SEP 85 | X | X | X |
| 18 SEP 85 | | X | |
| 24 SEP 85 | X | | |
| 01 OCT 85 | X | | |
| 02 OCT 85 | | X | |
| 08 OCT 85 | X | | |
| 09 OCT 85 | | X | |
| 15 OCT 85 | X | X | |
| 16 OCT 85 | | X | |
| 22 OCT 85 | X | | |
| 29 OCT 85 | X | | |
| 05 NOV 85 | X | X | |
| 13 NOV 85 | | X | |
| 19 NOV 85 | X | | |
| 24 DEC 85 | | X | |
| 31 DEC 85 | | X | |

**Table 1**


| DATE | UNIT 1 | UNIT 2 | UNIT 3 |
|---|---|---|---|
| 07 JAN 86 | | X | |
| 08 JAN 86 | | X | |
| 21 JAN 86 | | | X |
| 22 JAN 86 | | X | X |
| 28 JAN 86 | | X | X |
| 29 JAN 86 | | X | X |
| 04 FEB 86 | | | X |
| 05 FEB 86 | | | X |
| 19 FEB 86 | | X | |
| 20 FEB 86 | | X | |
| 25 FEB 86 | | X | |
| 26 FEB 85 | | X | |
| 04 MAR 86 | | X | |
| 05 MAR 86 | | X | |
| 11 MAR 86 | | X | |
| 12 MAR 86 | | X | |
| 25 MAR 86 | | | X |
| 26 MAR 86 | | | X |
| 01 APR 86 | | | X |
| 02 APR 86 | | | X |
| 08 APR 86 | | | X |
| 09 APR 86 | | | X |
| 15 APR 86 | | | X |
| 16 APR 86 | | | X |
| 22 APR 86 | | | X |
| 23 APR 86 | | | X |
| 29 APR 86 | | | X |
| 30 APR 86 | | | X |
| 07 MAY 86 | | | X |
| 20 MAY 86 | | | X |
| 21 MAY 86 | | | X |
| 28 MAY 86 | | | X |
| 29 MAY 86 | | | X |
| 03 JUN 86 | | | X |
| 04 JUN 86 | | | X |
| 10 JUN 86 | | X | X |
| 11 JUN 86 | | X | X |
| 17 JUN 86 | X | | |
| 18 JUN 86 | | | X |
| 24 JUN 86 | | | X |
| 25 JUN 86 | | | X |
| 01 JUL 86 | X | X | X |
| 02 JUL 86 | | X | X |
| 08 JUL 86 | X | | |
| 15 JUL 86 | | X | |

**Table 1**
**page 5 of 5**

| DATE | UNIT 1 | UNIT 2 | UNIT 3 |
|---|---|---|---|
| 16 JUL 86 | | X | |
| 22 JUL 86 | | X | X |
| 23 JUL 86 | | X | X |
| 06 AUG 86 | X | | |
| 12 AUG 86 | X | | |
| 19 AUG 86 | X | X | |
| 20 AUG 86 | | X | |
| 26 AUG 86 | X | X | X |
| 27 AUG 86 | | | X |

## Table 2

**List of dates on which heat treatments occurred at SONGS Units 1, 2, or 3 during May 1983 - August 1986.**

| DATE | UNIT 1 | UNIT 2 | UNIT 3 |
|---|---|---|---|
| 30 MAY 83 | | X | |
| 04 JUN 83 | | X | |
| 20 AUG 83 | | X | |
| 01 OCT 83 | | X | |
| 17 OCT 83 | | | X |
| 05 NOV 83 | | | X |
| 14 NOV 83 | | X | |
| 21 DEC 83 | | X | |
| 17 MAR 84 | | X | |
| 05 APR 84 | | | X |
| 28 APR 84 | | X | |
| 23 MAY 84 | | | X |
| 14 JUL 84 | | | X |
| 29 JUL 84 | | X | |
| 25 AUG 84 | | | X |
| 15 SEP 84 | | X | |
| 06 OCT 84 | | | X |
| 20 OCT 84 | | X | |
| 25 JAN 85 | X | | |
| 08 MAR 85 | X | | |
| 21 MAR 85 | | | X |
| 04 MAY 85 | | X | |
| 13 MAY 85 | X | | |
| 26 MAY 85 | | | X |
| 22 JUN 85 | | X | |
| 30 JUN 85 | X | | |
| 12 JUL 85 | | | X |
| 03 AUG 85 | | X | |
| 10 AUG 85 | X | | |
| 07 SEP 85 | | X | |
| 14 SEP 85 | X | | |
| 03 NOV 85 | X | | |
| 22 DEC 85 | | X | |
| 09 FEB 86 | | | X |
| 16 JUN 86 | | X | |
| 06 JUL 86 | | | X |
| 02 AUG 86 | | | X |
| 24 AUG 86 | X | | |
| 31 AUG 86 | | X | |

## Table 3
page 1 of 2

**Number of full flow operational days per month for SONGS Units 1, 2, and 3 for the period May 1983 - August 1986. Calculations are based on total monthly flow rate daily normal-flow rate. The daily flow rate for each unit is:**

**Unit 1: $1.7 \times 10^6$ $m^3/dy$**
**Unit 2: $4.5 \times 10^6$ $m^3/dy$**
**Unit 3: $4.5 \times 10^6$ $m^3/dy$**

| DATE | UNIT 1 | UNIT 2 | UNIT 3 | UNITS 2 & 3 |
|---|---|---|---|---|
| MAY 83 | 9.50 | 25.15 | 9.65 | 34.80 |
| JUN 83 | 11.52 | 22.39 | 14.26 | 36.65 |
| JUL 83 | 6.77 | 30.99 | 15.08 | 46.08 |
| AUG 83 | 15.17 | 29.85 | 15.49 | 45.35 |
| SEP 83 | 9.88 | 30.00 | 18.24 | 48.24 |
| OCT 83 | 13.62 | 31.00 | 29.49 | 60.49 |
| NOV 83 | 21.68 | 30.00 | 29.99 | 59.99 |
| DEC 83 | 21.58 | 18.25 | 25.99 | 44.24 |
| JAN 84 | 24.88 | 21.00 | 12.99 | 33.99 |
| FEB 84 | 23.36 | 19.25 | 4.89 | 24.13 |
| MAR 84 | 21.51 | 30.75 | 26.99 | 57.74 |
| APR 84 | 11.36 | 30.00 | 29.99 | 59.99 |
| MAY 84 | 7.41 | 31.00 | 24.49 | 55.49 |
| JUN 84 | 0.79 | 21.50 | 21.49 | 42.99 |
| JUL 84 | 0.87 | 17.50 | 21.99 | 39.50 |
| AUG 84 | 0.00 | 30.49 | 30.24 | 60.74 |
| SEP 84 | 0.32 | 30.00 | 29.99 | 59.99 |
| OCT 84 | 23.01 | 20.00 | 28.49 | 48.49 |
| NOV 84 | 29.96 | 0.00 | 14.99 | 14.99 |
| DEC 84 | 30.95 | 0.00 | 29.00 | 29.00 |
| JAN 85 | 29.68 | 3.25 | 28.00 | 31.25 |
| FEB 85 | 16.51 | 12.00 | 14.00 | 26.00 |
| MAR 85 | 27.97 | 21.00 | 30.50 | 51.50 |
| APR 85 | 29.86 | 23.50 | 29.75 | 53.25 |
| MAY 85 | 26.00 | 31.00 | 30.92 | 61.92 |
| JUN 85 | 29.78 | 30.00 | 30.00 | 60.00 |
| JUL 85 | 29.51 | 31.00 | 31.00 | 62.00 |
| AUG 85 | 24.86 | 31.00 | 31.00 | 62.00 |
| SEP 85 | 27.69 | 30.00 | 17.00 | 47.00 |
| OCT 85 | 30.67 | 31.00 | 0.00 | 31.00 |
| NOV 85 | 23.91 | 19.77 | 0.42 | 20.20 |
| DEC 85 | 15.50 | 29.57 | 15.67 | 45.25 |

## Table 3
page 2 of 2

| DATE | UNIT 1 | UNIT 2 | UNIT 3 | UNITS 2 & 3 |
|---|---|---|---|---|
| JAN 86 | 4.86 | 30.82 | 26.22 | 57.05 |
| FEB 86 | 0.00 | 28.00 | 25.30 | 53.30 |
| MAR 86 | 0.00 | 18.92 | 22.07 | 40.99 |
| APR 86 | 0.00 | 0.34 | 30.00 | 30.34 |
| MAY 86 | 7.20 | 2.68 | 31.00 | 33.68 |
| JUN 86 | 17.72 | 27.32 | 30.00 | 57.32 |
| JUL 86 | 23.83 | 30.74 | 29.46 | 60.20 |
| AUG 86 | 28.23 | 30.65 | 28.68 | 59.33 |
| TOTALS | 677.92 | 931.70 | 914.74 | 1846.47 |

Total possible number of full-pumping days for each unit = 1,218

Percent of Full Pumping for period May 1983 - August 1986:

| | |
|---|---|
| Unit 1: | 677.92/1218 = 56% |
| Unit 2: | 931.70/1218 = 76% |
| Unit 3: | 914.75/1218 = 75% |
| Units 2 & 3: | 1846.47/2436 = 76% |

## Table 4

**Results of regressions of percent queenfish mortality vs. (A) initial abundance of queenfish or (B) initial abundance of total fishes in experimental, control and pooled (experimental + control) pens in study of survivorship of fishes discharged from the FRS at SONGS Units 2 and 3.**

**(A) Queenfish mortality vs. Initial abundance of queenfish.**

| | N | SLOPE | $R^2$ | P |
|---|---|---|---|---|
| Experimental Pens | 18 | 0.00 | 0.05 | 0.35 |
| Control Pens | 9 | 0.00 | 0.01 | 0.76 |
| Pooled Pens (experimental + control) | 27 | 0.00 | 0.00 | 0.98 |

**(B) Queenfish mortality vs. Initial abundance of total fish.**

| | N | SLOPE | $R^2$ | P |
|---|---|---|---|---|
| Experimental Pens | 18 | 0.00 | 0.01 | 0.77 |
| Control Pens | 9 | 0.00 | 0.05 | 0.55 |
| Pooled Pens (experimental + control) | 27 | 0.00 | 0.01 | 0.58 |

## Table 5
page 1 of 2

**List of species collected in quantitative samples at SONGS Units 1, 2 and 3 for the period May 1983 - August 1986.**

| COMMON NAME | SCIENTIFIC NAME |
|---|---|
| barred sand bass | *Paralabrax nebulifer* |
| barred surfperch | *Amphistichus argenteus* |
| basketweave cusk-eel | *Ophidion scrippsae* |
| bat ray | *Myliobatis californica* |
| black croaker | *Cheilotrema saturnum* |
| black perch | *Embiotoca jacksoni* |
| blacksmith | *Chromis punctipinnis* |
| blenny spp. | *Hypsoblennius* spp. |
| bocaccio | *Sebastes paucispinis* |
| brown rockfish | *Sebastes auriculatus* |
| cabezon | *Scorpaenichthys marmoratus* |
| Pacific barracuda | *Sphyraena argentea* |
| California butterfly ray | *Gymnura marmorata* |
| California corbina | *Menticirrhus undulatus* |
| California halibut | *Paralichthys californicus* |
| California lizardfish | *Synodus lucioceps* |
| California moray | *Gymnothorax mordax* |
| California scorpionfish | *Scorpaena guttata* |
| California sheephead | *Semicossyphus pulcher* |
| California tonguefish | *Symphurus atricauda* |
| thresher shark | *Alopias vulpinus* |
| crevice kelpfish | *Gibbonsia montereyensis* |
| deepbody anchovy | *Anchoa compressa* |
| diamond turbot | *Hypsopsetta guttulata* |
| Dover sole | *Microstomus pacificus* |
| fantail sole | *Xystreurys liolepis* |
| finescale triggerfish | *Balistes polylepis* |
| garibaldi | *Hypsypops rubicundus* |
| giant kelpfish | *Heterostichus rostratus* |
| goby spp. | *Gobiidae* spp. |
| grass rockfish | *Sebastes rastrelliger* |
| gray smoothhound | *Mustelus californicus* |
| California California grunion | *Leuresthes tenuis* |
| halfmoon | *Medialuna californiensis* |
| horn shark | *Heterodontus francisci* |
| hornyhead turbot | *Pleuronichthys verticalis* |
| jack mackerel | *Trachurus symmetricus* |
| jacksmelt | *Atherinopsis californiensis* |
| kelp bass | *Paralabrax clathratus* |
| kelp perch | *Brachyistius frenatus* |
| northern anchovy | *Engraulis mordax* |
| onespot fringehead | *Neoclinus uninotatus* |
| opaleye | *Girella nigricans* |
| Pacific angel shark | *Squatina californica* |
| Pacific bonito | *Sarda chiliensis* |

| COMMON NAME | SCIENTIFIC NAME |
|---|---|
| Pacific pompano | *Peprilus simillimus* |
| Pacific electric ray | *Torpedo californica* |
| Pacific halibut | *Hippoglossus stenolepis* |
| Pacific herring | *Clupea harengus pallasi* |
| chub mackerel | *Scomber japonicus* |
| Pacific sanddab | *Citharichthys sordidus* |
| Pacific sardine | *Sardinops sagax* |
| Pacific staghorn sculpin | *Leptocottus armatus* |
| pile perch | *Rhacochilus vacca* |
| pipefish | *Syngnathus* spp. |
| plainfin midshipman | *Porichthys notatus* |
| queenfish | *Seriphus politus* |
| rainbow seaperch | *Hypsurus caryi* |
| rock wrasse | *Halichoeres semicinctus* |
| rockfish spp. | *Sebastes* spp. |
| round herring | *Etrumeus teres* |
| round stingray | *Urolophus halleri* |
| rubberlip seaperch | *Rhacochilus toxotes* |
| salema | *Xenistius californiensis* |
| sarcastic fringehead | *Neoclinus blanchardi* |
| sargo | *Anisotremus davidsoni* |
| senorita | *Oxyjulis californica* |
| shiner perch | *Cymatogaster aggregata* |
| shovelnose guitarfish | *Rhinobatos productus* |
| slough anchovy | *Anchoa delicatissima* |
| speckled sanddab | *Citharichthys stigmaeus* |
| specklefin midshipman | *Porichthys myriaster* |
| spiny boxfish | *Ostracion diaphanum* |
| spiny dogfish | *Squalus acanthias* |
| spotfin croaker | *Roncador stearnsi* |
| spotted cusk-eel | *Chilara taylori* |
| spotted kelpfish | *Gibbonsia elegans* |
| spotted sand bass | *Paralabrax maculatofasciatus* |
| spotted turbot | *Pleuronichthys ritteri* |
| striped kelpfish | *Gibbonsia metzi* |
| thornback | *Platyrhinoidis triseriata* |
| topsmelt | *Atherinops affinis* |
| treefish | *Sebastes serriceps* |
| walleye surfperch | *Hyperprosopon argenteum* |
| white croaker | *Genyonemus lineatus* |
| white seabass | *Atractoscion nobilis* |
| white seaperch | *Phanerodon furcatus* |
| yellow snake eel | *Ophichthus zophochir* |
| yellowfin croaker | *Umbrina roncador* |
| yellowfin goby | *Acanthogobius flavimanus* |
| yellowtail | *Seriola lalandei* |
| zebra perch | *Hermosilla azurea* |

# Table 6
page 1 of 2

**Number, biomass and mean weight per fish for fish IMPINGED on travelling screens in SONGS Units 2 & 3. Totals are the sum of 191 samples taken during full-flow operations for the period May 1983 - August 1986. Sample dates are shown in Table 1. Only species which had ≥ 20 fish entrapped are shown. Total fish includes all species in samples. Species are ranked by the combined weight of impinged and diverted (Table 7).**

| SPECIES | NUMBER | BIOMASS (KG) | MEAN WT. PER FISH (G) |
|---|---|---|---|
| queenfish | 127,730 | 1,384.685 | 11 |
| northern anchovy | 86,081 | 311.275 | 4 |
| jacksmelt | 3,095 | 374.094 | 121 |
| yellowfin croaker | 11 | 0.834 | 76 |
| bat ray | 26 | 100.810 | 3,877 |
| Pacific electric ray | 30 | 237.748 | 7,925 |
| zebra perch | 0 | 0 | 0 |
| white croaker | 34,995 | 156.913 | 4 |
| shovelnose guitarfish | 7 | 3.601 | 514 |
| salema | 91 | 1.300 | 14 |
| California corbina | 83 | 10.555 | 127 |
| kelp bass | 11 | 0.573 | 52 |
| sargo | 41 | 0.938 | 23 |
| round stingray | 47 | 18.489 | 393 |
| California halibut | 65 | 13.286 | 204 |
| white seabass | 58 | 2.573 | 44 |
| topsmelt | 31 | 0.894 | 29 |
| gray smoothhound | 8 | 3.061 | 383 |
| Pacific pompano | 2,701 | 28.727 | 11 |
| chub mackerel | 88 | 12.409 | 141 |
| thornback | 122 | 41.082 | 337 |
| barred sand bass | 51 | 14.443 | 283 |
| spotfin croaker | 6 | 1.100 | 183 |
| slough anchovy | 12,412 | 35.125 | 3 |
| deepbody anchovy | 2,158 | 21.762 | 10 |
| walleye surfperch | 226 | 3.562 | 16 |
| specklefin midshipman | 128 | 28.634 | 224 |
| white seaperch | 683 | 5.264 | 8 |
| spiny dogfish | 29 | 15.504 | 535 |
| plainfin midshipman | 576 | 21.755 | 38 |
| opaleye | 2 | 0.656 | 328 |
| pile perch | 2 | 0.004 | 2 |
| California scorpionfish | 119 | 10.049 | 84 |
| black croaker | 1 | 0.005 | 5 |
| black perch | 19 | 0.280 | 15 |
| Pacificbarracuda | 101 | 3.568 | 35 |
| jack mackerel | 345 | 3.008 | 9 |
| giant kelpfish | 219 | 6.396 | 29 |

**Table 6**
**page 2 of 2**

| SPECIES | NUMBER | BIOMASS (KG) | MEAN WT. PER FISH (G) |
|---|---|---|---|
| spotted turbot | 64 | 5.141 | 80 |
| blacksmith | 2 | 0.100 | 50 |
| halfmoon | 0 | 0 | 0 |
| California California grunion | 82 | 2.357 | 29 |
| shiner perch | 339 | 2.391 | 7 |
| diamond turbot | 12 | 3.460 | 288 |
| garibaldi | 0 | 0 | 0 |
| Pacific sardine | 38 | 1.484 | 39 |
| pipefish | 139 | 3.815 | 27 |
| spotted cusk-eel | 35 | 2.122 | 61 |
| rock wrasse | 15 | 0.811 | 54 |
| cabezon | 5 | 0.545 | 109 |
| fantail sole | 19 | 0.563 | 30 |
| rockfish spp. | 2 | 1.408 | 704 |
| rubberlip seaperch | 0 | 0 | 0 |
| Pacific staghorn sculpin | 19 | 0.726 | 38 |
| kelp perch | 10 | 0.162 | 16 |
| speckled sanddab | 35 | 0.519 | 15 |
| basketweave cusk-eel | 28 | 0.417 | 15 |
| bocaccio | 12 | 0.079 | 7 |
| blenny spp. | 45 | 0.147 | 3 |
| spotted kelpfish | 6 | 0.074 | 12 |
| striped kelpfish | 1 | 0.003 | 3 |
| California sheephead | 0 | 0 | 0 |
| all other species combined | 97 | 13.376 | |
| Total Fishes | 273,403 | 2,914.662 | |

# Table 7

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**Number, biomass and mean weight per fish for fish DIVERTED to the Fish Return System at SONGS Units 2 & 3. Totals are the sum of 191 samples taken during full-flow operations for the period May 1983 - August 1986. Sample dates are shown in Table 1. Only species which had ≥ 20 fish entrapped are shown. Total fish includes all species in samples. Species are ranked in the same order as Table 6.**

| SPECIES | NUMBER | BIOMASS (KG) | MEAN WT. PER FISH (G) |
|---|---|---|---|
| queenfish | 329,792 | 5,245.597 | 16 |
| northern anchovy | 872,874 | 1,191.997 | 1.4 |
| jacksmelt | 4,440 | 649.958 | 146 |
| yellowfin croaker | 2,602 | 639.949 | 246 |
| bat ray | 52 | 398.250 | 7,659 |
| Pacific electric ray | 21 | 244.850 | 11,660 |
| zebra perch | 720 | 402.055 | 558 |
| white croaker | 33,996 | 233.376 | 7 |
| shovelnose guitarfish | 76 | 269.440 | 3,545 |
| salema | 5,063 | 200.660 | 40 |
| California corbina | 495 | 123.574 | 250 |
| kelp bass | 505 | 124.977 | 247 |
| sargo | 586 | 124.389 | 212 |
| round stingray | 197 | 82.845 | 421 |
| California halibut | 204 | 82.812 | 406 |
| white seabass | 359 | 88.703 | 247 |
| topsmelt | 951 | 82.316 | 87 |
| gray smoothhound | 61 | 72.015 | 1,181 |
| Pacific pompano | 2,110 | 40.598 | 19 |
| Chub mackerel | 308 | 54.440 | 177 |
| thornback | 46 | 23.960 | 521 |
| barred sand bass | 198 | 45.564 | 230 |
| spotfin croaker | 170 | 48.578 | 286 |
| slough anchovy | 4,663 | 11.565 | 2 |
| deepbody anchovy | 2,812 | 24.605 | 9 |
| walleye surfperch | 3,504 | 41.891 | 12 |
| specklefin midshipman | 24 | 7.304 | 304 |
| white seaperch | 1,115 | 25.005 | 22 |
| spiny dogfish | 15 | 7.600 | 507 |
| plainfin midshipman | 25 | 1.272 | 51 |
| opaleye | 29 | 19.540 | 674 |
| pile perch | 43 | 18.413 | 428 |
| California scorpionfish | 31 | 4.300 | 139 |
| black croaker | 77 | 12.076 | 157 |
| black perch | 94 | 11.069 | 118 |
| Pacific barracuda | 53 | 7.566 | 143 |
| jack mackerel | 175 | 6.926 | 40 |
| giant kelpfish | 60 | 3.043 | 51 |

## Table 7


| SPECIES | NUMBER | BIOMASS (KG) | MEAN WT. PER FISH (G) |
|---|---|---|---|
| spotted turbot | 45 | 2.778 | 62 |
| blacksmith | 81 | 6.697 | 83 |
| halfmoon | 27 | 6.624 | 245 |
| California grunion | 105 | 3.005 | 29 |
| shiner perch | 272 | 2.712 | 10 |
| diamond turbot | 8 | 1.377 | 172 |
| garibaldi | 11 | 4.800 | 436 |
| Pacific sardine | 112 | 2.855 | 25 |
| pipefish | 0 | 0 | 0 |
| spotted cusk-eel | 17 | 0.793 | 47 |
| rock wrasse | 13 | 1.400 | 108 |
| cabezon | 3 | 1.559 | 520 |
| fantail sole | 14 | 0.920 | 66 |
| rockfish spp. | 0 | 0 | 0 |
| rubberlip seaperch | 14 | 1.114 | 80 |
| Pacific staghorn sculpin | 1 | 0.100 | 100 |
| kelp perch | 11 | 0.566 | 51 |
| speckled sanddab | 8 | 0.031 | 4 |
| basketweave cusk-eel | 4 | 0.068 | 17 |
| bocaccio | 11 | 0.064 | 6 |
| blenny spp. | 0 | 0 | 0 |
| spotted kelpfish | 1 | 0.012 | 12 |
| striped kelpfish | 0 | 0 | 0 |
| California sheephead | 0 | 0 | 0 |
| all other species combined | 74 | 78.347 | |
| Total Fishes | 1,269,378 | 10,788.900 | |

# Table 8
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**Average body weight and size classification for fishes entrapped at SONGS Units 2 & 3. Estimates and classification are based on the average weight of fish in all impingement and diversion samples (n = 191) at both new unit during the period May 1983 - August 1986. Fishes are classified either as small (S, < 30 g), medium (M, 30 - 199 g), or large (L, $\geq$ 200 g).**

| Species | Average Body Weight (g) | Body Size Classification |
|---|---|---|
| Pacific sanddab | 1 | S |
| dover sole | 2 | S |
| northern anchovy | 2 | S |
| Pacific herring | 2 | S |
| round herring | 2 | S |
| blenny spp. | 3 | S |
| slough anchovy | 3 | S |
| striped kelpfish | 3 | S |
| rockpool blenny | 4 | S |
| bocaccio | 6 | S |
| treefish | 6 | S |
| white croaker | 6 | S |
| shiner perch | 8 | S |
| deepbody anchovy | 9 | S |
| spotted kelpfish | 12 | S |
| walleye surfperch | 12 | S |
| speckled sanddab | 13 | S |
| Pacific pompano | 14 | S |
| queenfish | 14 | S |
| basketweave cusk-eel | 15 | S |
| white seaperch | 17 | S |
| jack mackerel | 19 | S |
| yellowfin goby | 22 | S |
| California tonguefish | 23 | S |
| pipefish | 27 | S |
| California grunion | 29 | S |
| Pacific sardine | 29 | S |
| giant kelpfish | 34 | M |
| kelp perch | 35 | M |
| senorita | 36 | M |
| plainfin midshipman | 38 | M |
| salema | 39 | M |
| Pacific staghorn sculpin | 41 | M |
| spiny boxfish | 43 | M |
| fantail sole | 45 | M |
| spotted cusk-eel | 56 | M |
| Pacific barracuda | 72 | M |
| spotted turbot | 73 | M |
| rock wrasse | 79 | M |

**Table 8**
**page 2 of 2**

| SPECIES | AVERAGE BODY WEIGHT (G) | BODY SIZE CLASSIFICATION |
|---|---|---|
| rubberlip seaperch | 80 | M |
| blacksmith | 82 | M |
| hornyhead turbot | 82 | M |
| topsmelt | 85 | M |
| California scorpionfish | 96 | M |
| black perch | 100 | M |
| jacksmelt | 136 | M |
| black croaker | 154 | M |
| barred surfperch | 156 | M |
| Chub mackerel | 169 | M |
| spotted sand bass | 170 | M |
| California lizardfish | 188 | M |
| rainbow seaperch | 200 | L |
| sargo | 200 | L |
| white seabass | 219 | L |
| California corbina | 232 | L |
| specklefin midshipman | 236 | L |
| barred sand bass | 241 | L |
| diamond turbot | 242 | L |
| kelp bass | 243 | L |
| halfmoon | 245 | L |
| yellowfin croaker | 245 | L |
| cabezon | 263 | L |
| spotfin croaker | 282 | L |
| California halibut | 357 | L |
| thornback | 387 | L |
| pile perch | 409 | L |
| round stingray | 415 | L |
| garibaldi | 436 | L |
| spiny dogfish | 525 | L |
| zebra perch | 558 | L |
| yellow snake eel | 620 | L |
| opaleye | 651 | L |
| Pacific bonito | 700 | L |
| brown rockfish | 704 | L |
| brown smoothhound | 730 | L |
| gray smoothhound | 1088 | L |
| horn shark | 1149 | L |
| California butterfly ray | 1814 | L |
| finescale triggerfish | 2150 | L |
| leopard shark | 2777 | L |
| shovelnose guitarfish | 3289 | L |
| bat ray | 6398 | L |
| Pacific angel shark | 8500 | L |
| Pacific electric ray | 9463 | L |

## Table 9
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**Number, biomass and mean weight per fish for fish impinged during HEAT TREATMENTS at SONGS Units 2 & 3 for the period May 1983 - August 1986. Dates of heat treatments are given in Table 2. Only species which had ≥ 20 fish entrapped during the period are shown. Total fish includes all species in samples. Species are ranked in the same order as Table 6.**

| SPECIES | NUMBER | BIOMASS (KG) | MEAN WT. PER FISH (G) |
|---|---|---|---|
| queenfish | 79,112 | 698.066 | 9 |
| northern anchovy | 98,325 | 300.678 | 3 |
| jacksmelt | 462 | 61.537 | 133 |
| yellowfin croaker | 8,785 | 3,084.650 | 351 |
| bat ray | 3 | 10.140 | 3,380 |
| Pacific electric ray | 2 | 17.300 | 8,650 |
| zebra perch | 3,361 | 1,881.662 | 560 |
| white croaker | 506 | 10.136 | 20 |
| shovelnose guitarfish | 45 | 137.030 | 3,045 |
| salema | 3,615 | 159.207 | 44 |
| California corbina | 36 | 8.294 | 230 |
| kelp bass | 925 | 187.658 | 203 |
| sargo | 8,147 | 2,139.265 | 263 |
| round stingray | 61 | 29.808 | 489 |
| California halibut | 65 | 17.360 | 267 |
| white seabass | 36 | 7.352 | 204 |
| topsmelt | 115 | 6.045 | 53 |
| gray smoothhound | 7 | 4.045 | 578 |
| Pacific pompano | 240 | 4.809 | 20 |
| Chub mackerel | 32 | 4.433 | 139 |
| thornback | 7 | 2.080 | 297 |
| barred sand bass | 1,395 | 354.448 | 254 |
| spotfin croaker | 626 | 375.385 | 600 |
| slough anchovy | 212 | 1.014 | 5 |
| deepbody anchovy | 1,746 | 24.101 | 14 |
| walleye surfperch | 140 | 5.762 | 41 |
| specklefin midshipman | 8 | 2.409 | 301 |
| white seaperch | 45 | 1.543 | 34 |
| spiny dogfish | 0 | 0 | 0 |
| plainfin midshipman | 72 | 3.968 | 55 |
| opaleye | 89 | 49.640 | 558 |
| pile perch | 29 | 9.020 | 311 |
| California scorpionfish | 89 | 13.244 | 149 |
| black croaker | 197 | 33.658 | 171 |
| black perch | 76 | 12.339 | 162 |
| Pacific barracuda | 64 | 3.789 | 59 |
| jack mackerel | 284 | 23.184 | 82 |
| giant kelpfish | 63 | 2.010 | 32 |

| Species | Number | Biomass (kg) | Mean Wt. per Fish (g) |
|---|---|---|---|
| spotted turbot | 28 | 0.582 | 21 |
| blacksmith | 135 | 10.907 | 81 |
| halfmoon | 25 | 6.614 | 265 |
| California grunion | 26 | 0.268 | 10 |
| shiner perch | 98 | 1.041 | 11 |
| diamond turbot | 2 | 0.222 | 111 |
| garibaldi | 32 | 14.655 | 458 |
| Pacific sardine | 4 | 0.025 | 6 |
| pipefish | 12 | 0.025 | 2 |
| spotted cusk-eel | 3 | 0.124 | 41 |
| rock wrasse | 87 | 13.190 | 152 |
| cabezon | 39 | 6.083 | 156 |
| fantail sole | 0 | 0 | 0 |
| rockfish spp. | 23 | 4.596 | 200 |
| rubberlip seaperch | 10 | 2.933 | 293 |
| Pacific staghorn sculpin | 1 | 0.003 | 3 |
| kelp perch | 12 | 0.317 | 26 |
| speckled sanddab | 2 | 0.020 | 10 |
| basketweave cusk-eel | 8 | 0.038 | 5 |
| bocaccio | 4 | 0.071 | 18 |
| blenny spp. | 5,369 | 11.753 | 2 |
| spotted kelpfish | 55 | 0.123 | 2 |
| striped kelpfish | 120 | 0.192 | 2 |
| California sheephead | 26 | 18.630 | 717 |
| all other species combined | 40 | 22.334 | |
| Total Fishes | 215,183 | 9,801.815 | |
| Total No. Taxa = 63 | | | |

**Number, biomass and mean weight per fish for fish impinged during HEAT TREATMENTS at SONGS Unit 1 for the period May 1983 - August 1986. Dates of heat treatments are shown in Table 2. (Note that no heat treatments occurred at Unit 1 during May 1983 - Dec 1984.) Species are ranked by total weight.**

| SPECIES | NUMBER | BIOMASS (KG) | MEAN WT. PER FISH (G) |
|---|---|---|---|
| sargo | 2885 | 423.840 | 147 |
| yellowfin croaker | 1241 | 170.044 | 137 |
| spotfin croaker | 221 | 109.522 | 496 |
| zebra perch | 521 | 92.080 | 177 |
| jacksmelt | 485 | 54.050 | 111 |
| queenfish | 1776 | 47.670 | 27 |
| walleye surfperch | 1193 | 46.470 | 39 |
| black perch | 271 | 39.630 | 146 |
| black croaker | 330 | 38.879 | 118 |
| kelp bass | 146 | 37.840 | 259 |
| opaleye | 79 | 34.627 | 438 |
| salema | 858 | 33.527 | 39 |
| barred sand bass | 191 | 33.290 | 174 |
| halfmoon | 106 | 25.226 | 238 |
| shovelnose guitarfish | 4 | 15.700 | 3925 |
| California corbina | 69 | 14.380 | 208 |
| pile perch | 50 | 13.265 | 265 |
| garibaldi | 31 | 11.820 | 381 |
| white seabass | 75 | 11.037 | 147 |
| thresher shark | 1 | 9.500 | 9500 |
| Pacific angel shark | 1 | 9.500 | 9500 |
| California sheephead | 11 | 9.070 | 825 |
| blacksmith | 95 | 6.013 | 63 |
| round stingray | 10 | 5.330 | 533 |
| California scorpionfish | 19 | 2.955 | 156 |
| topsmelt | 63 | 2.905 | 46 |
| white seaperch | 36 | 2.553 | 71 |
| horn shark | 1 | 2.030 | 2030 |
| brown rockfish | 11 | 1.738 | 158 |
| giant kelpfish | 23 | 1.690 | 73 |
| Pacific barracuda | 7 | 1.531 | 219 |
| grass rockfish | 4 | 1.310 | 327 |
| rock wrasse | 16 | 1.222 | 76 |
| cabezon | 8 | 0.930 | 116 |
| thornback | 2 | 0.640 | 320 |
| Chub mackerel | 4 | 0.630 | 158 |
| specklefin midshipman | 2 | 0.450 | 225 |
| barred surfperch | 1 | 0.390 | 390 |

## Table 10
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| SPECIES | NUMBER | BIOMASS (KG) | MEAN WT. PER FISH (G) |
|---|---|---|---|
| deepbody anchovy | 33 | 0.366 | 11 |
| spotted sand bass | 4 | 0.350 | 88 |
| Pacific pompano | 5 | 0.224 | 45 |
| rubberlip seaperch | 1 | 0.190 | 190 |
| Pacific halibut | 1 | 0.140 | 140 |
| white croaker | 3 | 0.102 | 34 |
| shiner perch | 4 | 0.091 | 23 |
| spotted turbot | 4 | 0.084 | 21 |
| jack mackerel | 2 | 0.076 | 38 |
| blenny spp. | 11 | 0.053 | 5 |
| plainfin midshipman | 1 | 0.041 | 41 |
| northern anchovy | 2 | 0.034 | 17 |
| California grunion | 1 | 0.016 | 16 |
| fantail sole | 1 | 0.009 | 9 |
| spotted kelpfish | 2 | 0.006 | 3 |
| Total Fishes | 10,922 | 1,315.066 | |

Total No. Taxa = 54

## Table 11

**Annual (12-month) estimates of entrapment for SONGS Unit 1 and Units 2 & 3. Estimates are based on heat treatment, impingement and diversion samples during the 39 month period from May 1983 - August 1986. Shown are estimates for both numbers and biomass (kg) for 17 selected species, all other species combined and the total of all species combined. [a] indicates that Unit 1 estimates for queenfish, northern anchovy and white croaker were calculated from Units 2 & 3 estimates rather than from Unit 1 samples because large numbers of these species were extruded through the large-mesh screen in Unit 1 and therefore were missing from Unit 1 samples. See methods for a detailed description of techniques used to calculate the annual estimates.**

| | Annual Estimates | | | |
|---|---|---|---|---|
| | Numbers | | Biomass (kg) | |
| | Unit 1 | Units 2 & 3 | Unit 1 | Units 2 & 3 |
| queenfish | 53,864[a] | 1,125,508 | 681[a] | 14,226 |
| northern anchovy | 199,988[a] | 4,178,858 | 230[a] | 4,799 |
| jacksmelt | 450 | 29,021 | 55 | 3,927 |
| yellowfin croaker | 425 | 14,514 | 55 | 3,925 |
| Pacific electric ray | 116 | 136 | 1,231 | 1,336 |
| white croaker | 5,938[a] | 124,072 | 42[a] | 885 |
| salema | 1,018 | 14,355 | 27 | 519 |
| kelp bass | 67 | 1,577 | 15 | 377 |
| California corbina | 144 | 1,569 | 28 | 342 |
| barred sand bass | 82 | 1,274 | 19 | 307 |
| spotfin croaker | 93 | 788 | 52 | 246 |
| Pacific pompano | 204 | 12,970 | 4.5 | 214 |
| walleye surfperch | 2,219 | 12,471 | 58 | 163 |
| white seaperch | 371 | 5,324 | 4.4 | 75 |
| black croaker | 193 | 345 | 17 | 69 |
| topsmelt | 79 | 571 | 3.3 | 16 |
| California grunion | 17 | 498 | 0.2 | 10 |
| all other species combined | 7,052 | 75,760 | 1,663 | 5,432 |
| Total fish | 272,320 | 5,599,611 | 4,186 | 36,868 |

## Table 12

**Annual estimates of the NUMBER of fish either killed during HEAT TREATMENTS, IMPINGED on travelling screens or DIVERTED to the Fish Return System in SONGS Units 2 & 3. The annual estimate of the total number of fish entrapped in Units 2 & 3 is shown in Table 11. Percent diverted = (number of fish diverted / total number entrapped) x 100. Shown are estimates for 17 select species, all other species combined and total fish. Estimates for small, medium and large size classes are also shown. Average size classification for each species is indicated by $^{L}$ = large, $^{M}$ = medium, $^{S}$ = small.**

| SPECIES | HEAT TREATMENT | IMPINGED | DIVERTED | PERCENT DIVERTED |
|---|---|---|---|---|
| queenfish$^{S}$ | 24,342 | 307,225 | 793,941 | 70.5 |
| northern anchovy$^{S}$ | 30,254 | 373,374 | 3,775,230 | 90.3 |
| jacksmelt$^{M}$ | 142 | 11,869 | 17,010 | 58.6 |
| yellowfin croaker$^{L}$ | 2,703 | 32 | 11,779 | 81.2 |
| Pacific electric ray$^{L}$ | 0.6 | 79.4 | 56 | 41.2 |
| white croaker$^{S}$ | 156 | 62,825 | 61,091 | 49.2 |
| salema$^{M}$ | 1,112 | 238 | 13,005 | 90.6 |
| kelp bass$^{L}$ | 285 | 27 | 1,265 | 80.2 |
| California corbina$^{L}$ | 11 | 224 | 1,334 | 85.0 |
| barred sand bass$^{L}$ | 429 | 173 | 672 | 52.7 |
| spotfin croaker$^{L}$ | 193 | 20 | 575 | 73.0 |
| Pacific pompano$^{S}$ | 74 | 7,235 | 5,661 | 43.6 |
| walleye surfperch$^{S}$ | 43 | 758 | 11,670 | 93.6 |
| white seaperch$^{S}$ | 14 | 2,018 | 3,292 | 61.8 |
| black croaker$^{M}$ | 61 | 4 | 280 | 81.2 |
| topsmelt$^{M}$ | 35 | 17 | 519 | 90.9 |
| California grunion$^{S}$ | 8 | 215 | 275 | 55.2 |
| all other species combined | 6,347 | 27,418 | 41,995 | 55.4 |
| Total Fish | 66,210 | 793,751 | 4,739,650 | 84.6 |
| small species | 57,335 | 778,107 | 4,681,060 | 84.9 |
| medium species | 1,559 | 14,157 | 33,670 | 68.2 |
| large species | 7,316 | 1,487 | 24,920 | 73.9 |

## Table 13

**Annual estimates of the BIOMASS (kg) of fish either killed during HEAT TREATMENTS, IMPINGED on travelling screens or DIVERTED to the Fish Return System in SONGS Units 2 & 3. The annual estimate of the total biomass of fish entrapped in Units 2 & 3 is shown in Table 11. Percent diverted = (biomass of fish diverted / total biomass entrapped) x 100. Shown are estimates for 17 select species, all other species combined and total fish. Estimates for small, medium and large size classes are also shown. Average size classification for each species is indicated by $^{L}$ = large, $^{M}$ = medium, $^{S}$ = small.**

| SPECIES | HEAT TREATMENT | IMPINGED | DIVERTED | PERCENT DIVERTED |
|---|---|---|---|---|
| queenfish$^{S}$ | 215 | 2,928 | 11,083 | 77.9 |
| northern anchovy$^{S}$ | 93 | 974 | 3,732 | 77.8 |
| jacksmelt$^{M}$ | 19 | 1,426 | 2,482 | 63.2 |
| yellowfin croaker$^{L}$ | 949 | 1 | 2,975 | 75.8 |
| Pacific electric ray$^{L}$ | 5 | 656 | 675 | 50.5 |
| white croaker$^{S}$ | 3 | 355 | 527 | 59.5 |
| salema$^{M}$ | 49 | 3 | 467 | 90.0 |
| kelp bass$^{L}$ | 58 | 2 | 317 | 84.1 |
| California corbina$^{L}$ | 3 | 27 | 312 | 91.2 |
| barred sand bass$^{L}$ | 109 | 48 | 150 | 48.9 |
| spotfin croaker$^{L}$ | 116 | 3 | 127 | 51.6 |
| Pacific pompano$^{S}$ | 1.5 | 88 | 124.5 | 58.2 |
| walleye surfperch$^{S}$ | 2 | 13 | 148 | 90.8 |
| white seaperch$^{S}$ | 0.5 | 13 | 61.5 | 82.0 |
| black croaker$^{M}$ | 10 | 0 | 59 | 85.5 |
| topsmelt$^{M}$ | 2 | 0.2 | 13.8 | 86.3 |
| California grunion$^{S}$ | 0.1 | 4.4 | 5.5 | 55.0 |
| all other species combined | 1,381 | 697 | 3,354 | 61.7 |
| Total Fish | 3,016 | 7,239 | 26,613 | 72.2 |
| small species | 334 | 4,467 | 15,815 | 76.7 |
| medium species | 102 | 1,555 | 3,190 | 65.8 |
| large species | 2,580 | 1,217 | 7,608 | 66.7 |

## Table 14

**Results of 1983-1985 field experiments to estimate percent mortality of fishes entrapped in SONGS Units 2 & 3 and subsequently discharged from the Fish Return System (FRS). Shown is the total percent mortality during the first 4 days after discharge which includes fish that were dead when discharged. "other species" is the sum of all species with less than 10 fish in experimental pens. -- indicates there were no fish in the control nets. NC indicates that there was no control for this species since there were no fish in the control nets. [a] indicates that the control data were insufficient and therefore the results of the control were disregarded. [b] indicates only shiner surfperch were found in control pens. [c] indicates only black croaker were found in control pens. [d] indicates only 4 species were found in control pens. Numbers in ( ) are half-width of 95% CI. Size categories are given in Table 8. Estimate of % mortality of small fish is the weighted mean of mortality estimates for the 4 small species with adequate controls. Estimates for medium and large fish are weighted means of mortality estimates for all species in the 2 size classes.**

| | Experimental Pens | | | Control Pens | | | % Mortality due to FRS |
|---|---|---|---|---|---|---|---|
| | % Mortality | No. of Pens | No. of Fish | % Mortality | No. of Pens | No. of Fish | Experimental -- Control |
| SMALL SPECIES | | | | | | | |
| deepbody anchovy | 13 | 4 | 175 | -- | -- | -- | NC |
| northern anchovy | 3 | 10 | 5564 | 85 | 1 | 108 | NC[a] |
| slough anchovy | 100 | 3 | 100 | -- | -- | -- | NC |
| Pacific pompano | 7 | 2 | 14 | -- | -- | -- | NC |
| white croaker | 52 | 10 | 155 | 0 | 3 | 12 | 52 (8) |
| walleye surfperch | 3 | 9 | 40 | 0 | 5 | 20 | 3 (5) |
| white seaperch | 7 | 7 | 30 | 0 | 3 | 8 | 7 (9) |
| queenfish | 52 | 18 | 2753 | 20 | 9 | 185 | 32 (6) |
| 2 other species | 0 | 3 | 6 | 0 | 2 | 5[b] | NC |
| MEDIUM SPECIES | | | | | | | |
| salema | 0 | 12 | 122 | -- | -- | -- | NC |
| topsmelt | 30 | 2 | 466 | -- | -- | -- | NC |
| 6 other species | 0 | 9 | 12 | 0 | 2 | 6[c] | 0 |
| LARGE SPECIES | | | | | | | |
| yellowfin croaker | <1 | 9 | 405 | 0 | 3 | 15 | 0 |
| 9 other species | 5 | 10 | 22 | 0 | 5 | 12[d] | NC |

% Mortality for size classes
- Small species = 32%
- Medium species = 23%
- Large species = 0%

## Table 15

**Percent mortality of small (≤ 100 mm SL) and large (> 100 mm SL) queenfish entrapped in SONGS Units 2 and 3 and subsequently discharged in the Fish Return System (FRS). Shown is the total percent mortality during the first 4 days after discharge which includes fish that were dead when discharged. Numbers in ( ) are half-width of 95% CI. One experimental and one control pen were not included in the analysis because fish were not measured. No. of fish is the total of the initial numbers of fish in pens.**

| Size Class | Experimental Pens: % Mortality | Experimental Pens: No. of Pens | Experimental Pens: No. of Fish | Control Pens: % Mortality | Control Pens: No. of Pens | Control Pens: No. of Fish | Difference Experimental -- Control % Mortality due to FRS |
|---|---|---|---|---|---|---|---|
| SMALL | 57 | 17 | 1,625 | 20 | 8 | 46 | 37 (12) |
| LARGE | 46 | 17 | 1,126 | 19 | 8 | 130 | 27 (7) |

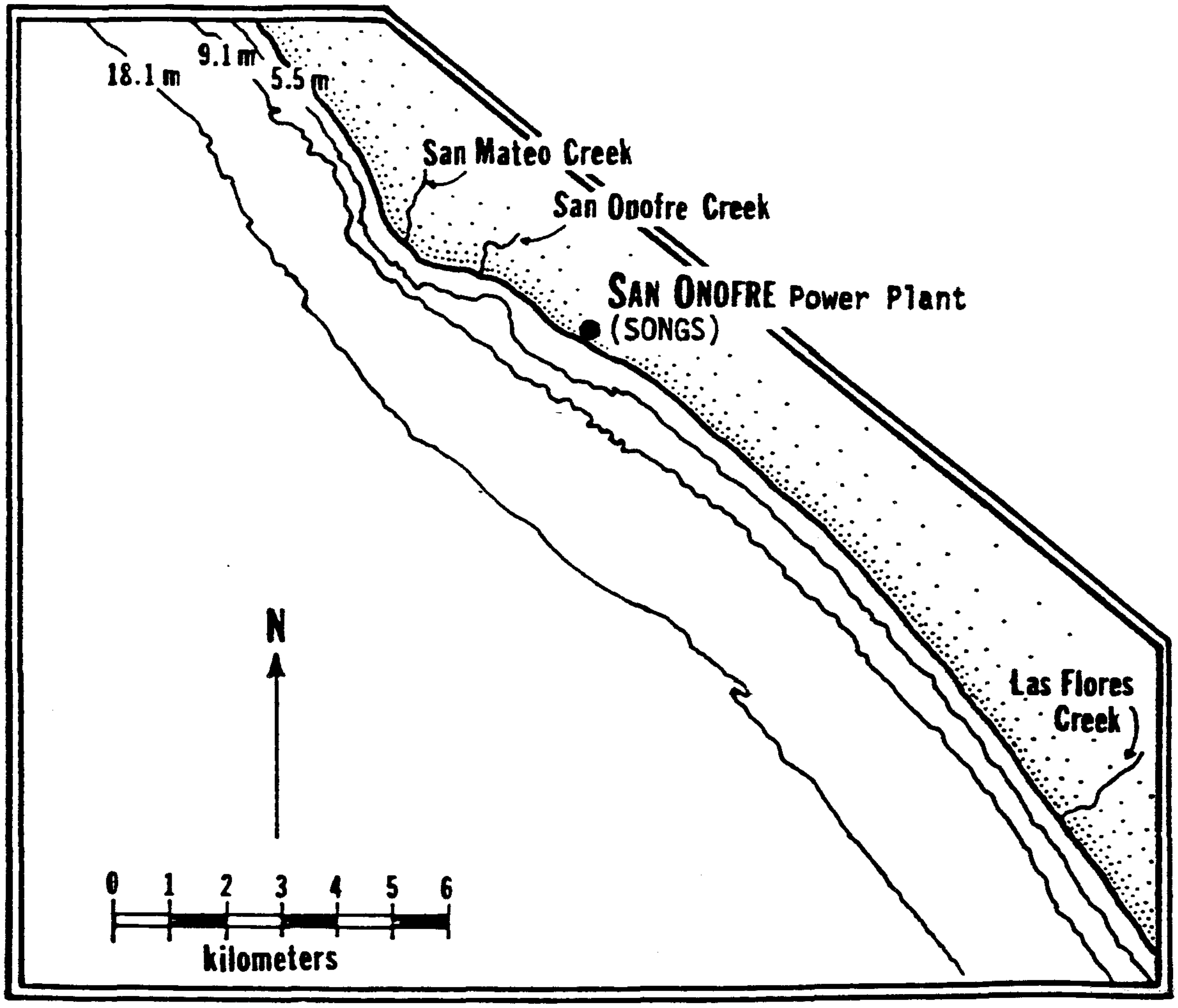
## Table 16

**Percent efficiency for number and biomass of fish for the Units 2 & 3 Fish Return System (FRS). Percent diversion estimates are from Tables 12 and 13. Diversion estimates for small, medium and large fish are weighted averages of percent diversion for small, medium and large species. Percent survivorship of transport through FRS was estimated from survivorship experiments reported in Table 14. Percent efficiency of FRS including FRS transport survivorship is the product of percent diversion and percent FRS transport survivorship.**

| Species/ Group | % Efficiency including survivorship of FRS transport only | | | | |
|---|---|---|---|---|---|
| | % Diversion | | % Surviv-orship FRS Transport | % Efficiency | |
| | Number | Biomass | | Number | Biomass |
| northern anchovy | 90 | 78 | 97 | 87 | 76 |
| Pacific pompano | 44 | 58 | 93 | 41 | 54 |
| white croaker | 49 | 60 | 48 | 24 | 29 |
| walleye surfperch | 94 | 91 | 97 | 91 | 88 |
| white seaperch | 62 | 82 | 93 | 58 | 76 |
| queenfish | 71 | 78 | 68 | 48 | 53 |
| salema | 91 | 90 | 100 | 91 | 90 |
| topsmelt | 91 | 86 | 70 | 64 | 60 |
| yellowfin croaker | 81 | 76 | 100 | 81 | 76 |
| Small-bodied species (minus anchovy) | 68 | 76 | 68 | 46 | 52 |
| Medium-bodied species | 68 | 66 | 77 | 52 | 51 |
| Large-bodied species | 74 | 67 | 100 | 74 | 67 |

# 7.0 FIGURES

**Figure 1:** Map of the Los Angeles - San Diego region showing the location of the San Onofre Nuclear Generating Station (SONGS). Schematic shows location of intake pipes and discharge conduit for the Fish Return System.


18.1 m
9.1 m
5.5 m
San Mateo Creek
San Onofre Creek
SAN ONOFRE Power Plant
(SONGS)
Las Flores
Creek
N
0 1 2 3 4 5 6
kilometers

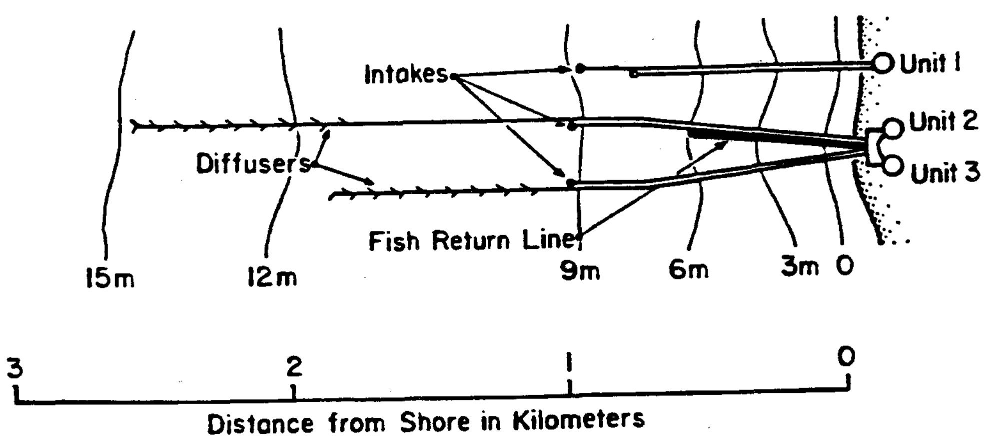

Intakes
Unit 1
Unit 2
Unit 3
Diffusers
Fish Return Line
15m
12m
9m
6m
3m
0
3
2
1
0
Distance from Shore in Kilometers

**Figure 2:** **Diagram of the SONGS Fish Return System.**

## SAN ONOFRE UNITS 2 & 3 SCREEN WELL

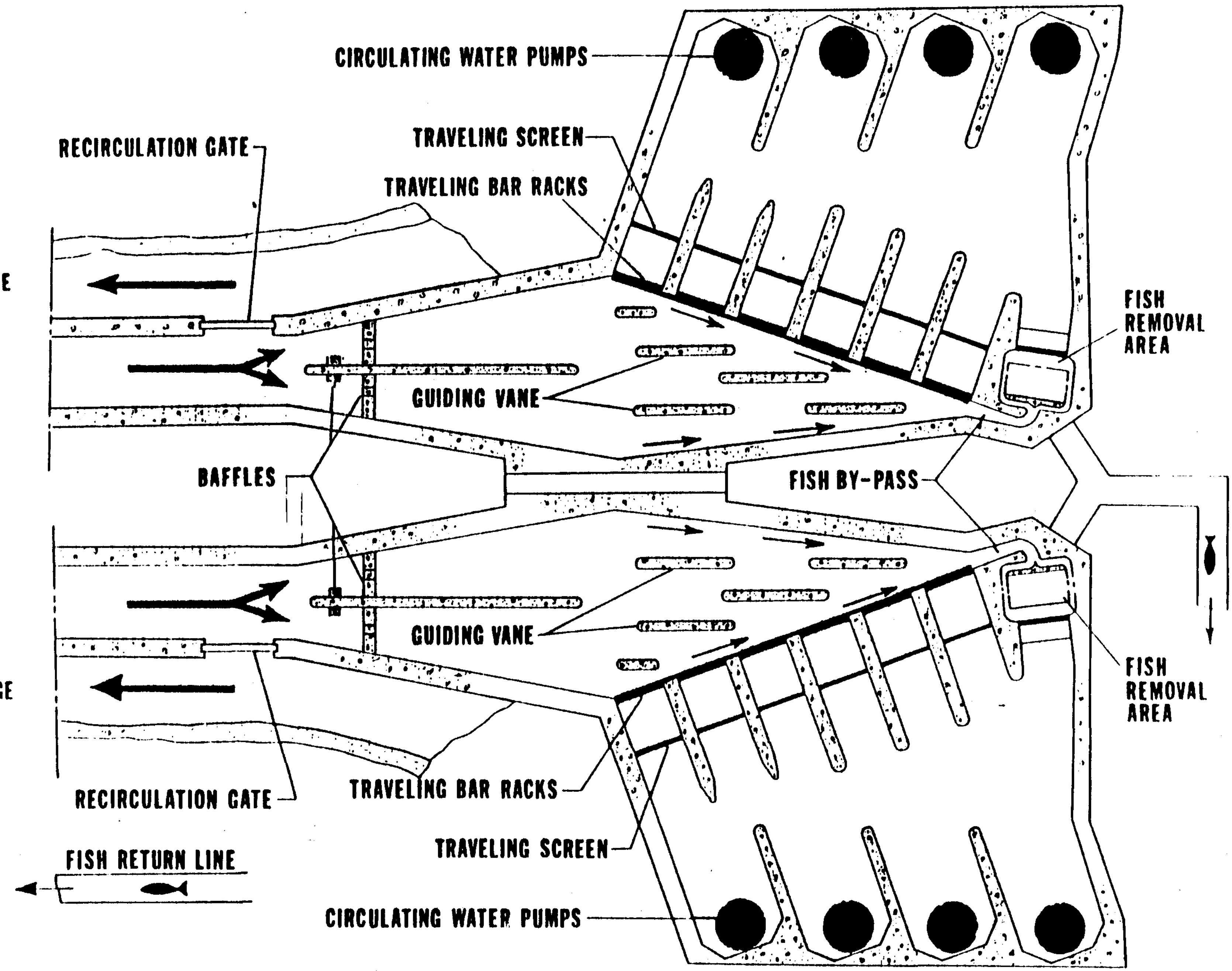


**Figure 3:** **Diagram of the elevation and sluicing channel for SONGS Fish Return System.**

# FISH REMOVAL ELEVATOR AND SLUICING CHANNEL

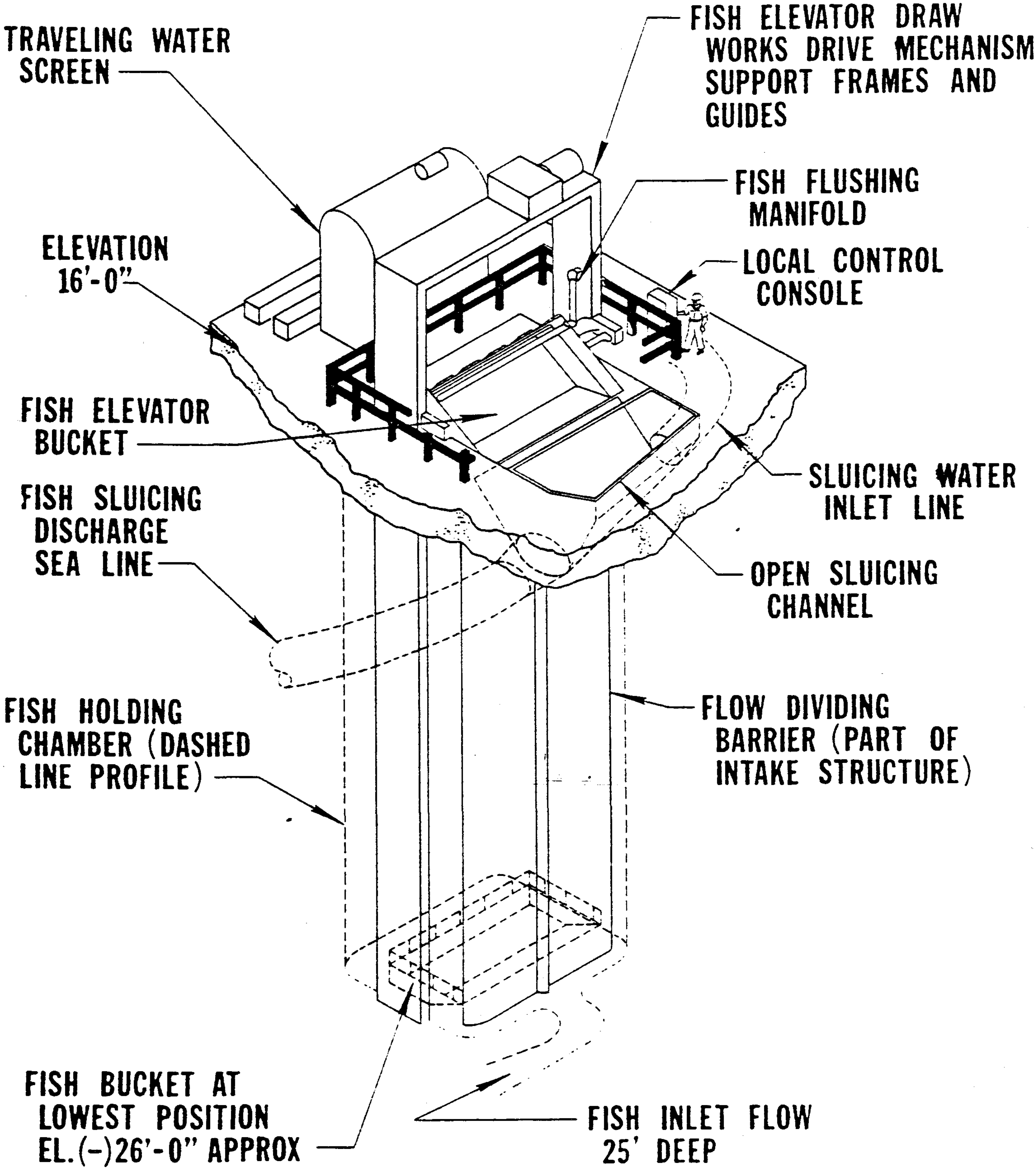


**Figure 4:** Histogram of the size distributions of queenfish in impingement and diversion samples in SONGS Units 2 & 3. Data were pooled over all 191 quantitative samples. Fish were divided into 20 mm length classes. n = total number of fish measured in samples.

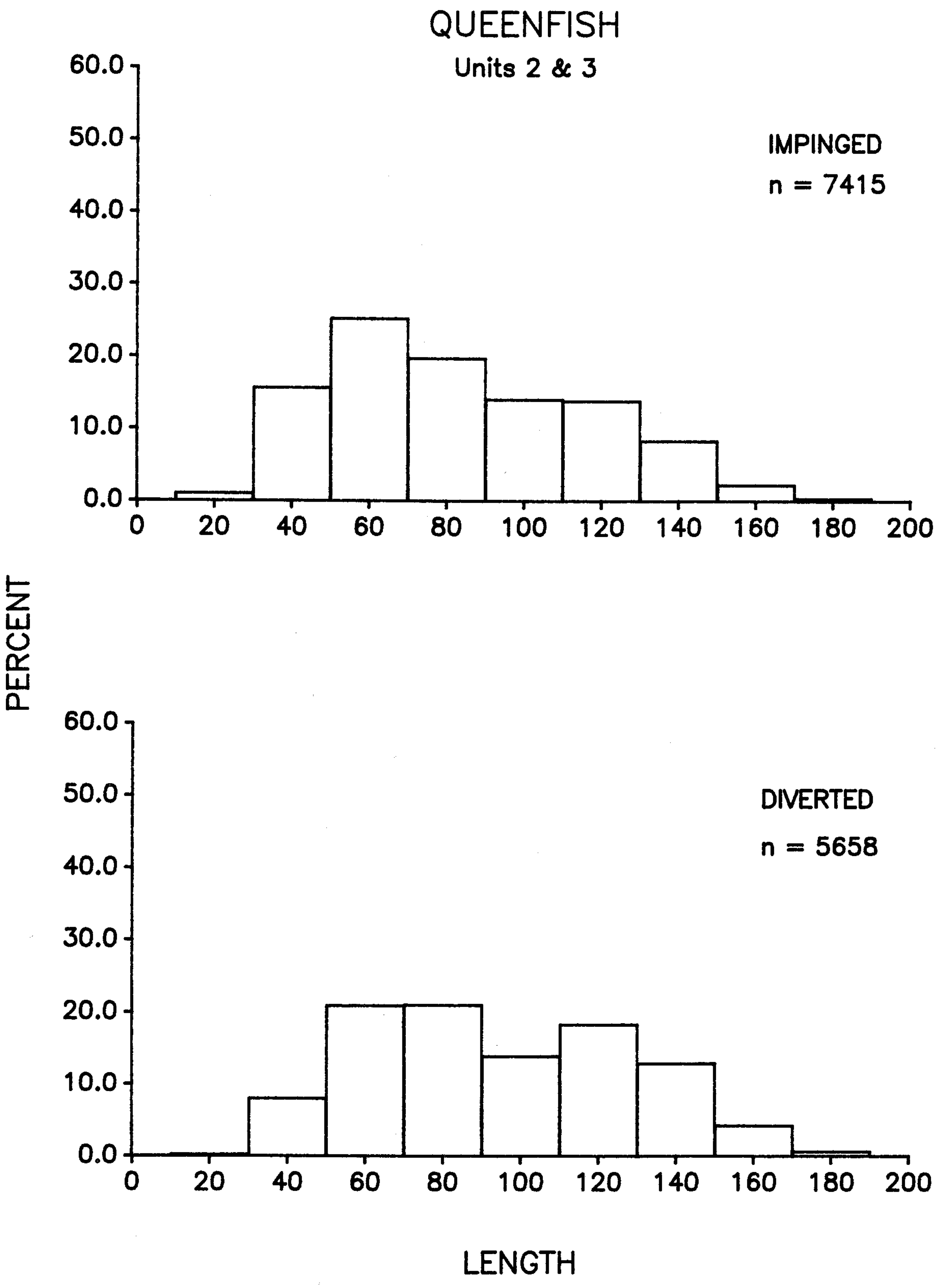

QUEENFISH
Units 2 & 3
IMPINGED
n = 7415
DIVERTED
n = 5658
PERCENT
LENGTH
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
20
40
60
80
100
120
140
160
180
200

**Figure 5:** Histogram of the size distributions of northern anchovy in impingement and diversion samples in SONGS Units 2 & 3. Data were pooled over all 191 quantitative samples. Fish were divided into 10 mm length classes. n = total number of fish measured in samples.

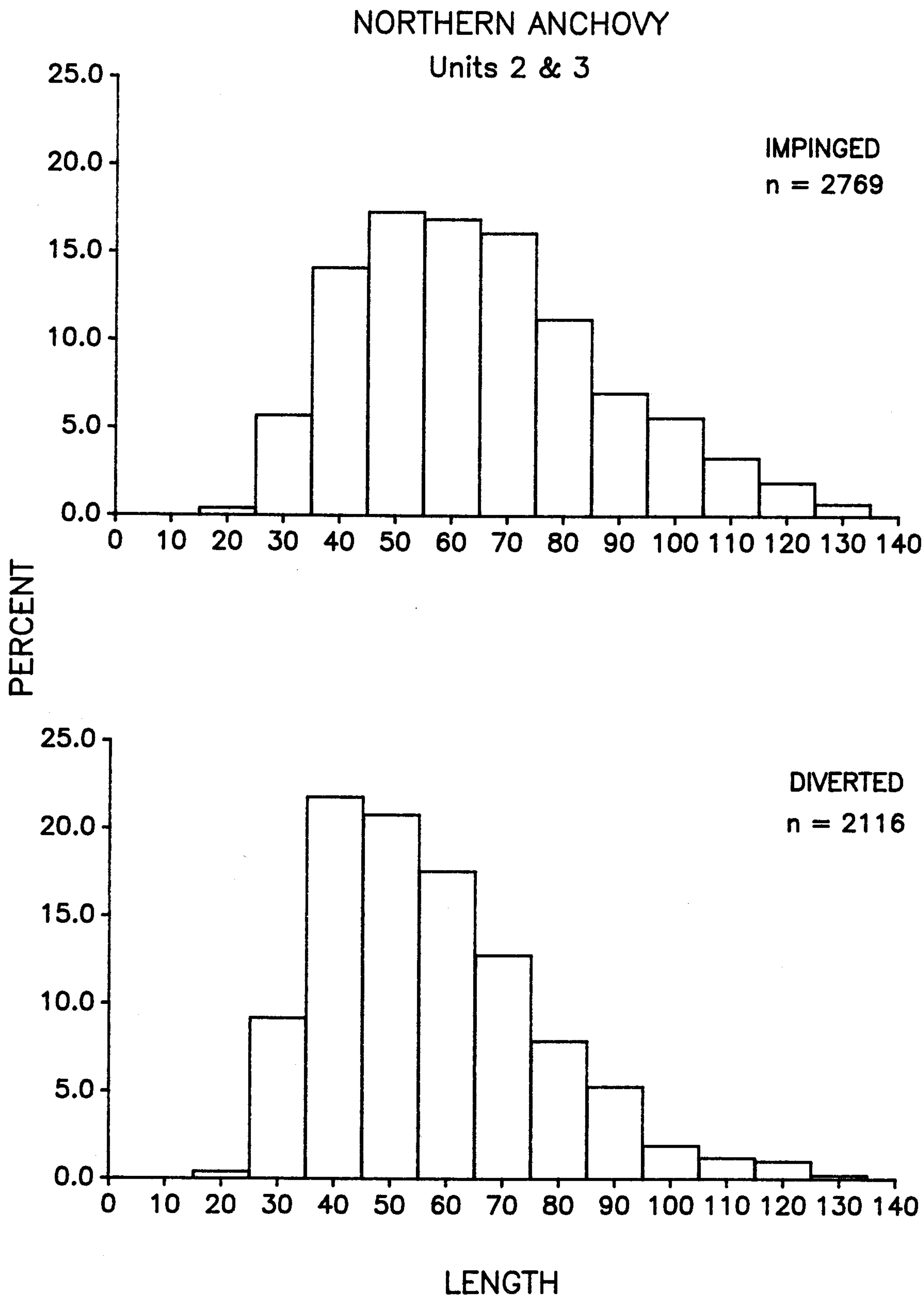

NORTHERN ANCHOVY
Units 2 & 3
IMPINGED
n = 2769
DIVERTED
n = 2116
PERCENT
LENGTH
0.0
5.0
10.0
15.0
20.0
25.0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140

**Figure 6:** Histogram of the size distribution of white croaker in impingement, diversion and heat treatment samples in SONGS Units 2 & 3. Data were pooled over all samples. Fish were divided into 20 mm length classes. n = total number of fish measured in samples.

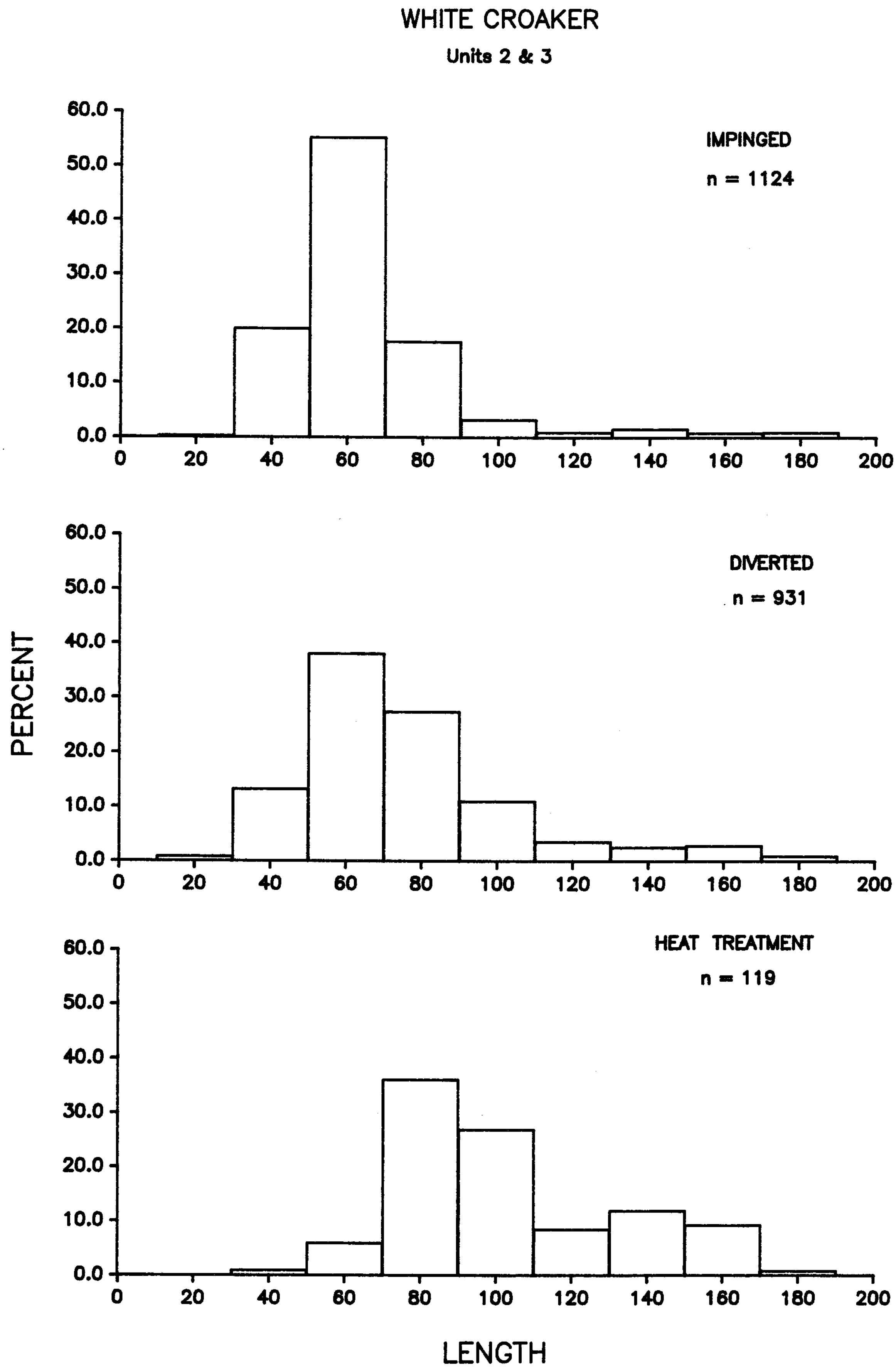

WHITE CROAKER
Units 2 & 3
IMPINGED
n = 1124
DIVERTED
n = 931
HEAT TREATMENT
n = 119
PERCENT
LENGTH
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
20
40
60
80
100
120
140
160
180
200

Figure 7: Histogram of size distributions of queenfish in impingement and heat treatment samples in SONGS Unit 1. Data were pooled over all samples. Fish were divided into 20 mm length classes. n = total number of fish measured in samples.

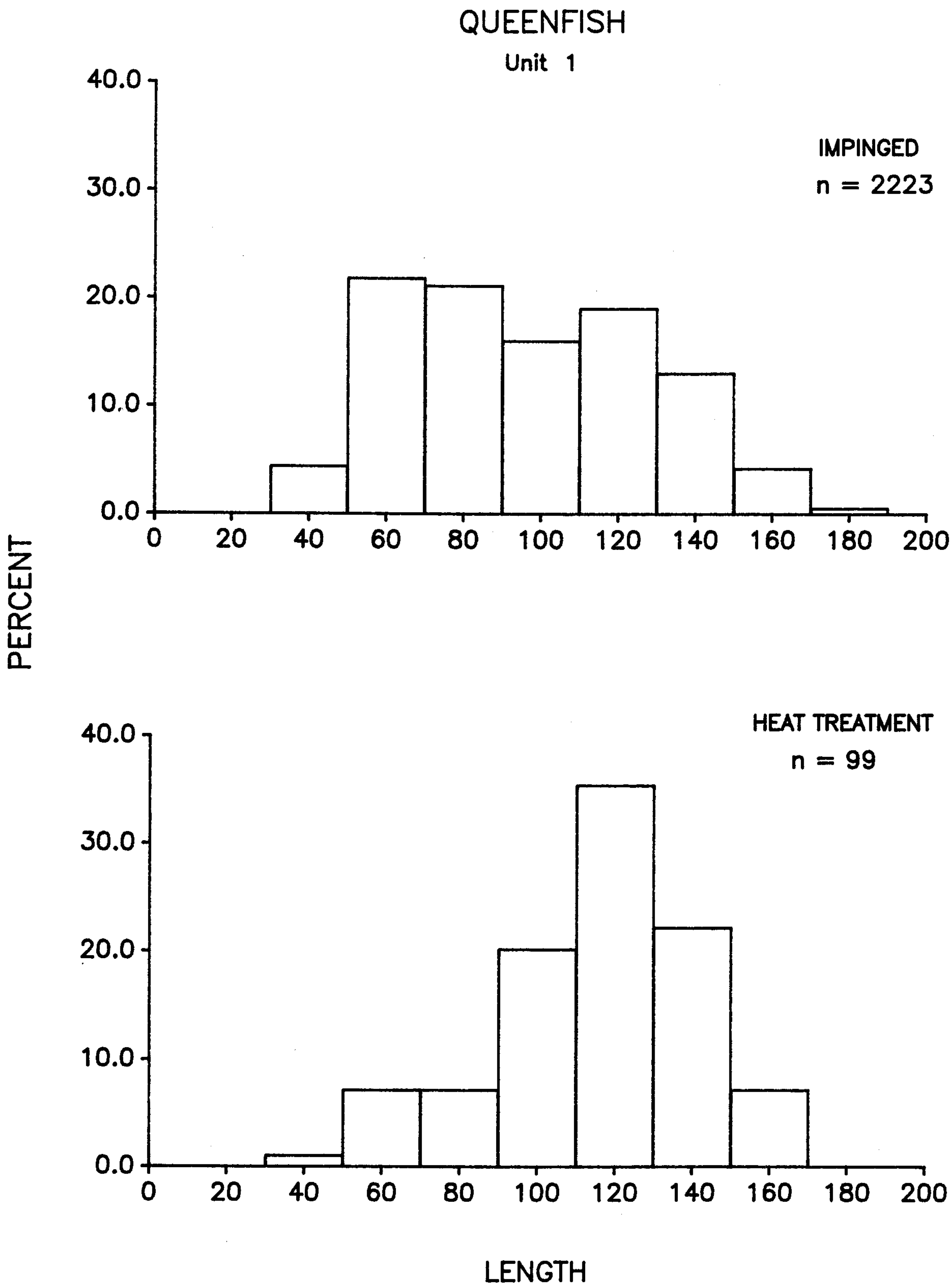
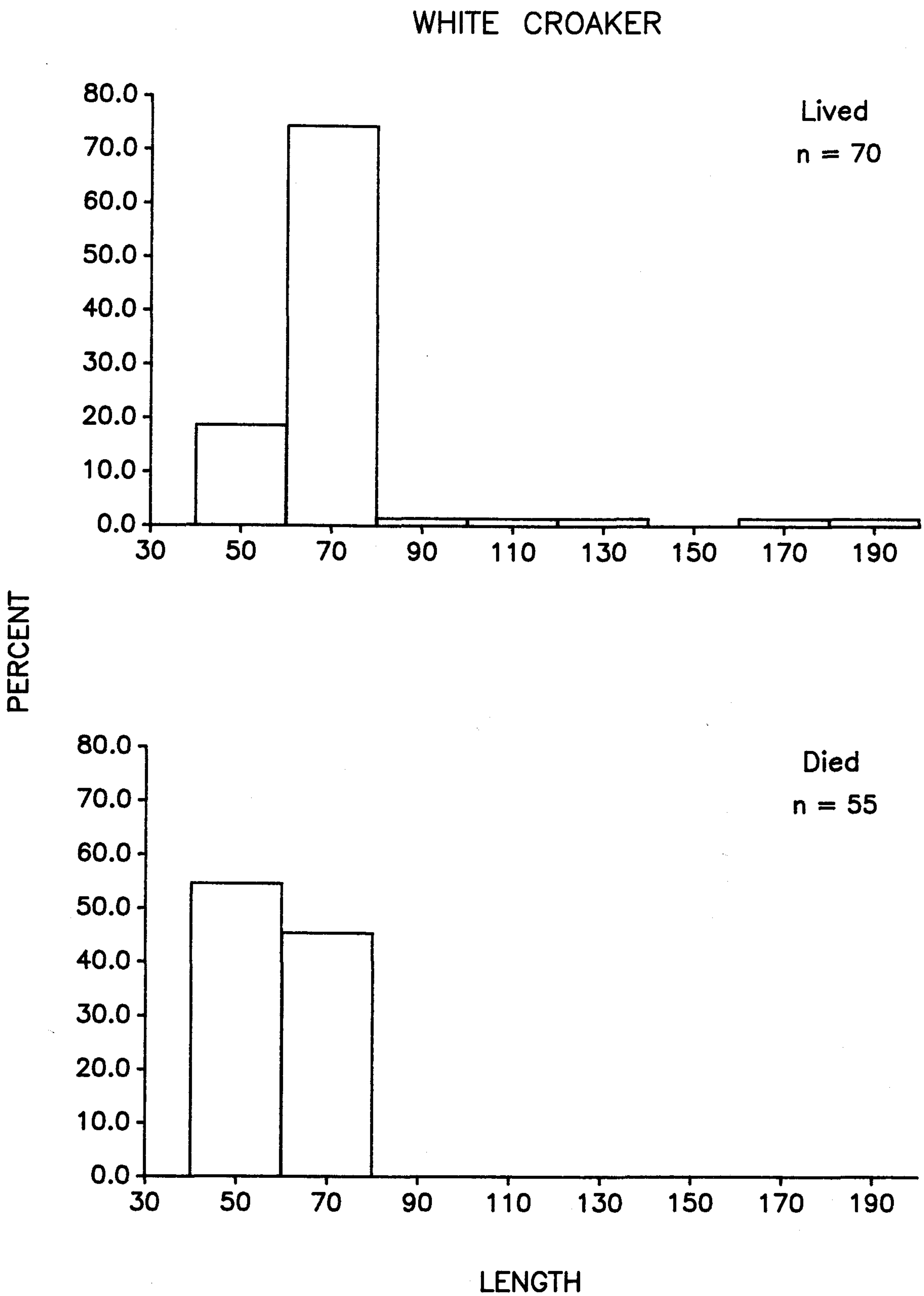

QUEENFISH
Unit 1
IMPINGED
n = 2223
HEAT TREATMENT
n = 99
PERCENT
LENGTH
40.0
30.0
20.0
10.0
0.0
0
20
40
60
80
100
120
140
160
180
200

**Figure 8:** Histogram of size distributions of white croaker that lived and died in pens in the survivorship field experiment. Data were pooled over all experimental trials. Fish were divided into 20 mm length classes. n = total number of fish measured.


WHITE CROAKER
Lived
n = 70
Died
n = 55
PERCENT
LENGTH
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
30
50
70
90
110
130
150
170
190

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# APPENDIX A

## Comparison of entrapment at Units 2 and 3

Since the design and operational features of SONGS Units 2 and 3 are the same, the composition and number of fish they entrap should be similar. Entrapment at Units 2 and 3 was compared using data from quantitative impingement and diversion samples collected over 24 hours during full flow (4 pumps) operations on the same day at the two units. Samples collected on 35 dates from March 1984 to September 1985 (Table A-1) were included in the analysis.

The rank order of the top 20 species caught in each unit, by abundance, is shown in Table A-2, and by biomass in Table A-3. The results of a Kendall's Tau test show that the rankings for Units 2 and 3 were correlated for both number and biomass (Table A-4). Therefore, the species composition at the two units is similar. Actual entrapment rates, both number and biomass, of the two most abundant species, queenfish and northern anchovy, and of total fishes were also not significantly different at the two units (Table A-5).

## Comparison of Entrapment at Different Flow Volumes

The method used to estimate monthly entrapment of fish at all SONGS units assumes that the number and biomass of fish entrapped is positively and linearly related to the volume of water pumped through a unit. This assumption was tested by comparing entrapment at one new unit when it was operating at full flow (4 pumps) and the other new unit when it was concurrently operating at less than full flow (fewer than 4 pumps). There were 17 dates that satisfied this criterion (Table A-6). First, entrapment in the unit operating at less than full flow was adjusted to the full flow level using the factors listed in Table A-6. Then a two-tailed paired t-test was used to test the hypothesis that there was no difference between entrapment at full flow and the adjusted entrapment. The analysis was done for the 4 of the most abundant species, queenfish, white croaker, walleye surfperch, and northern anchovy, as well as all fish combined and all fish minus northern anchovy. The results show that there is no significant difference between the entrapment, for either numbers or biomass, when it was measured under full-flow conditions and concurrently under less than full-flow conditions and then adjusted (Table A-7). Therefore, the assumption that the magnitude of entrapment is positively and linearly related to the volume of water pumped can be accepted.

**Comparison of Entrapment at Unit 1 with Units 2 and 3**

Comparisons of entrapment at Unit 1 with Units 2 and 3 were based on quantitative 24 hr full-flow (2 pumps for Unit 1 and 4 pumps for Units 2 and 3) entrapment samples collected on the same day at Unit 1 and at one or both of the new units. Since previous analyses showed that the magnitude of entrapment at Units 2 and 3 was not significantly different, if samples were collected at both Units 2 and 3 on the same day as Unit 1, the data from the new units were averaged and the mean was compared with data from Unit 1.

The 5/8 inch mesh of the travelling screens in Unit 1 is two-thirds larger than the 3/8 inch mesh of screens in Units 2 and 3. As a result, some small fish that are impinged on screens in Units 2 and 3 pass through the screens in Unit 1 and are lost from samples. This introduces a bias in any comparison of entrapment at Unit 1 with Units 2 and 3. This bias can be eliminated by including in the analysis only size classes of fish that are fully retained on the large mesh screens in Unit 1. The smallest size fish that would be unable to pass through screens in Unit 1 and Units 2 and 3 was determined using Margraff *et al.*'s (1985) application of the "fineness ratio" formula of Turnpenny (1981, Equation 14). For each species of fish, the fineness ratio is a function of body shape and is calculated as the mean of (body length / body depth). Fineness ratios were calculated for queenfish, white croaker, and northern anchovy, the most abundant species in impingement and diversion samples in Units 2 and 3. The ratio was based on measurements from at least 65 individuals covering a wide range of lengths for each species. Ratios were 3.9 for queenfish, 3.8 for white croaker and 6.6 for northern anchovy. The much higher ratio for northern anchovy reflects its relatively slender body.

The fineness ratio was used to determine the standard length of the smallest fish that would be retained by a screen of a specific mesh size. This was estimated as the minimum length of fish whose deepest body section cannot pass through the screen and is, therefore, very conservative. Minimum lengths for queenfish, white croaker and northern anchovy retained on screens at Unit 1 were 113 mm, 110 mm, and 190 mm, respectively, and at Units 2 and 3 were 57 mm, 55 mm, and 95 mm, respectively.

To avoid the bias caused by differences in screen mesh size at Units 1 and the new units, the comparison of entrapment at the units is based on the number of only large queenfish ($\geq$ 100 mm SL) in same-day samples; the very conservative estimate calculated from the "fineness ratio" for queenfish indicates that this size class should be fully retained on screens in all units. White croaker and northern anchovy were not used because there were too few individuals in the large size classes in entrapment samples at Unit 1.

Frequently, the lengths of all queenfish in a sample were not measured. To estimate the number of large queenfish, the total number of queenfish in a sample was multiplied by the proportion of measured individuals that were $\geq$ 100 mm. Samples were included in the analysis only if the following criteria were met: (1) there were at least 35 queenfish in the sample; (2) lengths of at least 75 individuals were measured in samples with more than 100 fish; (3) in samples with 100 fish or less, the lengths of at least 75% of the fish were measured. There were 15 dates when samples collected at Unit 1 and one or both of the new units satisfied the criteria (Table A-1).

When all pumps are operating, each of the new units pumps about 2 1/2 times the amount of water pumped by Unit 1. Based on this observation, DeMartini and Larson (1980) predicted that each new SONGS unit would entrap 2.5 times the amount of fish entrapped in Unit 1. This prediction was tested by comparing the number of queenfish entrapped in either new unit (or the average of the two units if both were sampled) with 2.5 times the number of fish entrapped in Unit 1.

There was a significant difference between the number of fish entrapped in Unit 1 and the new units (Table A-8). Therefore, the hypothesis that each new unit entraps 2.5 times the number of fish entrapped in Unit 1 must be rejected. The mean of the differences of the log transformed data for the sample pairs was used to determine that the number of queenfish entrapped in a new unit was about 7.7 times the entrapment at Unit 1, so Units 2 and 3 combined entrapped about 15.4 times more queenfish than Unit 1 (Table A-8).

The comparison between units was done for the number of fish entrapped only. Methods used to estimate the number of queenfish in the large size class cannot be used to estimate the weight of queenfish in the size class because individual fish in a sample were not weighed; only aggregate wet weights were measured for each species. The size distribution of large fish was used to estimate the ratio of biomass of entrapped fish at the different units. The size distributions of large queenfish in samples from Unit 1 and Units 2 and 3 were determined by pooling the lengths of all fish measured on the 15 sample dates over each type of unit and dividing the pooled data into 10 mm size classes. Although there may be a slightly higher proportion of individuals in the largest size classes in Unit 1 samples, the distributions are similar (Figure A-1). Therefore, the ratio of the number of queenfish entrapped in the new units and Unit 1 is also a good approximation for biomass.

It wasn't possible to compare entrapment at Unit 1 with Units 2 and 3 for species other than queenfish because the minimum size retained on screens could not be determined. (Although the minimum size of fish retained on screens was determined for white croaker and northern anchovy, sample sizes of the length classes that do not pass through the screens at Unit 1 were too small to use for comparisons.) Because the minimum lengths retained on screens for queenfish and white croaker are very similar (113 mm and 110 mm, respectively, for Unit 1), the ratio of entrapment at a new unit to entrapment at Unit 1 for queenfish is probably a good approximation for white croaker also. The minimum length of fish retained on screens in Unit 1 is much larger for northern anchovy than queenfish (190 mm and 110 mm, respectively). Therefore, although the ratio of entrapment for queenfish is the best estimate available for northern anchovy, it is most likely an underestimate of the actual ratio between the magnitude of entrapment at the new units and Unit 1.

## Table A-1
page 1 of 2

**List of dates (X) of quantitative entrapment collections at SONGS Unit 1, 2, or 3 during the 39-mo period from May 1983 through August 1986. Collections at Unit 1 are quantitative impingement samples and at Units 2 and 3 include both quantitative impingement and diversion samples. [a] indicates samples that were used to compare entrapment at Unit 1 with Units 2 and/or 3. [b] indicates samples that were used to compare entrapment under full flow operating conditions at Units 2 and 3.**

| DATE | UNIT 1 | UNIT 2 | UNIT 3 |
|---|---|---|---|
| 04 JAN 84[a] | X | X | |
| 20 MAR 84[b] | | X | X |
| 18 APR 84[b] | | X | X |
| 24 APR 84[b] | | X | X |
| 25 APR 84[b] | | X | X |
| 06 JUN 84[b] | | X | X |
| 14 AUG 84[b] | | X | X |
| 22 AUG 84[b] | | X | X |
| 05 SEP 84[b] | | X | X |
| 09 OCT 84[b] | | X | X |
| 10 OCT 84[b] | | X | X |
| 17 OCT 84[b] | | X | X |
| 11 DEC 84[a] | X | | X |
| 09 JAN 85[a] | X | | X |
| 23 JAN 85[a] | X | | X |
| 16 APR 85[b] | X | X | X |
| 17 APR 85[b] | X | X | X |
| 23 APR 85[b] | X | X | X |
| 24 APR 85[b] | X | X | X |
| 30 APR 85[ab] | X | X | X |
| 07 MAY 85[b] | | X | X |
| 08 MAY 85[b] | | X | X |
| 15 MAY 85[b] | | X | X |
| 04 JUN 85[a] | X | X | X |
| 05 JUN 85[b] | | X | X |
| 25 JUN 85[b] | | X | X |
| 26 JUN 85[ab] | X | X | X |
| 02 JUL 85[a] | X | | X |
| 16 JUL 85[b] | X | X | X |
| 17 JUL 85[b] | | X | X |
| 23 JUL 85[b] | | X | X |
| 24 JUL 85[b] | | X | X |
| 30 JUL 85[b] | | X | X |
| 31 JUL 85[ab] | X | X | X |
| 14 AUG 85[b] | | X | X |
| 21 AUG 85[b] | | X | X |

**Table A-1**
**page 2 of 2**

| DATE | UNIT 1 | UNIT 2 | UNIT 3 |
|---|---|---|---|
| 27 AUG 85[b] | | X | X |
| 28 AUG 85[b] | | X | X |
| 04 SEP 85[b] | X | X | X |
| 12 SEP 85[b] | | X | X |
| 17 SEP 85[ab] | X | X | X |
| 15 OCT 85[a] | X | X | |
| 05 NOV 85[a] | X | X | |
| 01 JUL 86[a] | X | X | X |
| 19 AUG 86[a] | X | X | |
| 26 AUG 86[a] | X | X | X |

## Table A-2

**Ranks by abundance of species at SONGS Units 2 and 3. Rankings are based on the total number of fish of each species in samples taken concurrently at the 2 units on dates in 1984 and 1985 when both units were operating at full flow (4 Pumps, see Table A-1). Only the top 20 species are ranked.**

| SPECIES | NUMERICAL RANK | |
|---|---|---|
| | UNIT 2 | UNIT 3 |
| northern anchovy | 1 | 1 |
| queenfish | 2 | 3 |
| white croaker | 3 | 2 |
| jacksmelt | 4 | 20 |
| salema | 5 | 5 |
| yellowfin croaker | 6 | 7 |
| slough anchovy | 7 | 4 |
| walleye surfperch | 8 | 10 |
| Pacific pompano | 9 | 11 |
| deepbody anchovy | 10 | 9 |
| zebra perch | 11 | 13 |
| white seaperch | 12 | 8 |
| sargo | 13 | 12 |
| plainfin midshipman | 14 | 14 |
| California corbina | 15 | 16 |
| kelp bass | 16 | 15 |
| barred sand bass | 17 | 19 |
| shiner perch | 18 | 17 |
| white seabass | 19 | 18 |
| topsmelt | 20 | 6 |

## Table A-3

**Ranks of biomass of species at SONGS Units 2 and 3. Rankings are based on the total biomass of each species in samples taken concurrently at the 2 units on dates in 1984 and 1985 when both units were operating at full flow (4 Pumps, see Table A-1). Only the top 20 species are ranked.**

| SPECIES | BIOMASS RANK | |
|---|---|---|
| | UNIT 2 | UNIT 3 |
| queenfish | 1 | 1 |
| northern anchovy | 2 | 4 |
| yellowfin croaker | 3 | 3 |
| jacksmelt | 4 | 20 |
| zebra perch | 5 | 7 |
| Pacific electric ray | 6 | 9 |
| white croaker | 7 | 2 |
| shovelnose guitarfish | 8 | 5 |
| salema | 9 | 14 |
| sargo | 10 | 10 |
| California corbina | 11 | 13 |
| kelp bass | 12 | 11 |
| barred sand bass | 13 | 18 |
| round stingray | 14 | 15 |
| spotfin croaker | 15 | 17 |
| Pacific pompano | 16 | 19 |
| bat ray | 17 | 6 |
| white seabass | 18 | 16 |
| California halibut | 19 | 12 |
| topsmelt | 20 | 8 |

## Table A-4

**Results of nonparametric correlations between species rankings at SONGS Units 2 and 3. Rankings are based on total number or biomass of each species in samples taken concurrently at the 2 units on dates in 1984 and 1985 when both units were operating at full flow (4 pumps). Numbers and biomass were analyzed for the top 20 species. The null hypothesis, $H_0$, is that there is no correlation, i.e., $\tau = 0$. Thus $p \leq 0.05$ indicates that the rankings for Units 2 and 3 are correlated.**

| TEST VARIABLE | KENDALL'S TAU | N | P |
|---|---|---|---|
| NUMBERS, Top 20 Species | 0.56 | 20 | <0.001 |
| BIOMASS, Top 20 Species | 0.38 | 20 | 0.02 |

## Table A-5

**Results of paired t-tests comparing entrapment at SONGS Units 2 and 3. A two-tailed paired t-test was used to test the hypothesis that entrapment, measured concurrently at the 2 units on dates in 1984 and 1985 when both units were operating at full flow (4 pumps, see Table A-1), was not significantly different. Data were $Log_{10}$ (x) transformed before the differences were calculated. Both numbers and biomass were tested for the 2 most abundant species and for all species combined.**

| | T-TEST STATISTICS | | |
|---|---|---|---|
| | T | DF | P |
| NUMBERS | | | |
| queenfish | -0.51 | 34 | 0.61 |
| northern anchovy | 0.55 | 34 | 0.59 |
| Total Fishes | -0.43 | 34 | 0.67 |
| BIOMASS | | | |
| queenfish | -0.81 | 34 | 0.42 |
| northern anchovy | 0.28 | 34 | 0.78 |
| Total Fishes | -1.62 | 34 | 0.11 |

## Table A-6

**Dates of 24 hr entrapment samples used to compare the magnitude of entrapment at different flow volumes in Units 2 and 3. Only dates with one unit pumping at full flow (4 pumps) and the other unit pumping at less than full flow were used. The factor used to scale entrapment at less than full flow up to the estimated full flow magnitude is also shown. Results of the analyses are presented in Table A-7.**

| | ---------- UNIT 2 ---------- | | ---------- UNIT 3 ---------- | |
|---|---|---|---|---|
| DATE | # PUMPS | FACTOR | # PUMPS | FACTOR |
| 18 JUL 84 | 2 | 2.0 | 4 | -- |
| 01 AUG 84 | 4 | -- | 2 | 2.0 |
| 06 MAR 85 | 3 | 1.33 | 4 | -- |
| 13 MAR 85 | 3 | 1.33 | 4 | -- |
| 20 MAR 85 | 3 | 1.33 | 4 | -- |
| 27 MAR 85 | 2 | 2.0 | 4 | -- |
| 02 APR 85 | 2 | 2.0 | 4 | -- |
| 03 APR 85 | 2 | 2.0 | 4 | -- |
| 10 APR 85 | 2 | 2.0 | 4 | -- |
| 07 JAN 86 | 4 | -- | 3 | 1.33 |
| 08 JAN 86 | 4 | -- | 3 | 1.33 |
| 26 FEB 86 | 4 | -- | 2 | 2.0 |
| 04 MAR 86 | 4 | -- | 2 | 2.0 |
| 05 MAR 86 | 4 | -- | 2 | 2.0 |
| 11 MAR 86 | 4 | -- | 2 | 2.0 |
| 03 JUN 86 | 3 | 1.33 | 4 | -- |
| 04 JUN 86 | 3 | 1.33 | 4 | -- |

## Table A-7

**Results of paired t-tests comparing the magnitude of entrapment in one new unit operating at full flow volume (4 pumps) with the magnitude of entrapment in the other new unit which was concurrently operating at less than full flow volume. To test the hypothesis that the magnitude of entrapment is directly proportional to flow volume, entrapment in the unit operating at less than full flow volume was adjusted to full flow level using the factor listed in Table A-6. A two-tailed paired t-test was then used to test the hypothesis that, when adjusted, the magnitude of entrapment measured concurrently at the 2 new units was not significantly different. Data were $Log_{10}$ (X) transformed before the differences were calculated. Shown are the means (SE) of the differences of the transformed data (full flow - adjusted to full flow). Both numbers and biomass were tested.**

| SPECIES/ GROUP | NO. OF PAIRED SAMPLES | NUMBER OF INDIVIDUALS | | | | BIOMASS | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MEAN | SE | T | P | MEAN | SE | T | P |
| queenfish | 17 | -0.081 | 0.131 | -0.62 | 0.55 | 0.087 | 0.136 | 0.64 | 0.53 |
| white croaker | 17 | 0.018 | 0.193 | 0.09 | 0.93 | 0.513 | 0.264 | 1.94 | 0.07 |
| walleye surfperch | 10 | 0.055 | 0.151 | 0.36 | 0.73 | 0.278 | 0.397 | 0.70 | 0.50 |
| northern anchovy | 16 | -0.164 | 0.251 | -0.65 | 0.52 | -0.274 | 0.270 | -1.01 | 0.33 |
| Total Fishes | 17 | -0.144 | 0.141 | -1.02 | 0.32 | -0.112 | 0.121 | -0.93 | 0.37 |
| Total fishes minus northern anchovy | 17 | -0.105 | 0.124 | -0.85 | 0.41 | -0.092 | 0.124 | -0.74 | 0.47 |

## Table A-8

**Results of paired t-test comparing the number of fish entrapped at Unit 1 operating at full flow, with the number of fish entrapped at a new unit (Unit 2 or 3) concurrently operating at full flow. A two-tailed paired t-test was used to test the hypothesis that entrapment at the new unit is 2.5 times entrapment at Unit 1. The number of fish entrapped at Unit 1 was multiplied by 2.5 and the data were $Log_{10}$ (x + 1) transformed before the differences were calculated. Shown is the mean (SE) of the difference of the transformed data [$Log_{10}$ (new unit) - $Log_{10}$ (Unit 1 x 2.5)]. The mean difference was used to calculate the actual relationship between the magnitude of entrapment at Unit 1 and at Units 2 & 3.**

| No. of Paired Samples | Mean | SE | T | P |
|---|---|---|---|---|
| 15 | 0.4899 | 0.1680 | 2.92 | 0.0113 |

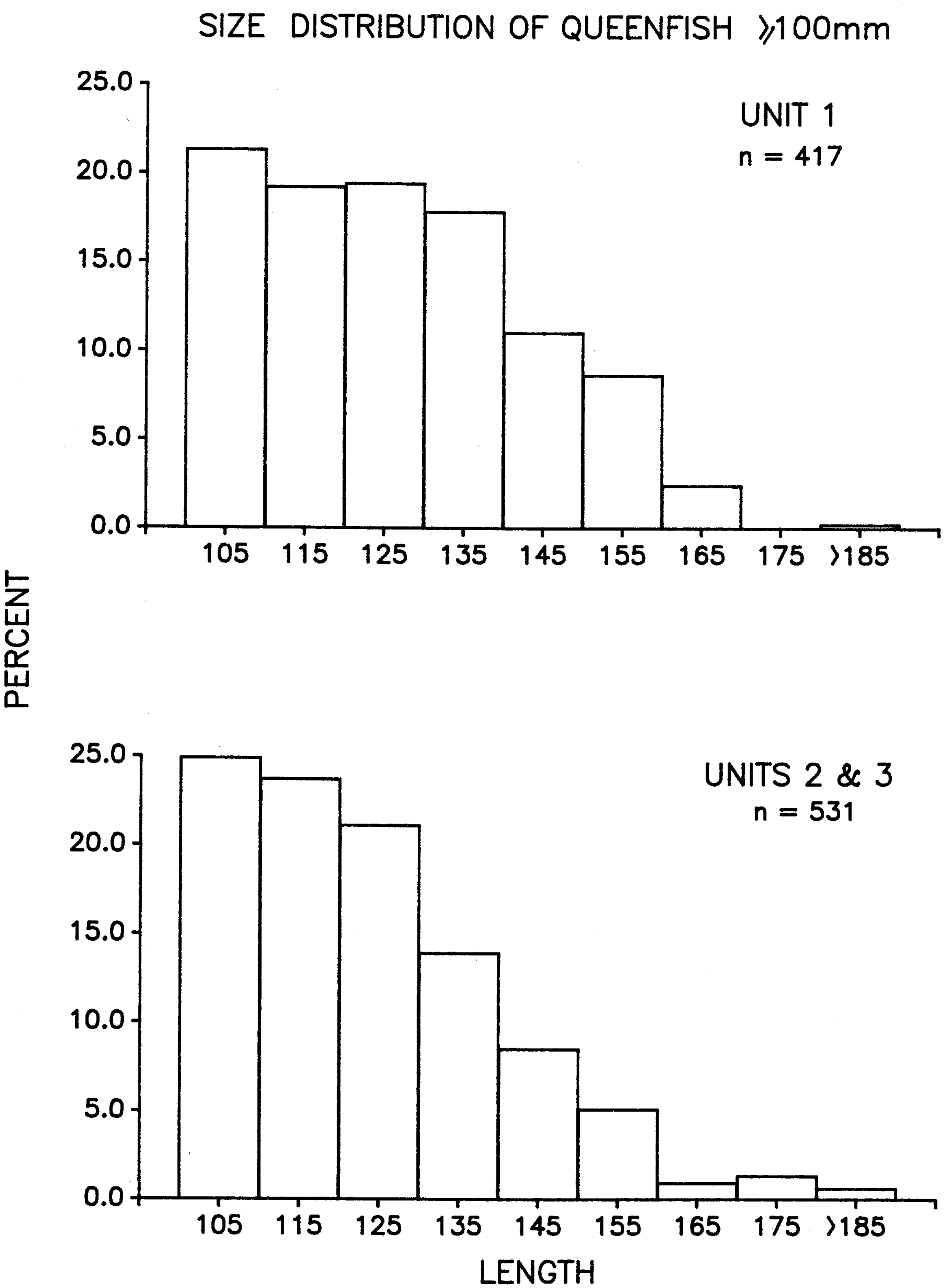
Calculations for relationship between magnitude of entrapment at Unit 1 and at Units 2 & 3.

$$Log_{10} \text{(Unit 2 or 3)} - Log_{10} \text{(Unit 1 x 2.5)} = 0.4899$$

$$\text{Unit 2 or 3} = 7.7 \text{ (Unit 1)}$$

$$\text{Unit 1} = \frac{\text{Unit 2 + Unit 3}}{15.4}$$

**Figure A-1:** **Histogram of the size distribution of large queenfish (≥ 100 mm SL). Data were pooled over 15 sample dates for SONGS Unit 1 and Units 2 & 3. Fish were divided into 10 mm length classes. n = total number of fish sampled in the different units.**


SIZE DISTRIBUTION OF QUEENFISH ≥100mm
UNIT 1
n = 417
UNITS 2 & 3
n = 531
PERCENT
LENGTH
25.0
20.0
15.0
10.0
5.0
0.0
105
115
125
135
145
155
165
175
>185

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# APPENDIX B

## Data Sources for Tables

Abbreviations: DeM 87 = DeMartini, E.E. and UCSB Staff. 1987. The effects of operations of the San Onofre Nuclear Generating Station on fish. Final Report submitted to the Marine Review Committee, Inc., December 1987.

TR C = This Report - Technical Report C. Entrapment of juvenile and adult fish at SONGS.

**Table 1:** List of dates of entrapment collections at SONGS Units 1, 2, or 3.

DATA SOURCE: Appendix F, Table 1 in DeM 87.

**Table 2:** List of dates on which heat treatments occurred at SONGS Units 1, 2, or 3.

DATA SOURCE: Appendix F, Table 3 in DeM 87.

**Table 3:** Number of full-flow operational days per month for SONGS Units 1, 2, and 3.

DATA SOURCE: Appendix F, Tables 4, 5, and 6 in DeM 87.
- combined the 3 tables
- summed all days over the 39 month period and recalculated percent full pumping for the period.

**Table 4:** Results of regressions of percent queenfish mortality vs. abundance of queenfish and total fish in pens.

DATA SOURCE: Table 15 in DeMartini *et al.* 1986.

| VARIABLE | SOURCE VARIABLE |
|---|---|
| N | n |
| $R^2$ | correlation coefficient (r) squared |
| P | P |

**Table 5:** List of species collected in samples at SONGS Units 1, 2 and 3.

DATA SOURCE: Common names of all species listed in Tables 11, 12, 13, 14, Appendix G, Tables 1-16 and Appendix H, Tables 1-4 in DeM 87.

scientific names from Guide to the Coastal Marine Fishes of California, Miller and Lea, 1972.

**Table 6:** Number, biomass and mean weight per fish for fish IMPINGED at Units 2 & 3.

DATA SOURCE: Appendix H, Table 1 in DeM 87.

| VARIABLE | SOURCE VARIABLE |
|---|---|
| Number | Total Number Impinged |
| Weight | Total Weight Impinged |
| Mean Wt./Fish | Weight/Number |

**Table 7:** Number, biomass and mean weight per fish for fish DIVERTED at Units 2 & 3.

DATA SOURCE: Appendix H, Table 1 in DeM 87.

| VARIABLE | SOURCE VARIABLE |
|---|---|
| Number | Total Number Returned |
| Weight | Total Weight Returned |
| Mean Wt. per Fish | Weight/Number |

**Table 8:** Average body weight and size classification for fishes entrapped at SONGS Units 2 & 3.

DATA SOURCE: Appendix H, Table 2 in DeM 87.

**Table 9**: Number, biomass and mean weight per fish for fish impinged during HEAT TREATMENTS at SONGS Units 2 & 3.

DATA SOURCE: Appendix G, Tables 11, 13 & 15 in DeM 87.

| VARIABLE | SOURCE VARIABLE |
|---|---|
| Number | sum of Total Fish Number in Tables 11, 13 & 15 |
| Weight | sum of Total Fish Weight in Table 11, 13 & 15 |
| Mean Wt. per Fish | Weight/Number |

**Table 10**: Number, biomass and mean weight per fish for fish impinged during HEAT TREATMENTS at SONGS Unit 1.

DATA SOURCE: Appendix G, Tables 12 & 14 in DeM 87.

| VARIABLE | SOURCE VARIABLE |
|---|---|
| Number | sum of Total Fish Number in Tables 12 & 14 |
| Weight | sum of Total Fish Weight in Tables 12 & 14 |
| Mean Wt. per Fish | Weight/Number |

**Table 11:** Annual estimates of entrapment at SONGS Unit 1 and Units 2 & 3.

DATA SOURCE: For species and groups

| SPECIES OR GROUP | ANNUAL ESTIMATES FOR NUMBER AND BIOMASS UNIT 1 | UNITS 2 & 3 |
|---|---|---|
| queenfish<br>northern anchovy<br>white croaker | estimated from<br>Units 2 & 3 -<br>see Methods. | Table 11,<br>DeM 87 |
| walleye surfperch<br>Pacific electric ray | Table 11,<br>Dem 87 | Table 11,<br>DeM 87 |
| white seaperch<br>Pacific pompano | sum of:<br>impinged + diverted<br>from DeM 87<br>plus heat treatment<br>from Table 10, TR C.<br>(12/39 X Number or Weight) | Table 11<br>DeM 87 |
| jacksmelt<br>yellowfin croaker<br>salema<br>kelp bass<br>barred sand bass<br>California corbina<br>spotfin croaker<br>black croaker<br>topsmelt<br>grunion | sum of:<br>impinged + diverted<br>from SAS program<br>ANLSU187 (fish<br>project E disk)<br>plus heat treatment<br>Table 10, TR C.<br>(12/39 X Number<br>or Weight) | sum of:<br>impinged + diverted<br>from SAS program<br>ANLSMV87 (fish<br>project E disk)<br>plus heat treatment<br>Table 10, TR C.<br>(12/39 X Number<br>or Weight) |
| Total Fishes | calculated as:<br>Total Fishes (from DeM 87)<br>minus queenfish, northern<br>anchovy & white croaker<br>from DeM 87<br>plus estimates for queenfish,<br>northern anchovy & white<br>croaker shown above | Table 11,<br>DeM 87 |
| all other species<br>combined | summed over 17<br>species listed<br>and subtracted the<br>sum from Total Fishes | summed over 17<br>species listed<br>and subtracted the<br>sum from Total Fishes |

**Table 12:** Annual estimates of the number of fish either killed in heat treatments, impinged on travelling screens or diverted to the FRS.

**(A) For 17 Individual Species**

(a) Heat treatment = (12/39) X Number in Table 9 (TR C) for each species

(b) Diverted = [(Number for Units 2 & 3 in Table 11(TR C)) - (Heat treatment in Table 12 (TR C))] X [(Percent Number Returned in Appendix H, Table 1 (DeM 87)/100]

(c) Impinged = (Number for Units 2 & 3 in Table 11 (TR C)) - (Heat treatment in Table 12 (TR C)) - (Diverted in Table 12 (TR C))

**(B) For All Other Species Combined**

(a) Heat treatment = (12/39) X (sum of all species in Table 9 (TR C)) <u>except</u> 17 individual species

(b) Diverted = [(Number for Units 2 & 3 in Table 11 (TR C)) - (heat treatment in Table 12 (TR C))] X [proportion diverted]; Proportion diverted = $D_s/(I_s + D_s$, where $D_s$ = sum of Total Number Returned in Appendix H, Table 1 (DeM 87), for all species <u>except</u> the 17 individual species Table 12 (TR C); and $I_s$ = sum of Total Number Impinged in Appendix H, Table 1 (DeM 87), for all species except the 17 individual species in Table 12 (TR C).

**(C) Total Fish**

Sum of the 16 individual species and all other species combined for heat treatment, impinged and diverted.

**(D) Small, Medium, Large Fish Categories**

1. divided "all other species combined: into size classes (see method below)
2. assigned each of 17 individual species to appropriate size class (Table 8 TR C)
3. summed over size classes

**Method for dividing "all other species combined" into size classes:**

(a) for impinged and diverted

i) in Appendix Hm, Table 1 (DeM 87), eliminated the 17 individual species in Table 12 (TR C) and then placed all remaining species in size classes based on Table 8 (TR C)

ii) summed Total Number Impinged (Appendix H, Table 1, DeM 87) for each size class and calculated the proportion comprised by each size class (large = 0.034, medium = 0.074, small = 0.892).

iii) summed Total Number Returned (Appendix H, Table 1, DeM 87) (note: this is diverted) for each size class and calculated proportion comprised by each size class (large = 0.220, medium = 0.068, small = 0.712)

iv) to calculate the number impinged or diverted in each size class, the proportions for each class calculated in (ii) and (iii) were multiplied be the number for "all other species combined" for impinged or diverted

(b) for heat treatment

i) assigned species in Table 9 (TR C) to size classes (based on Table 8, TR C)

ii) summed number in Table 9 (TR C) for each size class [excluding the 17 species listed individually in Table 12 (TR C)]

iii) calculated the proportion of the total in each size class (large = 0.582, medium = 0.033, small = 0.385)

iv) to calculate the number killed in heat treatments in each size class, the number of fish killed in heat treatments for "all other species combined" was multiplied by the proportions for each size class in (iii)

**(E) Percent diverted = Diverted / (Heat treatment + impinged + diverted) X 100, for all categories**

**Table 13:** Annual estimates of the biomass of fish either killed in heat treatments, impinged on travelling screens or diverted to the FRS.

Methods for calculating *biomass* were the same as for calculating *numbers* in Table 12 (above).

Proportion used for dividing the "all other species combined" category into size classes (see (a) ii, (a) iii, and b (iii) in Table 12 method above)

| | ---- Proportion of Biomass in Each Size Class ---- | | |
|---|---|---|---|
| Size Class | Heat Treatment | Impinged | Diverted |
| small | 0.014 | 0.131 | 0.040 |
| medium | 0.016 | 0.179 | 0.050 |
| large | 0.970 | 0.690 | 0.910 |

**Table 14:** Mortality of fish discharged from FRS.

Data Source: Appendix H, Table 1 in DeM 87.
% mortality for size classes:
small = weighted average of white croaker, queenfish, white seaperch, shiner surf perch (species without controls and northern anchovy were excluded)
medium = weighted average of all 8 medium species
large = weighted average of all 10 large species

**Table 15:** Percent mortality of small and large queenfish discharged from FRS.

Data Source: Appendix H, Table 4 in DeM 87.

**Table 16:** Percent efficiency for number and biomass of fish for FRS.

Data Source: % diversion number from Table 12 (TR C)
% diversion biomass from Table 13 (TR C)
% survivorship FRS transport from Table 14 (TR C),
(% survivorship = 1 - % mortality due to FRS)
% efficiency number = (% diversion number) X (% survivorship FRS)
% efficiency biomass = (% diversion biomass) X (% survivorship FRS)

## Appendix Tables

| | |
|---|---|
| **Table A-1** | Dates of quantitative entrapment samples, Appendix F, Tables 1 & 2, DeM 87 |
| **Table A-2, A-3, A-4** | SAS program KDTCCU23.SAS on Fish Project Disk E |
| **Table A-5** | SAS program U23TTEST.SAS on Fish Project Disk E |
| **Table A-6** | Dates of 24 hr entrapment samples used to compare the magnitude of entrapment at different flow volumes in Units 2 & 3<br><br>Appendix F, Table 8, DeM 87 |
| **Table A-7** | SAS program FLOWTST1.SAS on Fish Project Disk E |
| **Table A-8** | SAS program TTPRUNT2.SAS on Fish Project Disk E |