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U.S. Department of Commerce

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## ABSTRACT

**This study examined the efficiency of fish diversion and survivorship of diverted fishes in the San Onofre Nuclear Generating Station Fish Return System in 1984 and 1985. Generally, fishes were diverted back to the ocean with high frequency, particularly in 1984. Most species were diverted at rates of 80% or more. Over 90% of the most abundant species, *Engraulis mordax*, were diverted. The system worked particularly well for strong-swimming forms such as *Paralabrax clathratus*, *Atherinopsis californiensis*, and *Xenistius californiensis*, and did not appreciably divert weaker-swimming species such as *Porichthys notatus*, *Heterostichus rostratus*, and *Syngnathus* sp. Return rates of some species were not as high in 1985 as in 1984. Individuals of most tested species survived both transit through the fish return system and 96 hours in a holding net. Some species, such as *E. mordax*, *X. californiensis*, and *Umbrina roncador*, experienced little or no mortality. Survivorship of *Seriphus politus* was highly variable and no *Anchoa delicatissima* survived.**

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## Introduction

Coastal steam-electric plants in southern California obtain cooling water from 900-1000 m offshore via pipes 3-4 m in internal diameter. Water enters a bowl-like intake and flows shoreward to the plant, where traveling screens act as strainers. The filtered water flows through condenser cooling tubes and is discharged back into the ocean.

Fish may enter into these intakes (Helvey 1985, 1987) and are pulled shoreward swimming against the current (Downs and Meddock 1974). Small fishes or weaker-swimming species are impinged on the traveling screens and removed for disposal; stronger individuals may reside in the screen-wells in front of the screens for some time. The number of fishes killed in this manner can be large at times (Schuler and Larson 1975). Various control technologies have been developed to reduce fish loss at intake structures (EPRI 1981).

To minimize fish losses at the San Onofre Nuclear Generating Station (SONGS), Southern California Edison (SCE) has incorporated a fish return system (FRS) into the Units 2 and 3 cooling water system (Downs and Meddock 1974). In this system, fish may either be impinged on travelling screens or diverted into the fish return system. The system was, and remains, unique (Lawler et al. 1982a, EPRI 1984), and SCE contracted with the VANTUNA Research Group of Occidental College to determine its efficiency during 1984 and 1985. This report describes the results of that study. The objectives of this study were 1) to examine the efficiency of fish diversion within the SONGS return system, and 2) to test the survivorship of the diverted fish.

## Description of SONGS Units 2 and 3

SONGS is located on the California coast, at 33°22'N and 117°33.5'W, between San Clemente and Oceanside (Fig. 1). SONGS Units 2 and 3 are 1,100 MW facilities. Unit 2 became commercially operational in August 1983, Unit 3 in April 1984. Each unit has a once-through cooling system, with flow rates of 3,137 m³/min (830,000 gpm). The intakes are located 970.2 m offshore, at a depth of 9.8 m (Fig. 1). Both units have diffuser-type discharges, consisting of 63 ports spread over a distance of 750 m. The Unit 2 diffuser begins 1,795 m offshore extending to 2,545 m, at depths of 11.9-14.9 m. The Unit 3 diffuser begins 1,084 m offshore and extends to 1,830 m, at depths from 9.8 to 11.6 m (Yuge and Herbinson 1985).
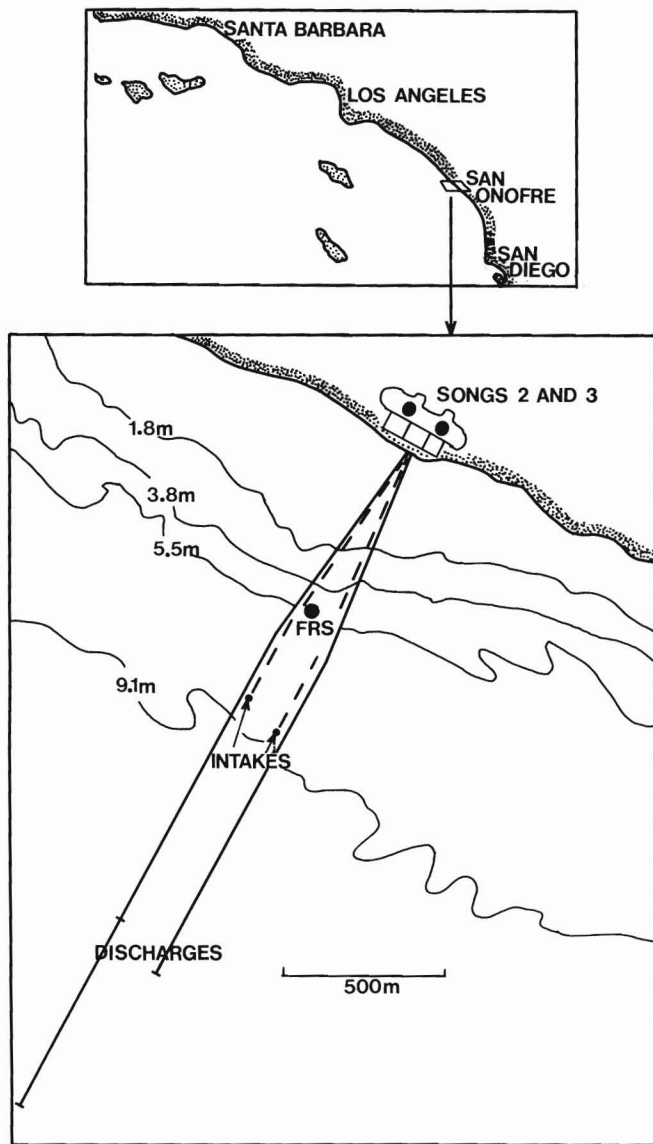
**Figure 1**
Location of the San Onofre Nuclear Generating Station (SONGS) and its fish return system.

## Description of the fish return system (FRS)

The FRS (Figs. 2,3) relies on behavioral responses of fish to varying water velocities and pressures. Fish within the cooling water encounter concrete vanes and angled plastic louvers situated in front of the traveling screens. These are angled toward a bypass area and create a pressure differential detected by the fish, which swim along the louvers (Downs and Meddock 1974, Schuler and Larson 1975). The bypass area, a quiet-water concrete-lined basin, measures $4.9 \times 4$ m. A watertight elevator basket, open at the top, sits within this basin. When activated, the elevator ascends, collecting most of the fish in the basin. Upon reaching its maximum height, the elevator tips, spilling the fish into a sluice channel. This procedure is repeated several times until most fish are removed. Simultaneously, additional water

flushes into the channel and the fishes are discharged into a pipe which empties in 6 m of water, about 400 m offshore.

## Methods and materials _____

### Diversion efficiency

Twice-weekly impingement and elevator samples were taken at Units 2 and 3 to establish the diversion efficiency of the FRS. We attempted two 24-hr samples on consecutive days during the week (though this was not always possible during periods of variable plant operation). Twenty-four hrs before sampling, the screens were cleaned of impinged fishes and the FRS was run to remove all entrapped fishes. Diversion efficiency was calculated for fish from samples that conformed to the following criteria: 1) The sample was drawn from a 22-26 hr impingement or elevator sample; 2) impingement and elevator samples were taken on the same day; and 3) all four circulating pumps were operating at the sampled unit. A total of 55 samples at Unit 2 and 65 samples at Unit 3 conformed to these criteria in 1984 and 1985. Of these samples, 35 impingement and elevator samples were taken on the same day. Fish from these samples were evaluated for diversion efficiency by species and size.

On each sample day, the traveling screens were run to wash any impinged fish into the impingement basket. At the same time, the contents of the elevator basket were dumped into the return sluiceway. Using two 15-inch diameter nets, two aliquot samples (sampling about one-tenth of all fish) were taken as fish were poured from the basket. This procedure was repeated until fish were no longer collected in the basket (three to four repetitions). Fish collected from the elevator samples and the impingement basket were identified, counted, measured, and weighed according to criteria previously described (DeMartini et al. 1984).

Return efficiency was computed for all fishes that went through the fish return system. Of the fish returned, two species, the northern anchovy (*Engraulis mordax*) and queenfish (*Seriphus politus*), accounted for a large percentage of all individuals. Detailed analyses were conducted for the most abundant fish—*E. mordax*, *S. politus*, white croaker (*Genyonemus lineatus*), walleye surfperch (*Hyperprosopon argenteum*, and white surfperch (*Phanerodon furcatus*). Other species were not analyzed due to the lack of sufficient measurement data. An attempt to group all other species into one category was abandoned because of the wide range of behavior of the remaining species.

During a sample period, thousands of fish go through the fish return system of which only a small proportion get impinged. Out of the large numbers of fish collected during each sample, approximately 200-400 fish were randomly sampled and measured for size from the fish return system. Similarly, 200-400 fish were measured for the impinged samples. The latter, however, represented almost all of the fish in the sample. In order to get a representation of the number of fish in each size-class that were diverted throughout the system or impinged on the screens, we computed

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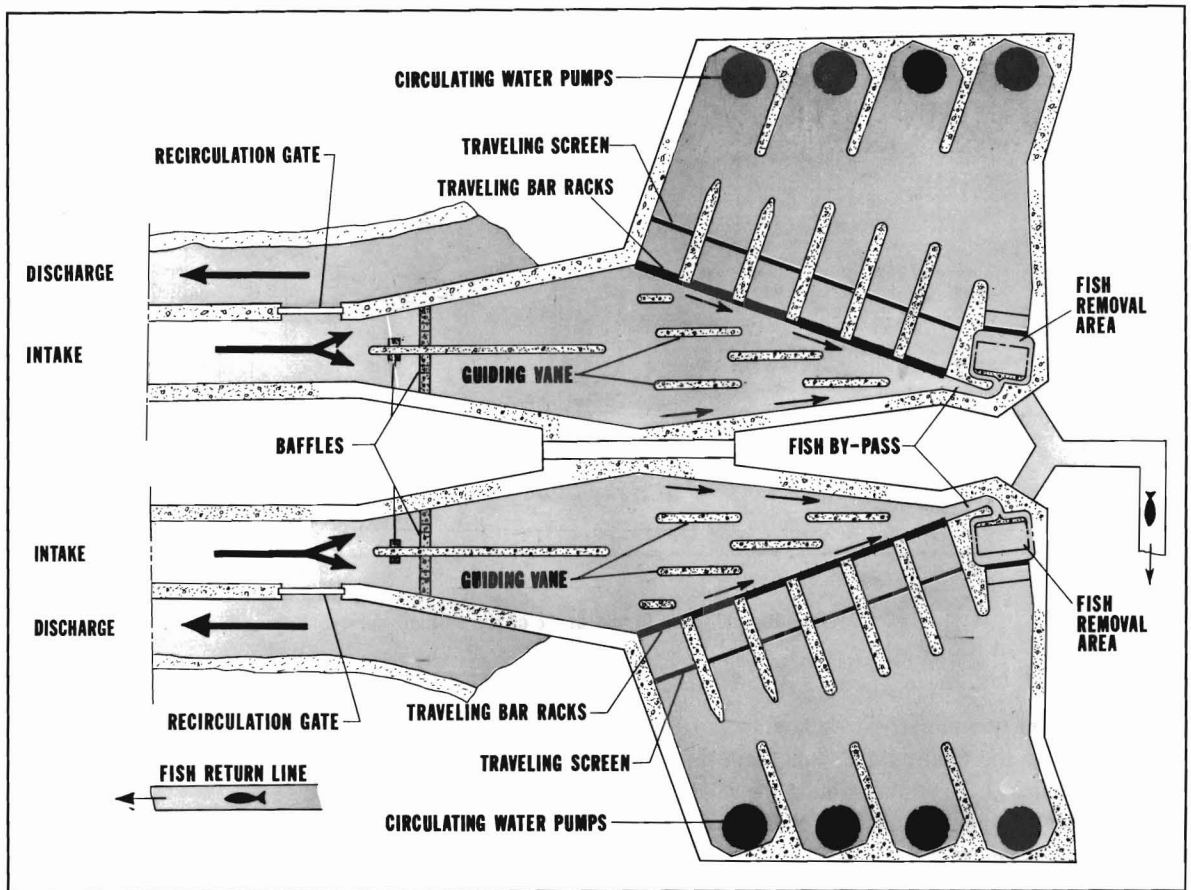
**Figure 2**
Fish return system of San Onofre Units 2 and 3, from intake through fish removal area.
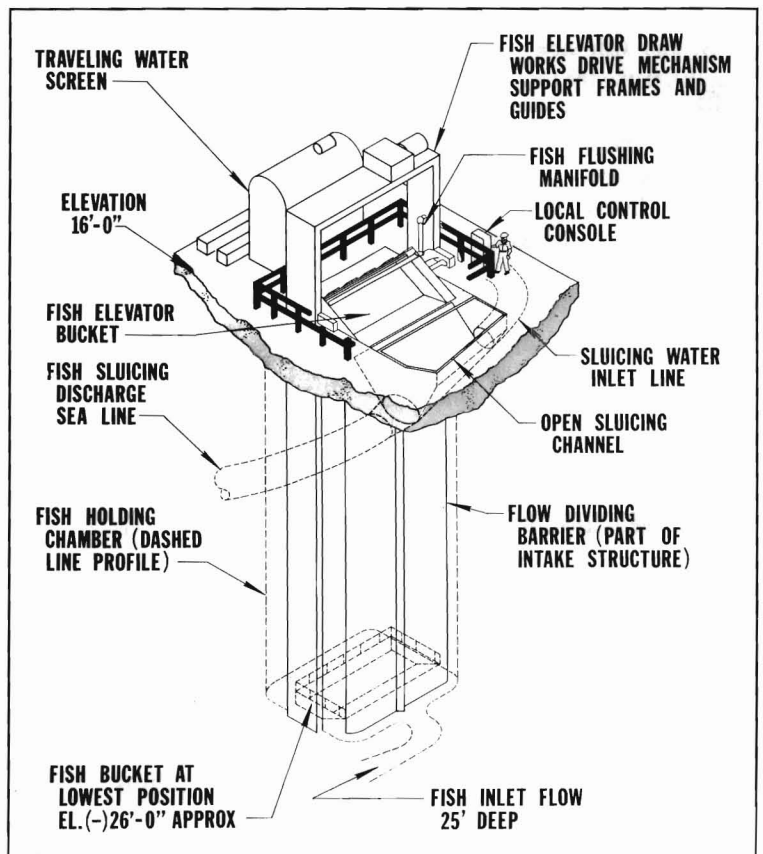


**Figure 3**
Removal elevator and sluicing channel of fish return system, San Onofre Units 2 and 3.
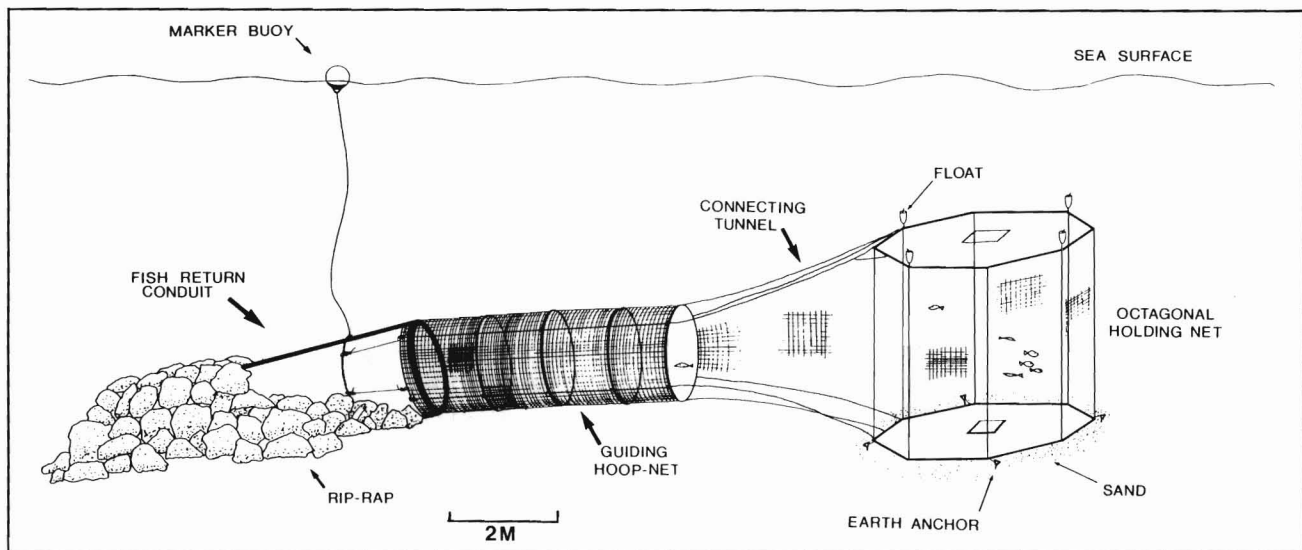
**Figure 4**
Holding net used in test phase of the 96-hour survivorship studies.

the proportion within each size-class and extrapolated the proportions to the total number that went through the fish return system. These adjusted data are what were used in the analyses. The actual number of fish measured in each 10-mm size-class by year is presented in Appendix A.

Our analyses tested the null hypothesis that the return efficiency did not vary under different conditions or by fish size. The conditions tested were year (1984, 1985) and units (Units 2,3). We tested the return efficiency between years, sites, and fish size-class (<100 mm, >100 mm standard length), using the three-way analysis of variance. (Note that return efficiency figures in Figures 6-10 are plotted in 10-mm size-class increments. We feel that this is more explicative than showing only two size-classes.) The ANOVA design was unbalanced since species may not necessarily be impinged and/or returned at each sampling time or in each size-class. Multiple comparisions were also performed using the Bonferroni test (Bailey 1977). Natural log (1% return) transformation (referred to as "transformed return efficiency" throughout the text) was utilized to remove the skewness of the data and heterogeneity of variance. The variable (1% return) was used to change the negatively skewed distribution to a positively skewed distribution which closely approximated the log normal distribution. Although other transformations were tried, it was found that the above transformation was the best in upholding the homogeneity of variance assumption necessary for the analysis of variance.

Due to the natural sequential order of time in the data, autocorrelation may be present which would violate the assumption of sample independence. The data were checked for autocorrelation by using sinusoidal curve fit where the transformed return efficiency was regressed against time for the five species by size-class. The sinusoidal curve fit was used, since the samples were irregularly spaced in time (Lorda and Saila 1986).

Plots of percent return efficiency were done by size-class, site, and year to examine the results from the analysis of variance.

## Survivorship

**Test experiments** We evaluated the survival rates of fish transported through the FRS by conducting *in situ* 96-hr survivorship tests at the terminus of the fish return conduit. Ninety-six hours is a standard assay period and represented the longest experimental time-sequence in which we felt animals could be maintained in holding nets without experimental bias. The experiments were on 24-hr samples of entrapped fish discharged offshore from the return conduit into a 3.5 m² holding net (Fig. 4). All survivorship results were obtained with a biologist coordinating the operation of the FRS in-plant. All phases of the operational procedure—running the sluicing water, lifting the elevator basket, and flushing the conduit—were done to minimize the trauma incurred by the returned fish.

Before connecting the net, we flushed the return conduit of any resident fish by running the conduit flushing water for 15 minutes. At the start of an experiment, an in-plant biologist coordinated the dumping of the fish elevator to coincide with offshore biologists connecting the holding net to the return conduit. After dumping the elevator contents, we flushed the conduit for an additional 15 min to insure that all fish were discharged into the net. At this point, the net was disconnected from the conduit and moved approximately 10 m either up or downcoast and secured to the bottom. Divers then assessed the number, condition, and species-composition of fish within the net and removed any dead individuals. Fish condition and behavior were assessed once every 24 hrs until the end of the test period, at which time all surviving fish were identified, counted, measured, and

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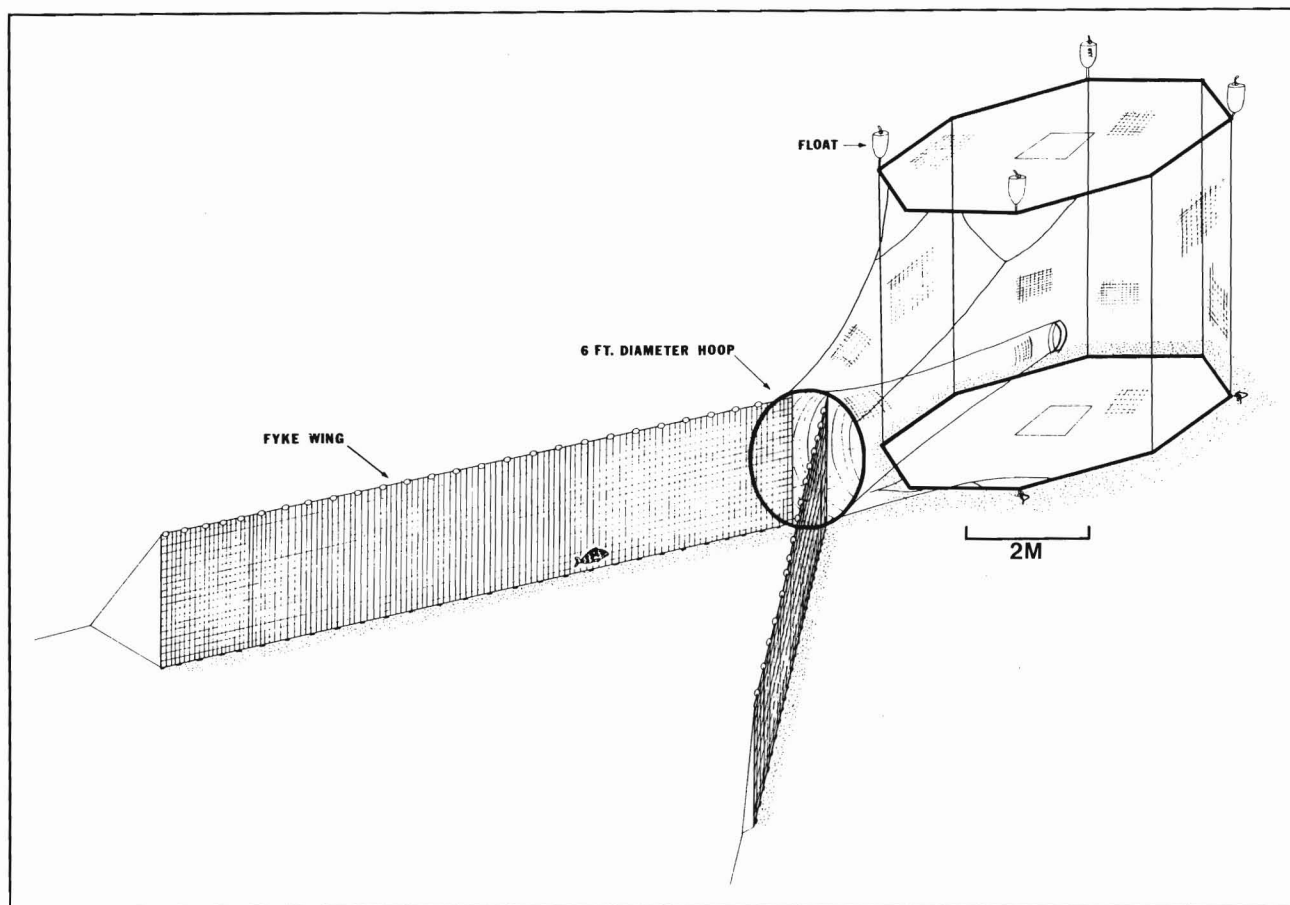
**Figure 5**
Holding net used in the 96-hour reference studies.

inspected for lesions and abrasions derived from the flushing process. Predation within the net was minimized by removing piscivorous species, such as the kelp bass (*Paralabrax clathratus*).

**Reference experiments**  To evaluate stress caused by containment within the nets, free-swimming fish were captured and held within the holding nets for 96-hr reference experiments. The reference specimens were captured by fishing the holding net with fyke wings (Fig. 5), thereby allowing fish to enter the net without the stress associated with being discharged through the return conduit. The reference tests were designed to determine holding-net effects on survivorship.

The reference nets were set with fyke wings offshore of San Onofre in the vicinity of the fish return conduit. After allowing a net to fish for 24 hrs, we disconnected the wings and sealed the net if sufficient numbers of fish were captured. We set the net one day prior to the start of the test. This method allowed the start of both experiments to coincide. As with the test nets, the reference nets were inspected every 24 hrs, and at the end of the 96-hr holding period all fish were collected and the appropriate data recorded.

We tested the null hypothesis that there was no difference in fish survivorship between site, years, and fish length. Comparisons were made between reference and return survivorship. Due to limited numbers of fish sampled, *E. mordax*, *G. lineatus*, and *S. politus* could be used in the analyses. Plots presenting the conditional probability of survival by each day and size (over the 96 hr-period) suggested grouping survivability by day-1 (24 hrs) and day 2-4 (>24 hrs). The percent survivorship was tested between years (1984, 1985), sites (reference, Unit 2, Unit 3), and size-class (<100 mm, >100 mm), using a three-way analysis of variance weighted by fish number.

Impingement and return data for 1984 and 1985 were obtained from Southern California Edison's database. Statistical Analysis System (SAS) was used to perform all statistical analyses, particularly the procedures REG, GLM, SURV-TEST, and LIFETEST (SAS 1983, 1985).

**Table 1**
Return efficiency of the fish return system at San Onofre Nuclear Generating Station, 1984. Fishes listed in order of abundance. Returns based on extrapolations from aliquot samplings.

| Species | Total no. taken in | No. impinged | No. returned | % returned | Species | Total no. taken in | No. impinged | No. returned | % returned |
|---|---|---|---|---|---|---|---|---|---|
| *Engraulis mordax* | 135,688 | 1,012 | 134,676 | 99.3 | *Scomber japonicus* | 16 | 4 | 12 | 75.0 |
| *Seriphus politus* | 50,566 | 6,197 | 44,369 | 87.7 | *Girella nigricans* | 13 | 0 | 13 | 100.0 |
| *Anchoa delicatissima* | 3,693 | 635 | 3,058 | 82.8 | *Syngnathus* sp. | 13 | 13 | 0 | 0 |
| *Atherinopsis californiensis* | 1,445 | 11 | 1,434 | 99.2 | *Trachurus symmetricus* | 13 | 2 | 11 | 84.6 |
| *Anchoa compressa* | 889 | 181 | 708 | 79.6 | *Rhinobatos productus* | 12 | 0 | 12 | 100.0 |
| *Xenistius californiensis* | 831 | 20 | 811 | 97.6 | *Mustelus henlei* | 10 | 0 | 10 | 100.0 |
| *Genyonemus lineatus* | 644 | 43 | 601 | 93.3 | *Platyrhinoidis triseriata* | 9 | 3 | 6 | 66.7 |
| *Atherinops affinis* | 601 | 11 | 590 | 98.2 | *Torpedo californica* | 9 | 2 | 7 | 77.8 |
| *Hermosilla azurea* | 436 | 0 | 436 | 100.0 | *Cymatogaster aggregata* | 8 | 3 | 5 | 62.5 |
| *Paralabrax clathratus* | 270 | 1 | 269 | 99.6 | *Hypsoblennius* spp. | 8 | 8 | 0 | 0 |
| *Peprilus simillimus* | 263 | 33 | 230 | 87.5 | *Pleuronichthys ritteri* | 8 | 4 | 4 | 50.0 |
| *Umbrina roncador* | 258 | 0 | 258 | 100.0 | *Damalichthys vacca* | 6 | 0 | 6 | 100.0 |
| *Hyperprosopon argenteum* | 227 | 6 | 221 | 97.4 | *Hypsypops rubicundus* | 6 | 0 | 6 | 100.0 |
| *Anisotremus davidsonii* | 211 | 1 | 210 | 99.5 | *Citharichthys stigmaeus* | 5 | 0 | 5 | 100.0 |
| *Porichthys notatus* | 111 | 108 | 3 | 2.7 | *Scorpaena guttata* | 5 | 3 | 2 | 40.0 |
| *Menticirrhus undulatus* | 108 | 1 | 107 | 99.1 | *Sebastes paucispinis* | 5 | 1 | 4 | 80.0 |
| *Paralabrax nebulifer* | 89 | 3 | 86 | 96.6 | *Halichoeres semicinctus* | 3 | 0 | 3 | 100.0 |
| *Phanerodon furcatus* | 80 | 21 | 59 | 73.7 | *Heterodontus francisci* | 3 | 0 | 3 | 100.0 |
| *Sardinops sagax* | 75 | 14 | 61 | 81.3 | *Mustelus californicus* | 3 | 1 | 2 | 66.7 |
| *Chromis punctipinnis* | 45 | 0 | 45 | 100.0 | *Gymnura marmorata* | 2 | 0 | 2 | 100.0 |
| *Paralichthys californicus* | 45 | 3 | 42 | 93.3 | *Gibbonsia metzi* | 1 | 1 | 0 | 0 |
| *Urolophus halleri* | 41 | 5 | 36 | 87.8 | *Gibbonsia* sp. | 1 | 1 | 0 | 0 |
| *Cheilotrema saturnum* | 38 | 0 | 38 | 100.0 | *Hypsoblennius gilberti* | 1 | 1 | 0 | 0 |
| *Roncador stearnsii* | 36 | 1 | 35 | 97.2 | *Medialuna californiensis* | 1 | 0 | 1 | 100.0 |
| *Leuresthes tenuis* | 35 | 10 | 25 | 71.4 | *Otophidium scrippsi* | 1 | 0 | 1 | 100.0 |
| *Atractoscion nobilis* | 25 | 0 | 25 | 100.0 | *Pleuronichthys verticalis* | 1 | 1 | 0 | 0 |
| *Embiotoca jacksoni* | 24 | 1 | 23 | 95.8 | *Porichthys myriaster* | 1 | 1 | 0 | 0 |
| *Heterostichus rostratus* | 20 | 18 | 2 | 10.0 | *Squatina californica* | 1 | 0 | 1 | 100.0 |
| *Sphyraena argentea* | 19 | 10 | 9 | 47.4 | Total | 196,978 | 8,395 | 188,583 | 95.7 |

## Results

### Diversion Efficiency

With some exceptions, fishes were diverted with high frequency into the FRS (Tables 1,2). This was particularly true in 1984, when 13 of the 15 most abundant species were diverted with 80% or better efficiency, 10 species exceeding 90%. The most abundant species, northern anchovy (*E. mordax*) and queenfish (*S. politus*), were diverted with 99.3% and 87.7% efficiency, respectively. The system worked particularly well for strong-swimming forms (i.e., jacksmelt, *Atherinopsis californiensis*; salema, *Xenistius californiensis*; topsmelt, *Atherinops affinis*; and kelp bass, *Paralabrax clathratus*). A high percentage of important sport and commercial fishes (*P. clathratus*; yellowfin croaker, *Umbrina roncador*; California corbina, *Menticirrhus undulatus*; California halibut, *Paralichthys californicus*) were also diverted with high frequency. The system did not appreciably divert weak-swimming species (such as plainfin midshipmen, *Porichthys notatus*; pipefish, *Syngnathus* spp.; giant kelpfish, *Heterostichus rostratus*).

Return rates of some species were not as high in 1985 as in the previous year (Tables 1,2). Nine of the 15 most abundant species were diverted 80% of the time or better. While *E. mordax* was diverted at about the same frequency between years (99.3 in 1984 vs. 94.3 in 1985), efficiencies for *S. politus* (87.7 vs. 73.7%), white croaker, *Genyonemus lineatus* (93.3 vs. 38.5%), deepbody anchovy, *Anchoa compressa* (79.6 vs. 49.4%), and slough anchovy, *Anchoa delicatissima* (82.8 vs. 4.5%) were considerably lower. With these exceptions, between-year return efficiency was similar.

No seasonal pattern was found in return efficiency based on an examination of the overall temporal pattern for seasonality by checking for significant autocorrelation. The three-way analysis of variance, with transformed return efficiency as the dependent variable and site, year, and size as the main effects, was then performed for the five species. We first analyzed samples collected on the same day between SONGS Unit 2 and 3. Using this matched data, it was found that *E. mordax* showed significant differences between year ($p < 0.05$), *S. politus* showed significant differences between size ($p < 0.001$) and year ($p < 0.001$), while the other three species analyzed showed no differences for any of the factors in the ANOVA.

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**Table 2**
Return efficiency of the fish return system at San Onofre Nuclear Generating Station, 1985, based on operation criteria of 22-26 hours and four circulating pumps. Fishes listed in order of abundance. Returns based on extrapolations from aliquot sampling.

| Species | Total no. taken in | No. impinged | No. returned | % returned | Species | Total no. taken in | No. impinged | No. returned | % returned |
|---|---|---|---|---|---|---|---|---|---|
| *Engraulis mordax* | 210,108 | 11,951 | 198,157 | 94.3 | *Torpedo californica* | 25 | 21 | 4 | 16.0 |
| *Seriphus politus* | 104,394 | 27,431 | 76,963 | 73.7 | *Myliobatis californica* | 21 | 1 | 20 | 95.2 |
| *Genyonemus lineatus* | 52,938 | 32,548 | 20,390 | 38.5 | *Scorpaena guttata* | 19 | 10 | 9 | 47.4 |
| *Anchoa delicatissima* | 27,514 | 26,284 | 1,230 | 4.5 | *Cheilotrema saturnum* | 17 | 0 | 17 | 100.0 |
| *Anchoa compressa* | 3,809 | 1,926 | 1,883 | 49.4 | *Sebastes paucispinis* | 16 | 11 | 5 | 31.3 |
| *Umbrina roncador* | 2,026 | 5 | 2,021 | 99.8 | *Mustelus californicus* | 13 | 4 | 9 | 69.2 |
| *Xenistius californiensis* | 1,885 | 61 | 1,824 | 96.8 | *Damalichthys vacca* | 12 | 1 | 11 | 91.7 |
| *Hyperprosopon argenteum* | 978 | 58 | 920 | 94.1 | *Etrumeus teres* | 12 | 1 | 11 | 91.7 |
| *Phanerodon furcatus* | 819 | 280 | 539 | 65.8 | *Medialuna californiensis* | 12 | 0 | 12 | 100.0 |
| *Peprilus simillimus* | 488 | 88 | 400 | 82.0 | *Citharichthys stigmaeus* | 7 | 7 | 0 | 0 |
| *Anisotremus davidsonii* | 284 | 2 | 282 | 99.3 | *Gymnura marmorata* | 7 | 3 | 4 | 57.1 |
| *Porichthys notatus* | 250 | 241 | 9 | 3.6 | *Hypsoblennius* spp. | 7 | 7 | 0 | 0 |
| *Menticirrhus undulatus* | 178 | 2 | 176 | 98.9 | *Halichoeres semicinctus* | 5 | 1 | 4 | 80.0 |
| *Atherinopsis californiensis* | 177 | 14 | 163 | 92.1 | *Hypsopsetta guttulata* | 5 | 0 | 5 | 100.0 |
| *Paralabrax clathratus* | 165 | 4 | 161 | 97.6 | *Mustelus henlei* | 5 | 3 | 2 | 40.0 |
| *Hermosilla azurea* | 158 | 0 | 158 | 100.0 | *Scorpaenichthys marmoratus* | 5 | 3 | 2 | 40.0 |
| *Cymatogaster aggregata* | 145 | 90 | 55 | 37.9 | *Triakis semifasciata* | 4 | 1 | 3 | 75.0 |
| *Heterostichus rostratus* | 141 | 105 | 36 | 25.5 | *Gibbonsia* sp. | 3 | 3 | 0 | 0 |
| *Atractoscion nobilis* | 138 | 18 | 120 | 87.0 | *Girella nigricans* | 3 | 0 | 3 | 100.0 |
| *Syngnathus species* | 116 | 116 | 0 | 0 | *Heterodontus franscisci* | 3 | 1 | 2 | 66.7 |
| *Scomber japonicus* | 98 | 13 | 85 | 86.7 | *Leptocottus armatus* | 3 | 3 | 0 | 0 |
| *Paralichthys californicus* | 83 | 9 | 74 | 89.2 | *Rhacochilus toxotes* | 3 | 0 | 3 | 100.0 |
| *Urolophus halleri* | 74 | 4 | 70 | 94.6 | *Oxyjulis californica* | 2 | 1 | 1 | 50.0 |
| *Porichthys myriaster* | 69 | 61 | 8 | 11.6 | *Sebastes serriceps* | 2 | 2 | 0 | 0 |
| *Atherinops affinis* | 57 | 11 | 46 | 80.7 | *Synodus lucioceps* | 2 | 2 | 0 | 0 |
| *Sphyraena argentea* | 54 | 33 | 21 | 38.9 | *Amphistichus argenteus* | 1 | 1 | 0 | 0 |
| *Paralabrax nebulifer* | 50 | 3 | 47 | 94.0 | *Clupea harengus pallasii* | 1 | 0 | 1 | 100.0 |
| *Trachurus symmetricus* | 46 | 3 | 43 | 93.5 | *Gibbonsia elegans* | 1 | 1 | 0 | 0 |
| *Roncador stearnsii* | 42 | 2 | 40 | 95.2 | *Hypsypops rubicundus* | 1 | 0 | 1 | 100.0 |
| *Rhinobatos productus* | 39 | 1 | 38 | 97.4 | *Microstomus pacificus* | 1 | 1 | 0 | 0 |
| *Pleuronichthys ritteri* | 33 | 13 | 20 | 60.6 | *Paralabrax maculatofasciatus* | 1 | 0 | 1 | 100.0 |
| *Embiotoca jacksoni* | 32 | 4 | 28 | 87.5 | *Pleuronichthys verticalis* | 1 | 0 | 1 | 100.0 |
| *Xystreurys liolepis* | 32 | 18 | 14 | 43.8 | *Sarda chiliensis* | 1 | 0 | 1 | 100.0 |
| *Platyrhinoidis triseriata* | 30 | 20 | 10 | 33.3 | *Sebastes auriculatus* | 1 | 1 | 0 | 0 |
| *Chromis punctipinnis* | 27 | 1 | 26 | 96.3 | *Squalus acanthias* | 1 | 1 | 0 | 0 |
| *Leuresthes tenuis* | 27 | 19 | 8 | 29.6 | *Symphus atricauda* | 1 | 1 | 0 | 0 |
| *Otophidium scrippsi* | 27 | 24 | 3 | 11.1 | Total | 407,755 | 101,555 | 306,200 | 75.1 |

As no differences were found for any of the species in transformed return efficiency between the two units, analyses were performed using all sampling dates for the two units for the period 1984-85 in order to increase the sample size (detailed computations are presented in Appendix B). Analyses with all dates included showed significant differences for size and year for *E. mordax* (Fig. 6), where fish <100 mm were returned more efficiently than those greater ≥100 mm, and the 1984 return efficiency was better than 1985 (Bonferroni test). Similarly, for *S. politus* the analyses revealed significant differences for size ($p < 0.001$). From the Bonferroni test and Figure 10, it is clear that the return efficiency in 1984 was consistently greater than 1985. In addition, return efficiency was better for fishes ≥100 mm

than for those <100 mm. For the other three species, *G. lineatus*, *H. argenteum*, and *P. furcatus* (Figs. 7-9), we again note that none of the factors showed significant differences. However, in examining their means it was seen that 1984 was consistently higher in return efficiency than 1985 and that lengths >100 mm was greater than <100 mm for all three species. It might be argued that the relatively few fish sampled over 100 mm would weaken the analysis of variance, but since no interactions were found in the ANOVA, this does not appear to be a problem.
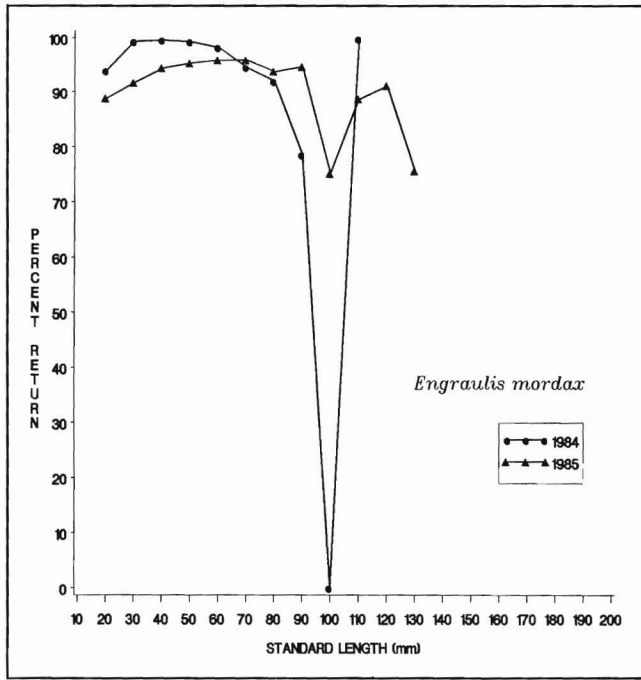
**Figure 6**
Return efficiency (%) by length of northern anchovy, *Engraulis mordax*, at San Onofre Units 2 and 3.
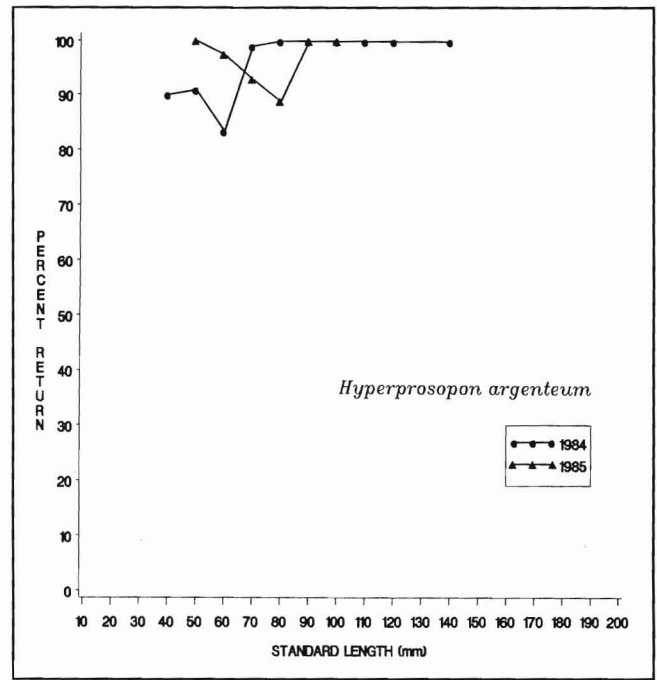


**Figure 8**
Return efficiency (%) by length of walleye surfperch, *Hyperprosopon argenteum*, at San Onofre Units 2 and 3.
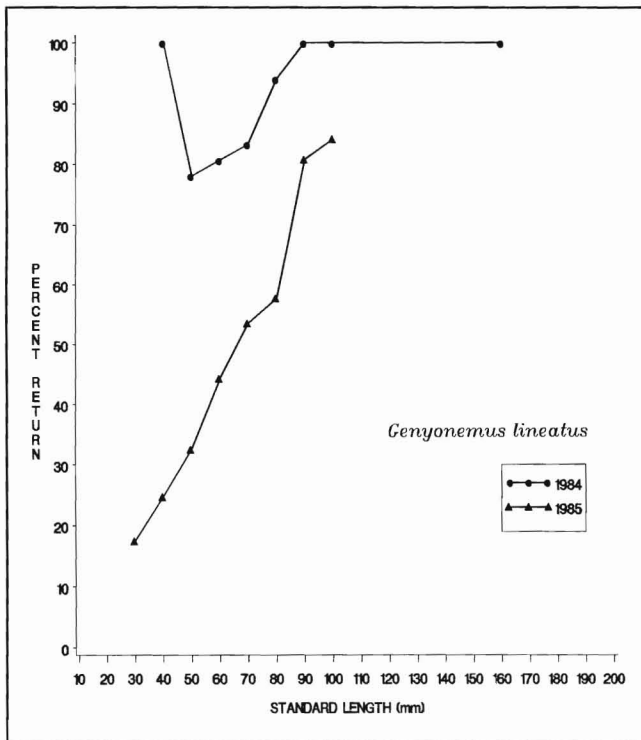


**Figure 7**
Return efficiency (%) by length of white croaker, *Genyonemus lineatus*, at San Onofre Units 2 and 3.
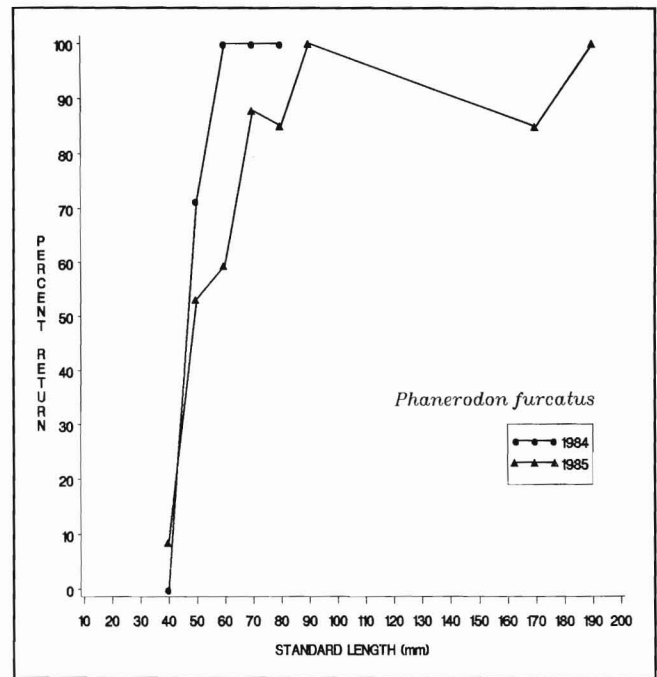


**Figure 9**
Return efficiency (%) by length of white surfperch, *Phanerodon furcatus*, at San Onofre Units 2 and 3.
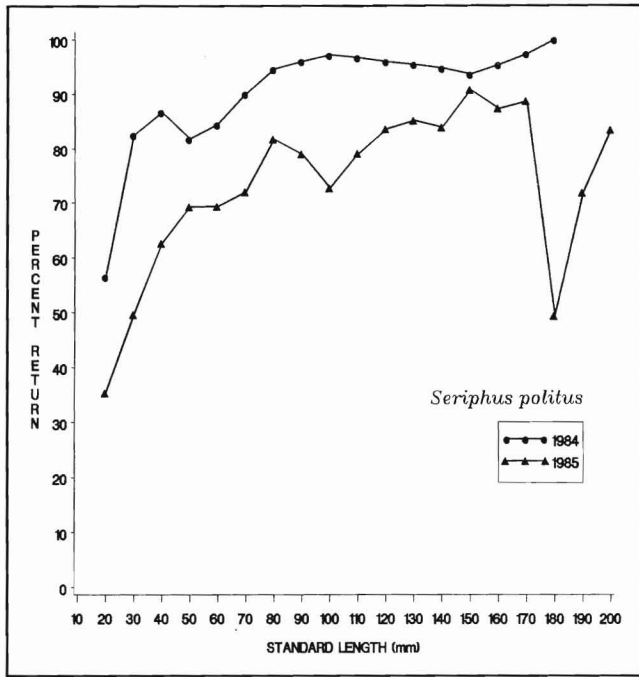
**Figure 10**
Return efficiency (%) by length of queenfish, *Seriphus politus*, at San Onofre Units 2 and 3.

## Survivorship

The results of the 96-hr survivorship studies are presented in Table 3. Individuals of most species survived both transit through the fish return system and 96 hrs in the holding net. There was little or no mortality for such species as *E. mordax*, *U. roncador*, and *X. californiensis*. No *Anchoa delicatissima* survived. With the exception of *E. mordax* and *S. politus*, all fishes survived in the reference net.

We examined most closely the survivorship of *E. mordax*, *S. politus*, and *G. lineatus*, three of the species given special attention in the return efficiency section. Survivorship of these three species, by length (10-mm increments) is shown in Figures 11-13. Figure 11 indicates that *E. mordax* small individuals (<60 mm) survived most frequently at both units. Mortality increased rapidly after 60 mm. Survivorship among *S. politus* exhibited a more complicated pattern (Fig. 12). Survivorship was poor among smaller fishes (<70 mm) traveling through Unit 2, and highest in 70-120 mm individuals. In contrast, smallest *S. politus* survived Unit 3 best and mortality increased with fish length. However, the ANOVA results indicate that this pattern probably only applies to day-1 survivorship. For *G. lineatus*, small individuals (≥70 mm) increased in survivorship with length at the two units (Fig. 13).

**Table 3**
Percent survivorship of species in 96-hour holding experiments, 1984-85. Numbers of individuals used in experiments are in parentheses.

| | Experimental | | | | | Reference | |
|---|---|---|---|---|---|---|---|
| | Unit 2 | | Unit 3 | | | | |
| Species | $n = 6$ | | $n = 8$ | | | $n = 7$ | |
| *Anchoa compressa* | 50.0 | (2) | | | | | |
| *Anchoa delicatissima* | 0.0 | (95) | | | | | |
| *Anisotremus davidsonii* | 100.0 | (2) | | | | 100.0 | (3) |
| *Atherinopsis californiensis* | 100.0 | (2) | | | | | |
| *Atractoscion nobilis* | 100.0 | (1) | 100.0 | (1) | | | |
| *Chromis punctipinnis* | 100.0 | (1) | 100.0 | (1) | | | |
| *Cymatogaster aggregata* | 100.0 | (1) | | | | 100.0 | (4) |
| *Damalichthys vacca* | | | 100.0 | (4) | | | |
| *Engraulis mordax* | 94.3 | (930) | 97.9 | (4630) | | 14.8 | (108) |
| *Genyonemus lineatus* | 49.5 | (95) | 25.0 | (40) | | 100.0 | (10) |
| *Hermosilla azurea* | 100.0 | (3) | | | | | |
| *Heterostichus rostratus* | 100.0 | (1) | 100.0 | (1) | | | |
| *Hyperprosopon argenteum* | 100.0 | (19) | 100.0 | (12) | | 100.0 | (1) |
| *Medialuna californiensis* | 100.0 | (1) | | | | | |
| *Menticirrhus undulatus* | | | 100.0 | (1) | | 100.0 | (2) |
| *Paralabrax clathratus* | 100.0 | (1) | | | | 100.0 | (3) |
| *Paralabrax nebulifer* | 100.0 | (1) | | | | 100.0 | (4) |
| *Peprilus simillimus* | | | 100.0 | (1) | | | |
| *Phanerodon furcatus* | 100.0 | (5) | 94.7 | (19) | | 100.0 | (8) |
| *Sebastes paucispinis* | | | 100.0 | (1) | | | |
| *Seriphus politus* | 31.6 | (753) | 54.1 | (846) | | 78.8 | (170) |
| *Umbrina roncador* | 100.0 | (58) | 97.0 | (133) | | 100.0 | (15) |
| *Xenistius californiensis* | 100.0 | (21) | 100.0 | (38) | | | |
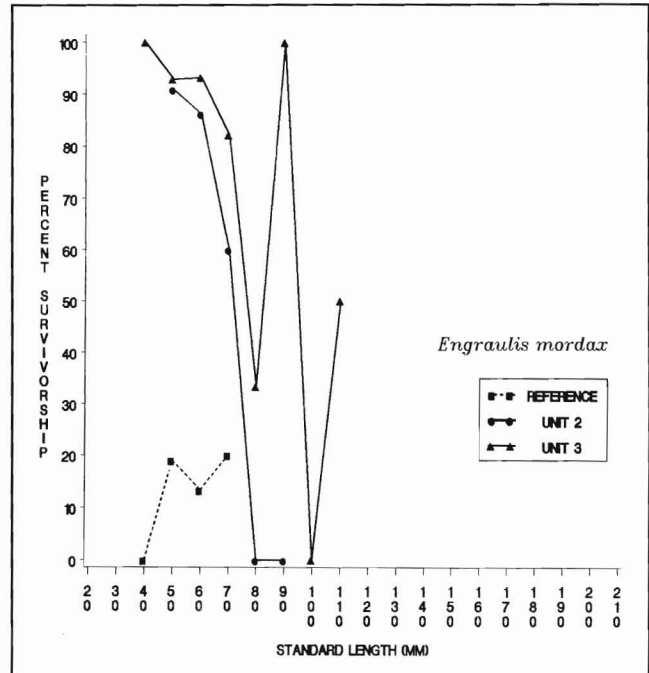


**Figure 11**
Percent survivorship by length of northern anchovy, *Engraulis mordax*, in the reference net and San Onofre Units 2 and 3.
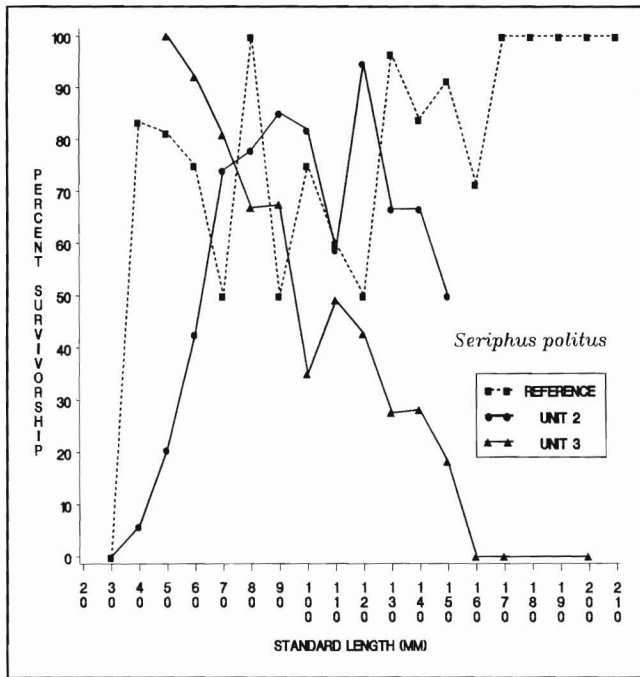
**Figure 12**
Percent survivorship by length of queenfish, *Seriphus politus*, in the reference net and San Onofre Units 2 and 3.
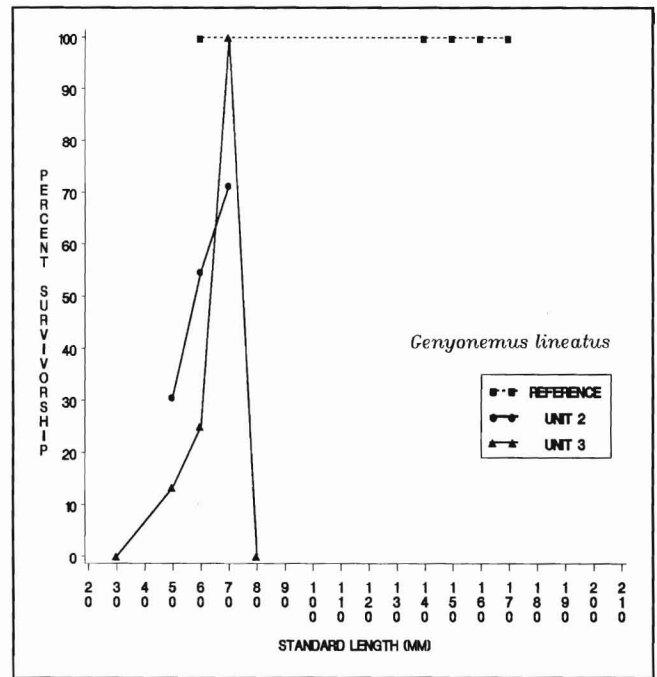


**Figure 13**
Percent survivorship by length of white croaker, *Genyonemus lineatus*, in the reference net and San Onofre Units 2 and 3.

Figure 14 presents the conditional probability of survival by reference experiments and Units 2 and 3 by size-class for the three species. Percent survivorship declined most precipitously by day-1, suggesting that survivorship through day-1 was most crucial. For this reason, analyses were conducted separating day-1 from days 2-4.

The three-way analysis of variance showed several statistically significant differences for *E. mordax* and *S. politus* and none for *G. lineatus* (Appendix C).

Site differences found in *E. mordax* for day-1 were due to the reference experiment being considerably lower in mean survivorship ($\bar{x} = 0.41$) than the two units (unit 2, $\bar{x} = 0.97$; unit 3, $\bar{x} = 0.94$). No differences for *E. mordax* were found for days 2-4 for any effects.

*Seriphus politus*, however, exhibited interaction between year and site for both day-1 and day 2-4 analyses when averaged over size. Examination of the day-1 mean percent survivorship showed that fishes in Unit 3 had better survivorship in 1984 than 1985. This was not the case at Unit 2. Here, in contrast, *S. politus* survivorship increased in 1985 (Appendix D). Thus, though there appears to be a between-site difference in *S. politus* survivorship, this Anova interaction makes it impossible to delineate whether the site differences were truly significant. Examination of days 2-4 mean percent survivorship showed that Unit 3 survivorship decreased relatively more than both reference and Unit 2 in 1985, causing significant interactions. A main-effect difference also existed for year. Main-effect differences for the year are due to 1984 survivorship percentage exceeding that of 1985.

Potentially, there may be several other variables that might explain differences seen in *S. politus* survivorship. The total biomass of fishes in the return sample was thus used as a covariate of percent survivorship that may eliminate the interaction seen. The three-way analysis of variance was therefore repeated, using biomass as a covariate for day-1 and days 2-4 survivorship for *S. politus* only. However, the results suggested that total biomass of fishes was an insignificant covariate for percent survivorship of *S. politus*.

## Discussion

Most species of fish entrapped by the Units 2 and 3 intakes were diverted efficiently by the SONGS fish return system. This was particularly true of such species as *Paralabrax clathratus*, *Xenistius californiensis*, *Umbrina roncador*, *Engraulis mordax*, and *Seriphus politus*. Very poor swimmers (i.e., *Syngnathus* spp. and *Heterostichus rostratus*) were not diverted well.

To a certain extent, these results were influenced by fish size. For instance, diversion, highest among small *E. mordax*, gradually declined with fish length. However, this pattern was the exception. In most species, larger individuals were diverted with highest frequency. In a similar study from a freshwater system, Lawler et al. (1982b) found that larger species and larger individuals within each species displayed the highest diversion efficiency. It is noteworthy that *E. mordax* did not follow this pattern, as the design of this system
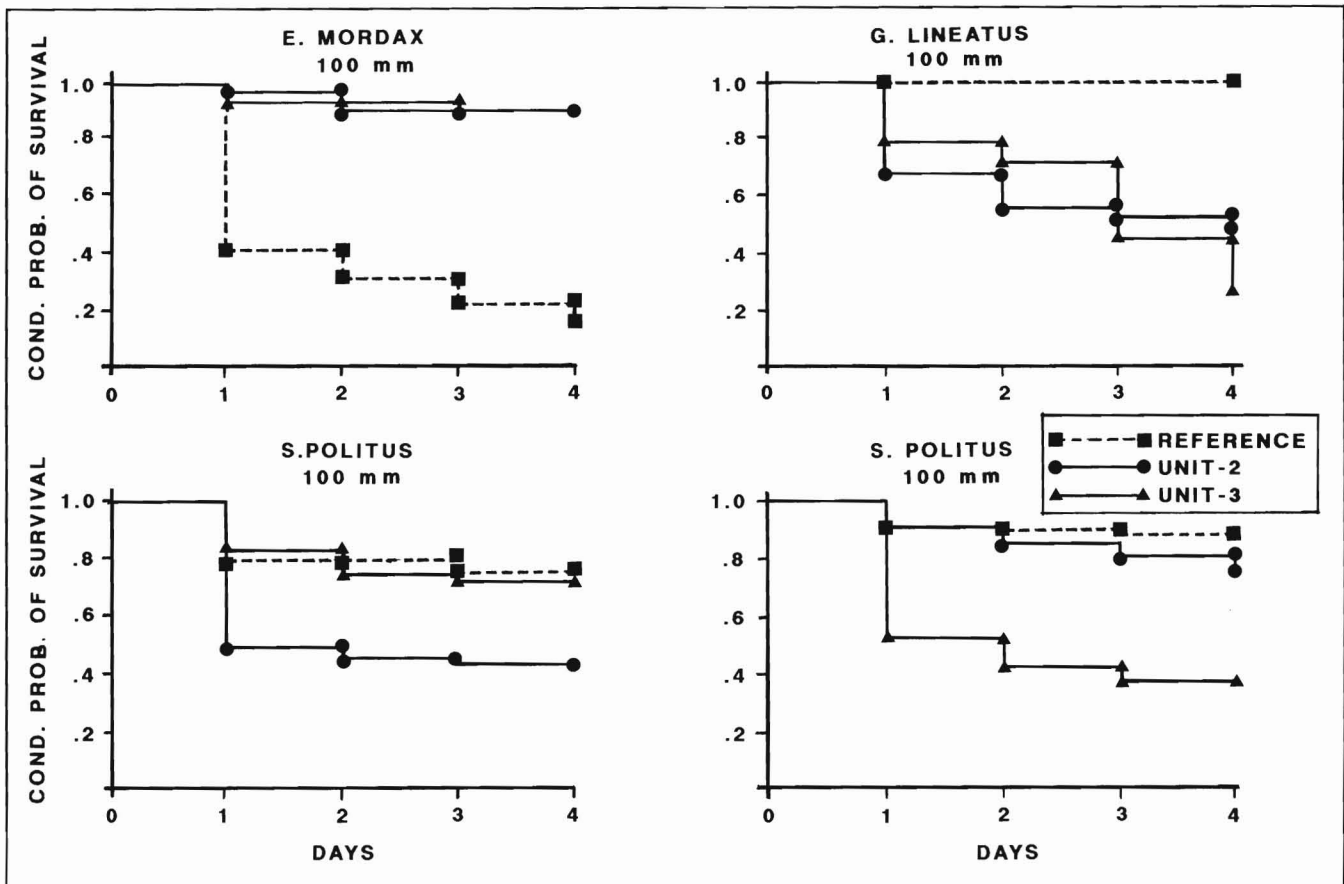
**Figure 14**
Conditional probability of survival of *Engraulis mordax*, *Seriphus politus*, and *Genyonemus lineatus* in the reference net and San Onofre Units 2 and 3 experiments.

(Schuler and Larson 1975) was derived from modeling studies using adult *E. mordax* as the principal species for fine-tuning the design of various system components.

The potential ability of fish in the smallest length-classes (<50 mm) to pass through the 9.5-mm mesh of the traveling screens and impingement baskets may confound our evaluation of diversion efficiency of larval and juvenile fishes. Frequently, large schools of larval and juvenile *E. mordax* appeared in fish return samples while being totally absent in the paired impingement samples. This absence may be attributed to the inability of the traveling screens to adequately filter the entrained water of fish of this size. Any fish of this size that was impinged would most likely be washed through the mesh of the impingement basket by the vigorous action of the sluicing water. We have observed this to occur at Unit 2, where larval anchovy are occasionally present in the water surrounding the impingement basket. Very small *E. mordax* appear especially susceptible because their small lateral surface area offers little "impingible" surface when compared with deeper-bodied fish of the same length, such as *S. politus*. Thus, the high diversion efficiency of small *E. mordax*, compared with *S. politus*, may have been due to the ability of small *E. mordax* to pass through the traveling screens and impingement baskets. This would bias our samples toward those small anchovies which were diverted and hence counted.

There was a lower rate of return for some species in 1985 compared with 1984. The phenomenon does not appear to be related to differences in fish sizes between years, as return rates for all size-classes of *S. politus* and nearly all of *E. mordax* were lower in 1985. As one examines the information for the two years, we see that the number of fish were higher in 1985, yet overall return efficiency was lower for 1985. There is a possibility that return efficiency may be negatively related to fish density. Examination of fish density patterns are beyond the scope of this paper although it is of interest biologically. Future studies might consider fish density when examining return efficiency.

Generally, fishes were not only diverted through the fish return system, but also survived the experience (based on our holding-net experiments). However, some species fared better than others. *Engraulis mordax*, *U. roncador*, and *X. californiensis* rarely died, while *Anchoa delicatissima* always did.

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Most fishes survived in the reference nets. However, high mortality occurred in *E. mordax* and *S. politus*. We believe, at least in the case of *E. mordax*, this was due to the species' apparent inability to school well in numbers less than about 40, a number we were unable to capture at any one time.

Our diver observations of captured fish in the reference nets indicate that small numbers of these two species frequently display difficulty in forming schools, show erratic swimming behavior, and appear to contact the net more often than individuals within large schools. Obligate schooling fishes, such as queenfish and anchovy, rely on visual cues to provide the attractive force between members of the school (Hemmings 1966, Partridge 1982), and within the school each member expends less energy than if swimming alone (Breder 1976). The small numbers of individuals in the reference nets may deter captured fish from forming cohesive schools. Any resultant increase in energy expenditure or collisions with the net would certainly have a deleterious influence on the survivorship of these relatively fragile species.

We noted some size-specific mortality, in *E. mordax*. Within this species mortality increased with size. Based on Figure 13, it would appear that there is a between-unit difference in size-specific *S. politus* mortality. However, based on our analysis of variance, this pattern was seen for day-1 but not for days 2-4.

We also noted differences in survivorship of *S. politus* between the two units in 1984 and 1985. For day-1 in 1984, survivorship was lower at Unit 2, but was lower in 1985 at Unit 3. This occurrence is not readily explainable, even when attempts were made to use total fish biomass as a covariate.

In some cases, variable survivorship of juveniles in the holding experiments may reflect the inability of some small individuals to orient to the discharge flow within the return conduit. Diver observations indicate that returned queenfish less than approximately 60 mm in length show a large variation in their ability to orient to the conduit flow. As they exit the discharge, most appear to "tumble" out of the conduit instead of slowly backing down with the flow, as larger individuals and members of other species have been observed to do. Tumbling within the return conduit would certainly increase the susceptibility of fish to abrasion and subsequent descaling and may subject them to fast, potentially damaging changes in hydrostatic pressure. Both of these effects have been demonstrated to cause mortalities in *S. politus* (Johnson 1981). In addition, we have observed that small queenfish often appear initially stunned or disoriented upon discharge from the conduit and are less able to school effectively within the holding net. These individuals frequently collide with the net walls and thereby may further increase their trauma.

Factors we cannot control or test for may also be important in determining the survival of fish discharged from the return system. Some of the fishes which survive passage through the plant are eaten by predators upon discharge from the return system. Small groups of barred sand bass (*Paralabrax nebulifer*) and kelp bass (*Paralabrax clathratus*) and solitary California halibut (*Paralichthys californicus*) congregate near the discharge, having apparently associated the conduit opening with food. However, it is the infrequent visits of schooling predators such as jack mackerel (*Trachurus symmetricus*), Pacific mackerel (*Scomber japonicus*), and large *S. politus* that appear to result in the highest predation pressure. We observed schools of these predators (as well as those of California barracuda, *Sphyraena argentea*) on 13 of 80 days of observations on the return system's discharge. Although we have observed this behavior only occasionally during the day, we do not know how often nocturnal or crepuscular predators frequent the fish discharge. Information such as this may be important in determining the time and frequency of running the fish return system to insure maximum survival of return fish.

We should also mention that survivorship in the net is "relative" survivorship. It is likely lower than true survivorship (excluding predation effects), due to such factors as the trauma to fish thrust into the holding net and restricted foraging of the individuals.

Although unexplained variations in efficiency of survivorship made the analysis of the effectiveness of the SONGS fish return system complex, we feel that these results strongly support the success of the SONGS fish return system. There is no doubt that this system is a considerable improvement in fish conservation over previously applied technologies.

## Acknowledgments

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## Appendix A
**Actual size-measurement data for five species impinged and entrained at Units 2 and 3, San Onofre Nuclear Generating Station.**

| Size (in 10-mm increments) | Engraulis mordax | Genyonemus lineatus | Hyperprosopon argenteum | Phanerodon furcatus | Seriphus politus |
|---|---|---|---|---|---|
| **1984** | | | | | |
| 10 | 1 | · | · | · | · |
| 20 | 30 | · | · | · | 42 |
| 30 | 1,053 | 1 | · | · | 526 |
| 40 | 1,511 | 6 | 3 | 9 | 1,921 |
| 50 | 1,211 | 15 | 3 | 15 | 2,204 |
| 60 | 582 | 18 | 3 | 4 | 1,719 |
| 70 | 223 | 13 | 15 | 1 | 1,657 |
| 80 | 94 | 41 | 8 | 1 | 882 |
| 90 | 35 | 14 | 3 | · | 305 |
| 100 | 7 | 3 | 6 | 1 | 191 |
| 110 | 3 | 1 | 5 | · | 329 |
| 120 | · | · | 2 | 1 | 248 |
| 130 | · | · | · | · | 127 |
| 140 | · | · | 1 | · | 56 |
| 150 | · | 1 | · | 1 | 16 |
| 160 | · | 2 | · | 2 | 8 |
| 170 | · | 1 | · | · | 6 |
| 180 | · | · | · | · | 2 |
| **1985** | | | | | |
| 10 | · | · | · | · | 2 |
| 20 | 161 | 1 | · | · | 74 |
| 30 | 1,630 | 36 | · | · | 837 |
| 40 | 2,828 | 507 | 1 | 8 | 2,954 |
| 50 | 2,037 | 2,590 | 27 | 247 | 2,875 |
| 60 | 1,130 | 2,187 | 96 | 79 | 1,897 |
| 70 | 667 | 482 | 80 | 35 | 1,395 |
| 80 | 251 | 89 | 53 | 16 | 1,777 |
| 90 | 94 | 20 | 18 | 3 | 2,198 |
| 100 | 151 | 7 | 7 | · | 2,332 |
| 110 | 79 | · | · | · | 2,016 |
| 120 | 33 | 1 | · | · | 1,458 |
| 130 | 9 | · | · | · | 959 |
| 140 | 1 | · | · | · | 486 |
| 150 | · | 1 | · | · | 246 |
| 160 | · | · | · | 2 | 89 |
| 170 | · | 3 | · | 3 | 42 |
| 180 | · | 1 | · | 1 | 6 |
| 190 | · | 2 | · | 2 | 9 |
| 200 | · | · | · | · | 2 |
| 210 | · | 1 | · | · | · |
| 230 | · | 1 | · | · | · |

## Appendix B

Three-way ANOVA of *Engraulis mordax*, *Genyonemus lineatus*, *Hyperprosopon argenteum*, *Phanerodon furcatus*, and *Seriphus politus* for transformed return efficiency using matched dates ($n = 37$) versus all criteria sampling dates for 1984-85. Variable: Ln(1% return).

| Species: | *Engraulis mordax* | | | *Genyonemus lineatus* | | | *Hyperprosopon argenteum* | | | *Phanerodon furcatus* | | | *Seriphus politus* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Type II | | | Type II | | | Type II | | | Type II | | | Type II | | |
| Factor | DF | SS | P-value | DF | SS | P-value | DF | SS | P-value | DF | SS | P-value | DF | SS | P-value |
| **Matched dates** | | | | | | | | | | | | | | | |
| Model | 7 | 79.76 | 0.13 | 6 | 36.62 | 0.50 | 5 | 49.86 | 0.25 | 5 | 48.30 | 0.31 | 7 | 153.21 | 0.001 |
| Error | 81 | 496.45 | — | 51 | 346.47 | — | 33 | 236.47 | — | 25 | 190.95 | — | 123 | 344.40 | — |
| Year | 1 | 39.35 | 0.02 | 1 | 0.49 | 0.79 | 1 | 19.82 | 0.11 | 1 | 0.01 | 0.98 | 1 | 52.57 | 0.0001 |
| Size | 1 | 18.18 | 0.11 | 1 | 24.22 | 0.06 | 1 | 3.11 | 0.51 | 1 | 18.85 | 0.13 | 1 | 98.79 | 0.0001 |
| Site | 1 | 8.03 | 0.28 | 1 | 7.20 | 0.31 | 1 | 0.15 | 0.89 | 1 | 0.11 | 0.90 | 1 | 3.18 | 0.29 |
| Year*Size | 1 | 0.01 | 0.98 | 1 | 1.30 | 0.66 | * | | | 1 | 8.67 | 0.30 | 1 | 5.68 | 0.16 |
| Year*Site | 1 | 9.53 | 0.24 | 1 | 3.51 | 0.47 | 1 | 0.42 | 0.81 | 1 | 4.15 | 0.47 | 1 | 0.11 | 0.84 |
| Size*Site | 1 | 0.00 | 0.98 | 1 | 0.79 | 0.73 | 1 | 0.16 | 0.80 | * | | | 1 | 0.32 | 0.74 |
| Year*Size*Size | 1 | 0.26 | 0.84 | * | | | * | | | * | | | 1 | 0.02 | 0.93 |
| **All dates** | | | | | | | | | | | | | | | |
| Model | 7 | 113.68 | 0.03 | 7 | 100.20 | 0.08 | 7 | 45.97 | 0.36 | 6 | 35.47 | 0.66 | 7 | 136.58 | 0.0001 |
| Error | 130 | 927.92 | — | 90 | 672.57 | — | 58 | 339.97 | — | 40 | 343.92 | — | 217 | 716.54 | — |
| Year | 1 | 36.34 | 0.03 | 1 | 13.73 | 0.18 | 1 | 8.46 | 0.23 | 1 | 0.88 | 0.75 | 1 | 40.22 | 0.0006 |
| Size | 1 | 27.62 | 0.05 | 1 | 26.94 | 0.06 | 1 | 13.69 | 0.13 | 1 | 25.25 | 0.09 | 1 | 92.66 | 0.0001 |
| Site | 1 | 2.57 | 0.55 | 1 | 13.10 | 0.19 | 1 | 3.03 | 0.47 | 1 | 1.21 | 0.71 | 1 | 1.91 | 0.45 |
| Year*Size | 1 | 15.62 | 0.14 | 1 | 0.03 | 0.95 | 1 | 1.26 | 0.64 | 1 | 2.13 | 0.62 | 1 | 1.27 | 0.53 |
| Year*Site | 1 | 10.90 | 0.22 | 1 | 0.39 | 0.82 | 1 | 4.51 | 0.38 | 1 | 0.41 | 0.83 | 1 | 0.70 | 0.64 |
| Size*Site | 1 | 4.35 | 0.44 | 1 | 28.01 | 0.06 | 1 | 0.81 | 0.71 | 1 | 7.24 | 0.36 | 1 | 0.25 | 0.78 |
| Year*Size*Size | 1 | 0.08 | 0.92 | 1 | 4.42 | 0.44 | 1 | 0.62 | 0.74 | * | | | 1 | 3.47 | 0.31 |

*Due to zero counts of total abundances at least once during the study, the interaction could not be considered in the model.

## Appendix C

Three-way ANOVA of *Engraulis mordax*, *Genyonemus lineatus*, and *Seriphus politus* for percent survivorship in the 96-hour study.

| Species: | *Engraulis mordax* | | | *Genyonemus lineatus* | | | *Seriphus politus* | | |
|---|---|---|---|---|---|---|---|---|---|
| | Type II | | | Type II | | | Type II | | |
| | DF | SS | P-value | DF | SS | P-value | DF | SS | P-value |
| **Percent survivorship at end of day-1** | | | | | | | | | |
| Model | 5 | 23.90 | 0.16 | 6 | 1.83 | 0.57 | 9 | 104.60 | 0.01 |
| Error | 4 | 6.55 | — | 2 | 0.60 | — | 29 | 52.96 | — |
| Year | 1 | 0.28 | 0.70 | 1 | 0.58 | 0.30 | 1 | 0.62 | 0.56 |
| Size | 1 | 0.07 | 0.84 | 1 | 0.00 | 1.00 | 1 | 0.13 | 0.79 |
| Site | 2 | 23.56 | 0.05 | 2 | 0.15 | 0.80 | 2 | 33.71 | 0.01 |
| Year*Size | 1 | 0.11 | 0.81 | * | | | 1 | 4.44 | 0.13 |
| Year*Site | * | | | 2 | 0.04 | 0.93 | 2 | 41.14 | 0.01 |
| Size*Site | * | | | * | | | 2 | 9.19 | 0.10 |
| **Percent survivorship from day-2 to end of study** | | | | | | | | | |
| Model | 5 | 13.11 | 0.36 | 6 | 10.14 | 0.50 | 9 | 43.83 | 0.01 |
| Error | 2 | 2.52 | — | 1 | 0.87 | — | 23 | 18.18 | — |
| Year | 1 | 0.03 | 0.90 | 1 | 4.33 | 0.27 | 1 | 22.07 | 0.01 |
| Size | 1 | 1.65 | 0.37 | 1 | 0.00 | 1.00 | 1 | 0.05 | 0.81 |
| Site | 2 | 11.25 | 0.18 | 2 | 6.71 | 0.34 | 2 | 7.99 | 0.02 |
| Year*Size | 1 | 0.06 | 0.85 | * | | | 1 | 0.59 | 0.39 |
| Year*Site | * | | | 2 | 0.68 | 0.75 | 2 | 13.93 | 0.01 |
| Size*Site | * | | | * | | | 2 | 0.43 | 0.76 |

*Due to zero counts of fish at least once during the study, the interaction could not be considered in the model.
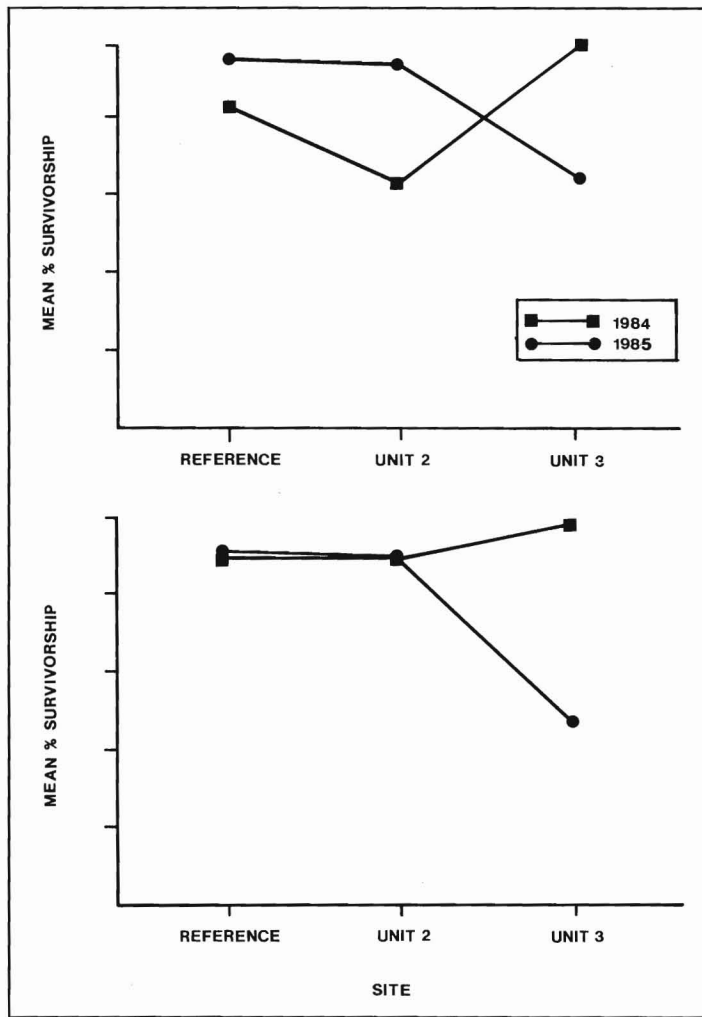
**Appendix D**
Significant interaction plots of site*year for *Seriphus politus* in the 96-hour study.