

MRC DOC:  
89-2043

TECHNICAL REPORT  
TO THE  
CALIFORNIA COASTAL COMMISSION

C. Entrapment of Juvenile and Adult Fish at SONGS

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July 1989

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,  $10.8 \times 10^6$  m<sup>3</sup> 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<sup>3</sup> /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<sup>3</sup> /day at full flow. Thus, when SONGS is fully operational, about  $10.7 \times 10^6$  m<sup>3</sup> 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 ( $\pm$  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 ( $1.7 \times 10^6 \text{ m}^3$  for Unit 1 and  $4.5 \times 10^6 \text{ m}^3$  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<sup>ths</sup> 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:

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

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