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Analysis of Fish Diversion Efficiency and Survivorship in the Fish Return System at San Onofre Nuclear Generating Station

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U.S. Department of Commerce

NOAA TECHNICAL REPORT NMFS

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U.S. DEPARTMENT OF COMMERCE
Robert Mosbacher, Secretary
National Oceanic and Atmospheric Administration
William E. Evans, Under Secretary for Oceans and Atmosphere
National Marine Fisheries Service
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An Analysis of Fish Diversion Efficiency and Survivorship in the Fish Return System at San Onofre Nuclear Generating Station

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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.

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 screenwells 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 m^3/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).

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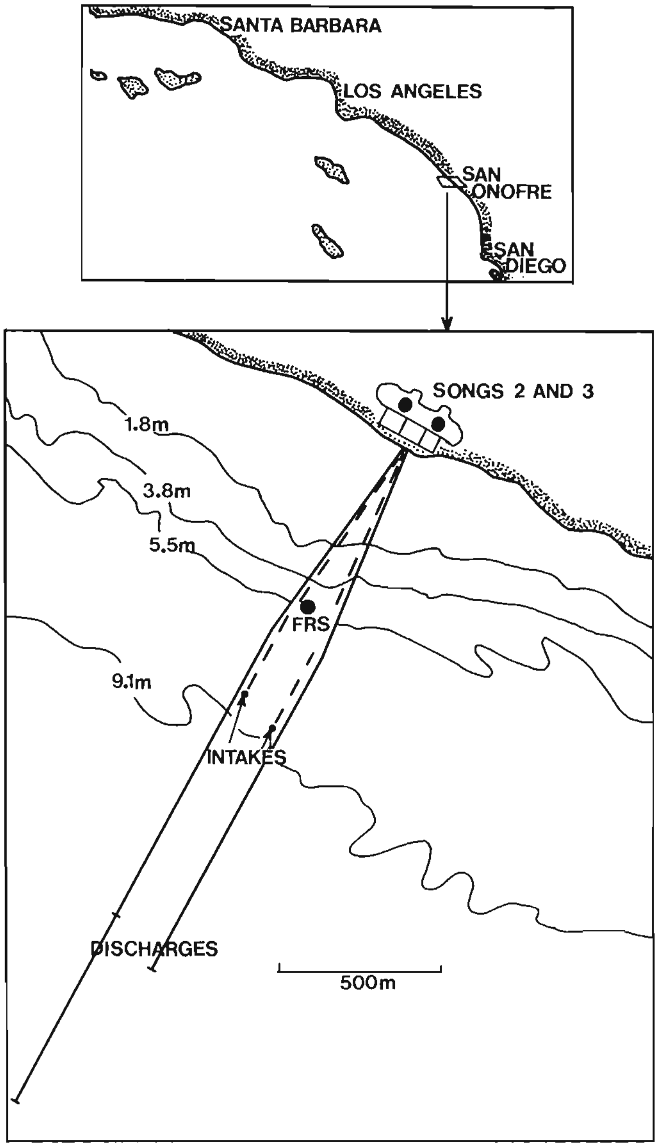

Figure 1
Location of the San Onofre Nuclear Generating Station (SONGS) and its fish return system.

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 × 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

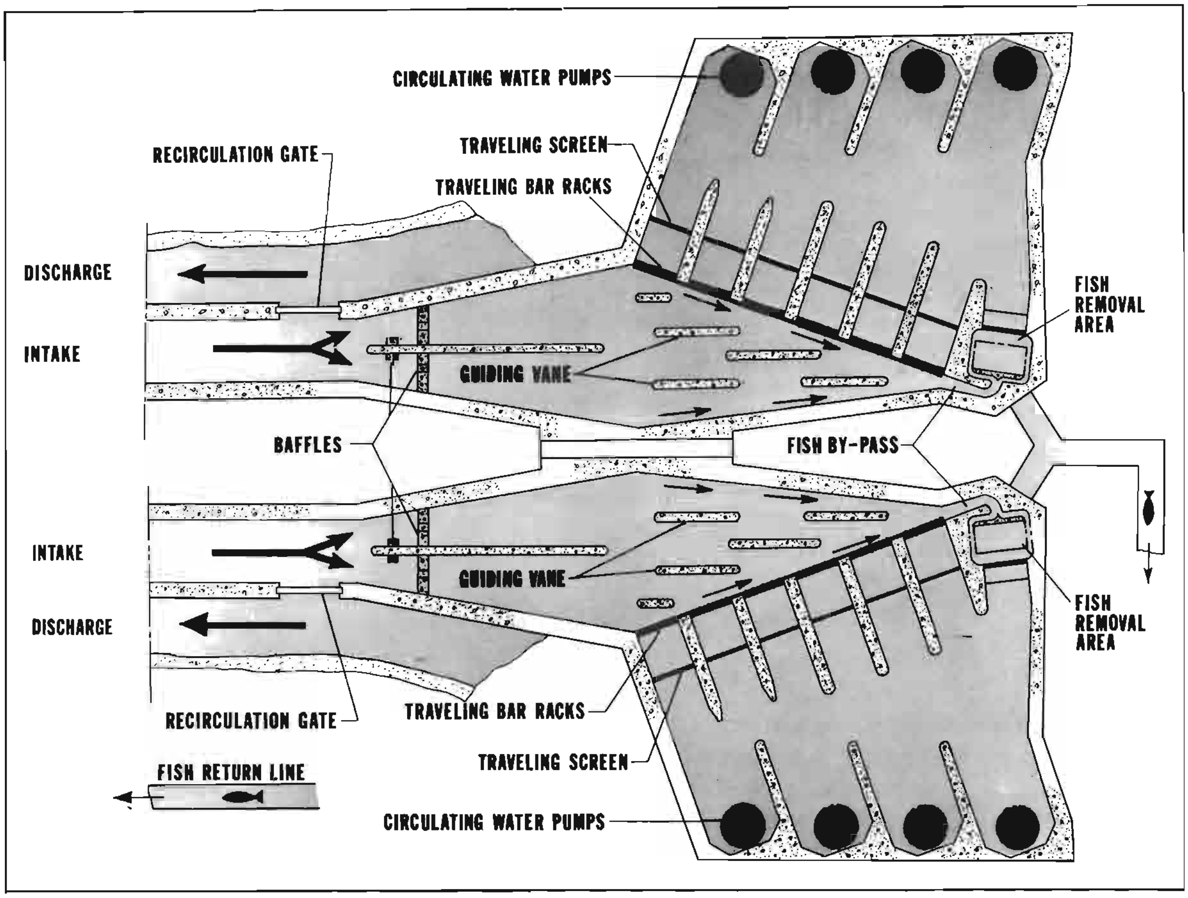

Figure 2
Fish return system of San Onofre Units 2 and 3, from intake through fish removal area.

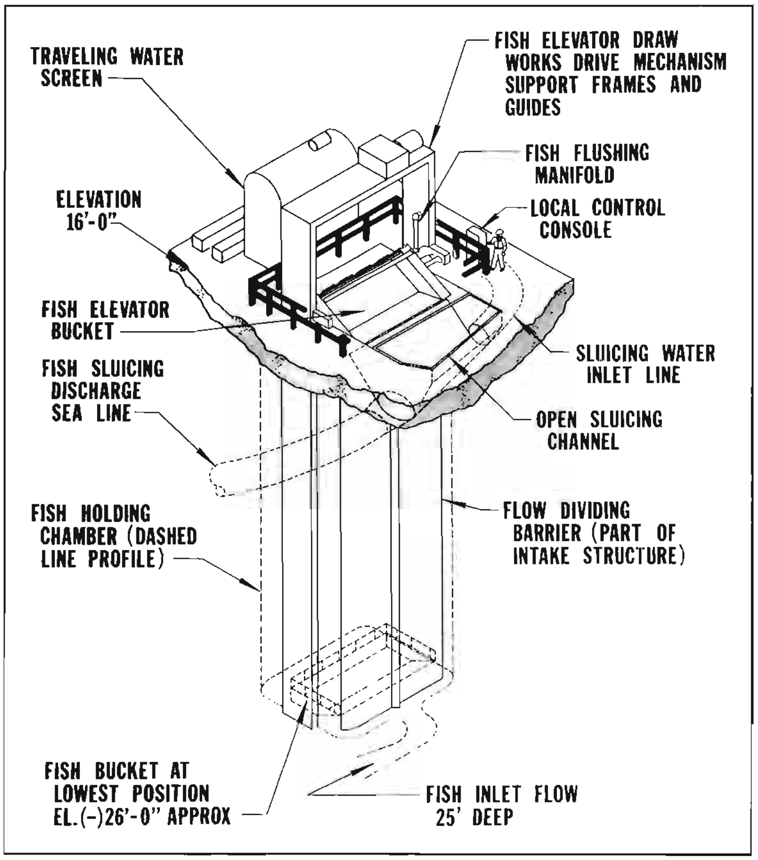

Figure 3
Removal elevator and sluicing channel of fish return system, San Onofre Units 2 and 3.

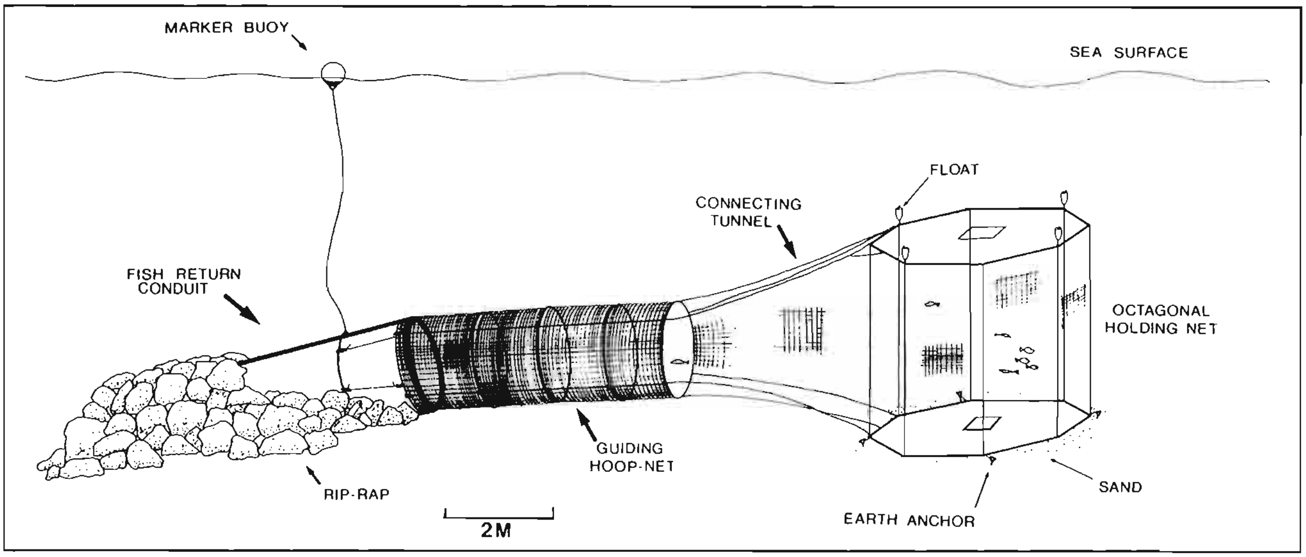

Figure 4
Holding net used in test phase of the 96-hour survivorship studies.

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 m^2 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

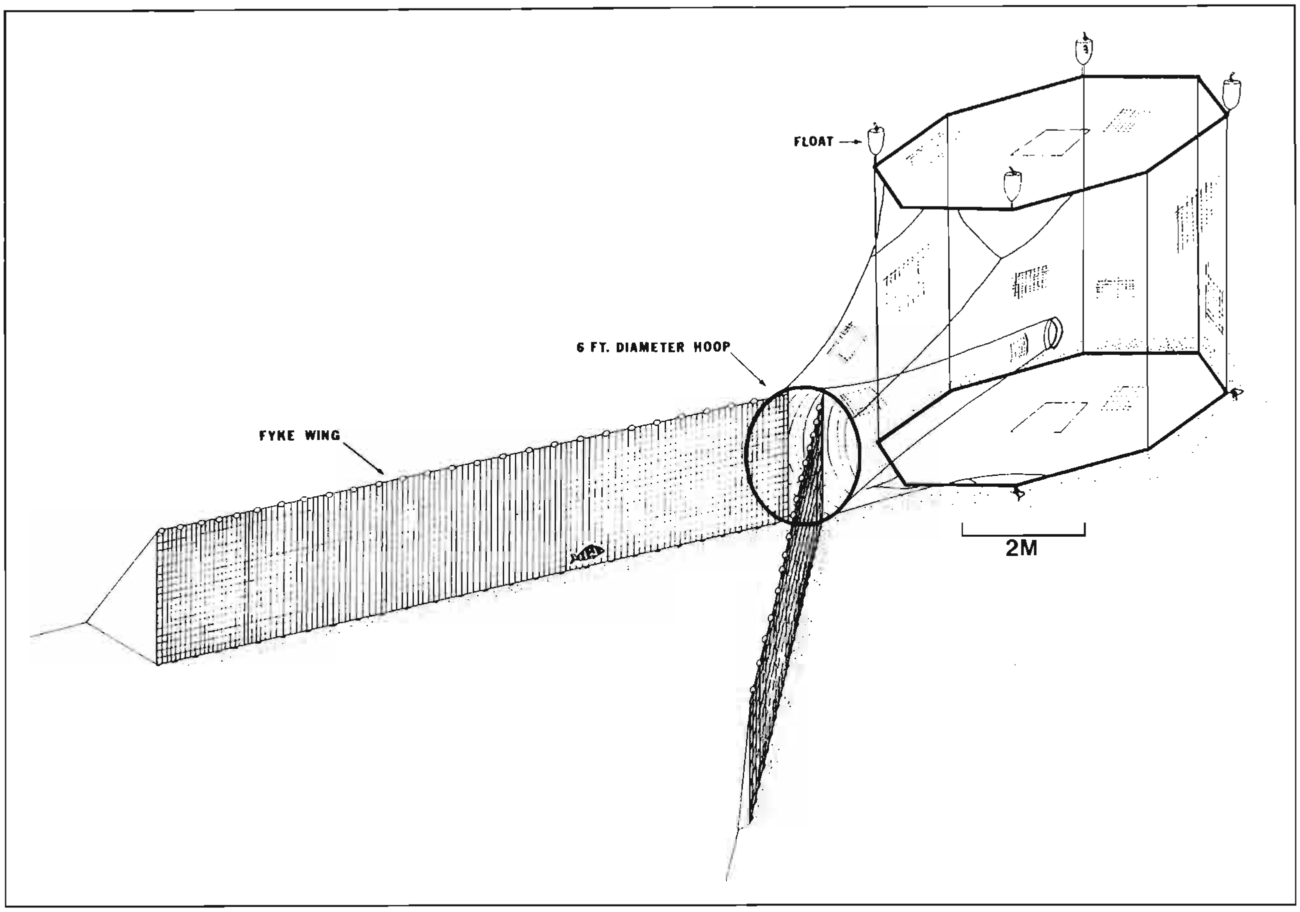

Figure 5
Holding net used in the 96-hour reference studies.

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, SURVTEST, 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
Engraulis mordax	135,688	1,012	134,676	99.3
Seriphus politus	50,566	6,197	44,369	87.7
Anchoa delicatissima	3,693	635	3,058	82.8
Atherinopsis californiensis	1,445	11	1,434	99.2
Anchoa compressa	889	181	708	79.6
Xenistius californiensis	831	20	811	97.6
Genyonemus lineatus	644	43	601	93.3
Atherinops affinis	601	11	590	98.2
Hermosilla azurea	436	0	436	100.0
Paralabrax clathratus	270	1	269	99.6
Peprilus simillimus	263	33	230	87.5
Umbrina roncador	258	0	258	100.0
Hyperprosopon argenteum	227	6	221	97.4
Anisotremus davidsonii	211	1	210	99.5
Porichthys notatus	111	108	3	2.7
Menticirrhus undulatus	108	1	107	99.1
Paralabrax nebulifer	89	3	86	96.6
Phanerodon furcatus	80	21	59	73.7
Sardinops sagax	75	14	61	81.3
Chromis punctipinnis	45	0	45	100.0
Paralichthys californicus	45	3	42	93.3
Urolophus halleri	41	5	36	87.8
Cheilotrema saturnum	38	0	38	100.0
Roncador stearnsii	36	1	35	97.2
Leuresthes tenuis	35	10	25	71.4
Atractoscion nobilis	25	0	25	100.0
Embiotoca jacksoni	24	1	23	95.8
Heterostichus rostratus	20	18	2	10.0
Sphyraena argentea	19	10	9	47.4
Scomber japonicus	16	4	12	75.0
Girella nigricans	13	0	13	100.0
Syngnathus sp.	13	13	0	0
Trachurus symmetricus	13	2	11	84.6
Rhinobatos productus	12	0	12	100.0
Mustelus henlei	10	0	10	100.0
Platyrhinoidis triseriata	9	3	6	66.7
Torpedo californica	9	2	7	77.8
Cymatogaster aggregata	8	3	5	62.5
Hypsoblennius spp.	8	8	0	0
Pleuronichthys ritteri	8	4	4	50.0
Damalichthys vacca	6	0	6	100.0
Hypsypops rubicundus	6	0	6	100.0
Citharichthys stigmaeus	5	0	5	100.0
Scorpaena guttata	5	3	2	40.0
Sebastes paucispinis	5	1	4	80.0
Halichoeres semicinctus	3	0	3	100.0
Heterodontus francisci	3	0	3	100.0
Mustelus californicus	3	1	2	66.7
Gymnura marmorata	2	0	2	100.0
Gibbonsia metzi	1	1	0	0
Gibbonsia sp.	1	1	0	0
Hypsoblennius gilberti	1	1	0	0
Medialuna californiensis	1	0	1	100.0
Otophidium scrippsi	1	0	1	100.0
Pleuronichthys verticalis	1	1	0	0
Porichthys myriaster	1	1	0	0
Squatina californica	1	0	1	100.0
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.

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
Engraulis mordax	210,108	11,951	198,157	94.3
Seriphus politus	104,394	27,431	76,963	73.7
Genyonemus lineatus	52,938	32,548	20,390	38.5
Anchoa delicatissima	27,514	26,284	1,230	4.5
Anchoa compressa	3,809	1,926	1,883	49.4
Umbrina roncador	2,026	5	2,021	99.8
Xenistius californiensis	1,885	61	1,824	96.8
Hyperprosopon argenteum	978	58	920	94.1
Phanerodon furcatus	819	280	539	65.8
Peprilus simillimus	488	88	400	82.0
Anisotremus davidsonii	284	2	282	99.3
Porichthys notatus	250	241	9	3.6
Menticirrhus undulatus	178	2	176	98.9
Atherinopsis californiensis	177	14	163	92.1
Paralabrax clathratus	165	4	161	97.6
Hermosilla azurea	158	0	158	100.0
Cymatogaster aggregata	145	90	55	37.9
Heterostichus rostratus	141	105	36	25.5
Atractoscion nobilis	138	18	120	87.0
Syngnathus species	116	116	0	0
Scomber japonicus	98	13	85	86.7
Paralichthys californicus	83	9	74	89.2
Urolophus halleri	74	4	70	94.6
Porichthys myriaster	69	61	8	11.6
Atherinops affinis	57	11	46	80.7
Sphyraena argentea	54	33	21	38.9
Paralabrax nebulifer	50	3	47	94.0
Trachurus symmetricus	46	3	43	93.5
Roncador stearnsii	42	2	40	95.2
Rhinobatos productus	39	1	38	97.4
Pleuronichthys ritteri	33	13	20	60.6
Embiotoca jacksoni	32	4	28	87.5
Xystreurys liolepis	32	18	14	43.8
Platyrhinoidis triseriata	30	20	10	33.3
Chromis punctipinnis	27	1	26	96.3
Leuresthes tenuis	27	19	8	29.6
Otophidium scrippsi	27	24	3	11.1
Torpedo californica	25	21	4	16.0
Myliobatis californica	21	1	20	95.2
Scorpaena guttata	19	10	9	47.4
Cheilotrema saturnum	17	0	17	100.0
Sebastes paucispinis	16	11	5	31.3
Mustelus californicus	13	4	9	69.2
Damalichthys vacca	12	1	11	91.7
Etrumeus teres	12	1	11	91.7
Medialuna californiensis	12	0	12	100.0
Citharichthys stigmaeus	7	7	0	0
Gymnura marmorata	7	3	4	57.1
Hypsoblennius spp.	7	7	0	0
Halichoeres semicinctus	5	1	4	80.0
Hypsopsetta guttulata	5	0	5	100.0
Mustelus henlei	5	3	2	40.0
Scorpaenichthys marmoratus	5	3	2	40.0
Triakis semifasciata	4	1	3	75.0
Gibbonsia sp.	3	3	0	0
Girella nigricans	3	0	3	100.0
Heterodontus franscisci	3	1	2	66.7
Leptocottus armatus	3	3	0	0
Rhacochilus toxotes	3	0	3	100.0
Oxyjulis californica	2	1	1	50.0
Sebastes serriceps	2	2	0	0
Synodus lucioceps	2	2	0	0
Amphistichus argenteus	1	1	0	0
Clupea harengus pallasii	1	0	1	100.0
Gibbonsia elegans	1	1	0	0
Hypsypops rubicundus	1	0	1	100.0
Microstomus pacificus	1	1	0	0
Paralabrax maculatofasciatus	1	0	1	100.0
Pleuronichthys verticalis	1	0	1	100.0
Sarda chiliensis	1	0	1	100.0
Sebastes auriculatus	1	1	0	0
Squalus acanthias	1	1	0	0
Symphus atricauda	1	1	0	0
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.

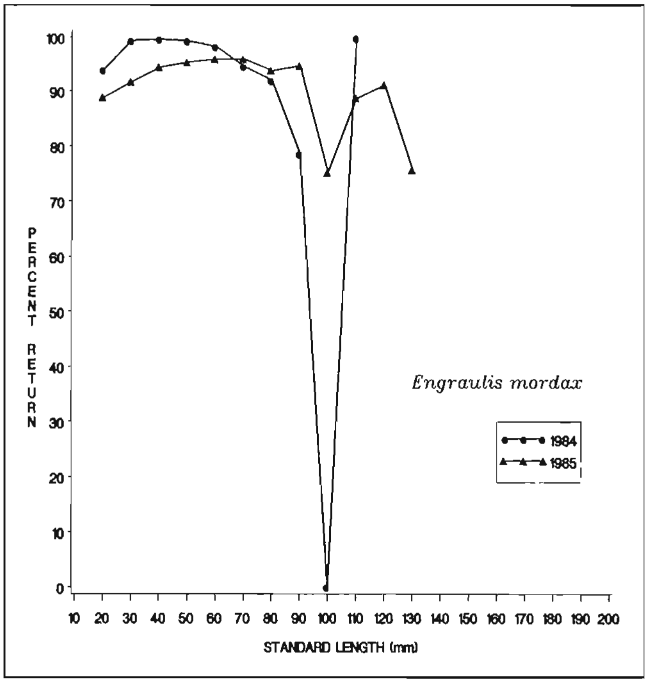

Figure 6
Return efficiency (%) by length of northern anchovy, *Engraulis mordax*, at San Onofre Units 2 and 3.

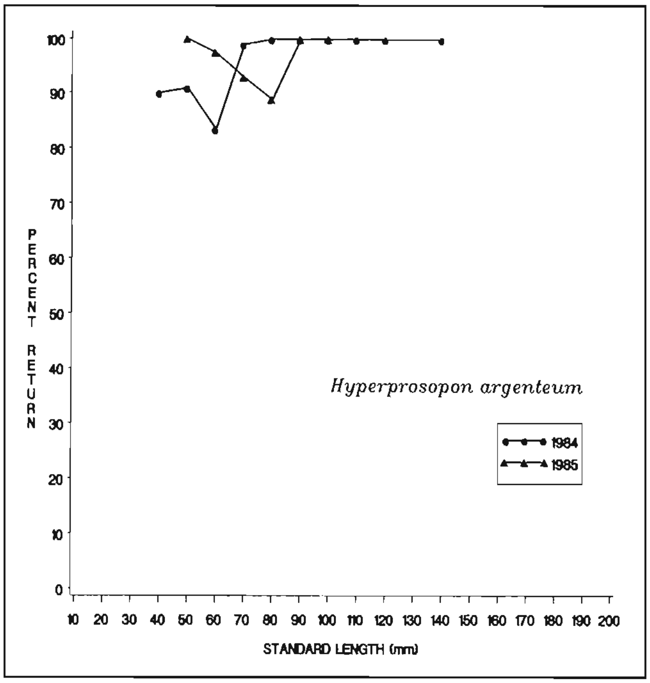

Figure 8
Return efficiency (%) by length of walleye surfperch, *Hyperprosopon argenteum*, at San Onofre Units 2 and 3.

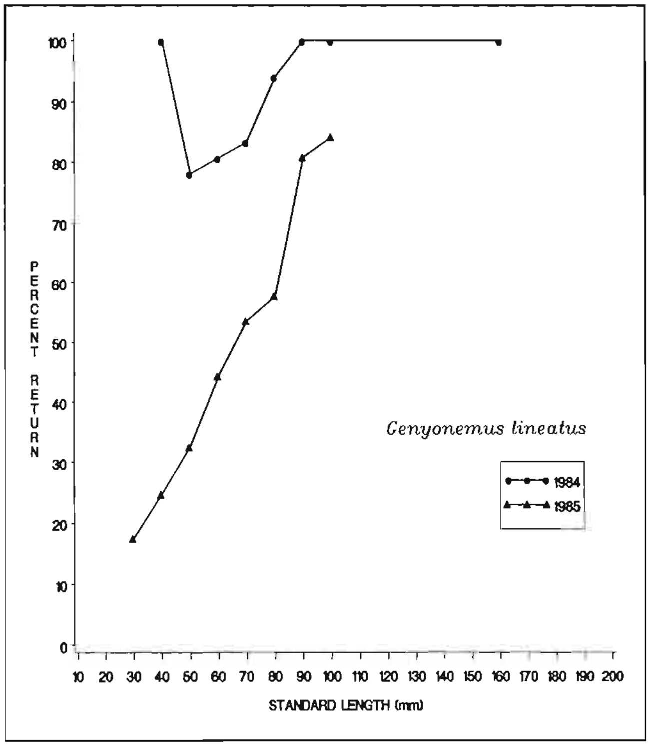

Figure 7
Return efficiency (%) by length of white croaker, *Genyonemus lineatus*, at San Onofre Units 2 and 3.

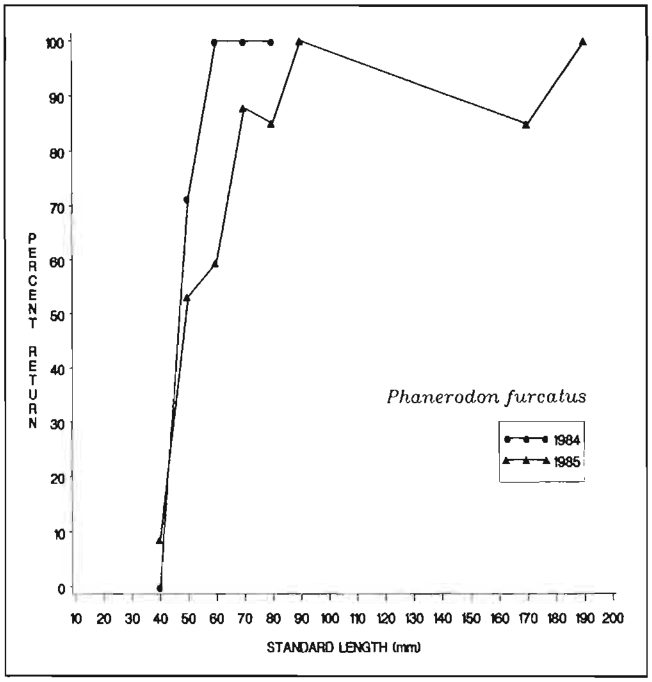

Figure 9
Return efficiency (%) by length of white surfperch, *Phanerodon furcatus*, at San Onofre Units 2 and 3.

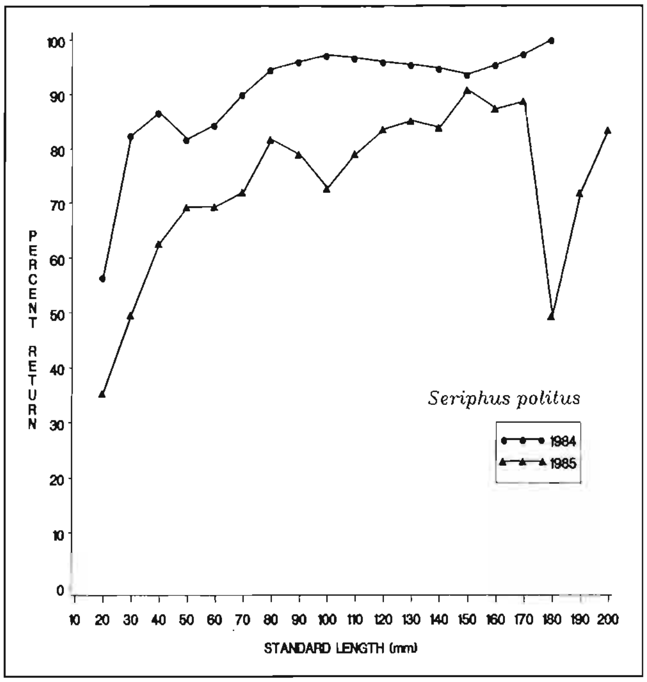

Figure 10
Return efficiency (%) by length of queenfish, *Seriphus politus*, at San Onofre Units 2 and 3.

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		
	Unit 2	Unit 3	Reference
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)	

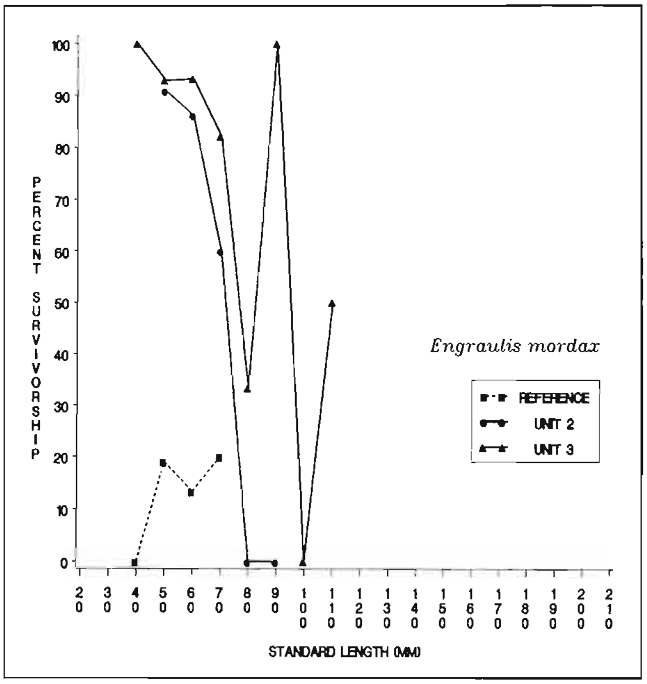

Figure 11
Percent survivorship by length of northern anchovy, *Engraulis mordax*, in the reference net and San Onofre Units 2 and 3.

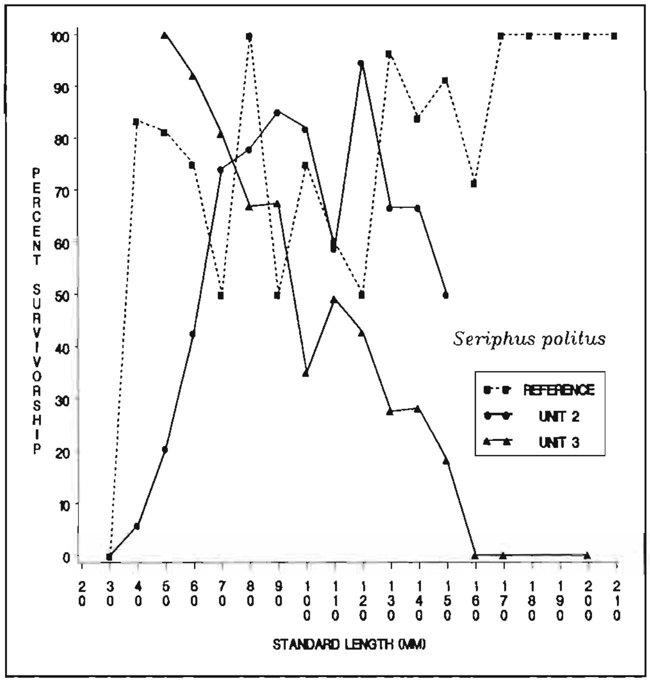

Figure 12
Percent survivorship by length of queenfish, *Seriphus politus*, in the reference net and San Onofre Units 2 and 3.

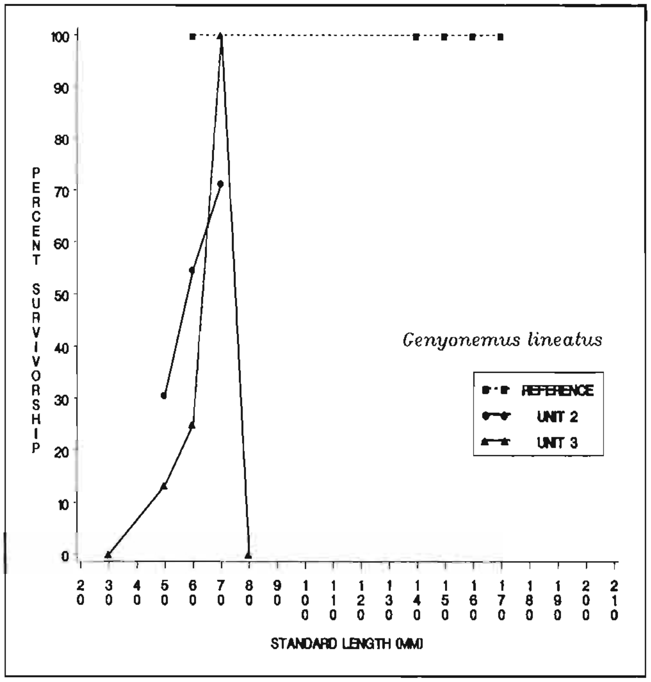

Figure 13
Percent survivorship by length of white croaker, *Genyonemus lineatus*, in the reference net and San Onofre Units 2 and 3.

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

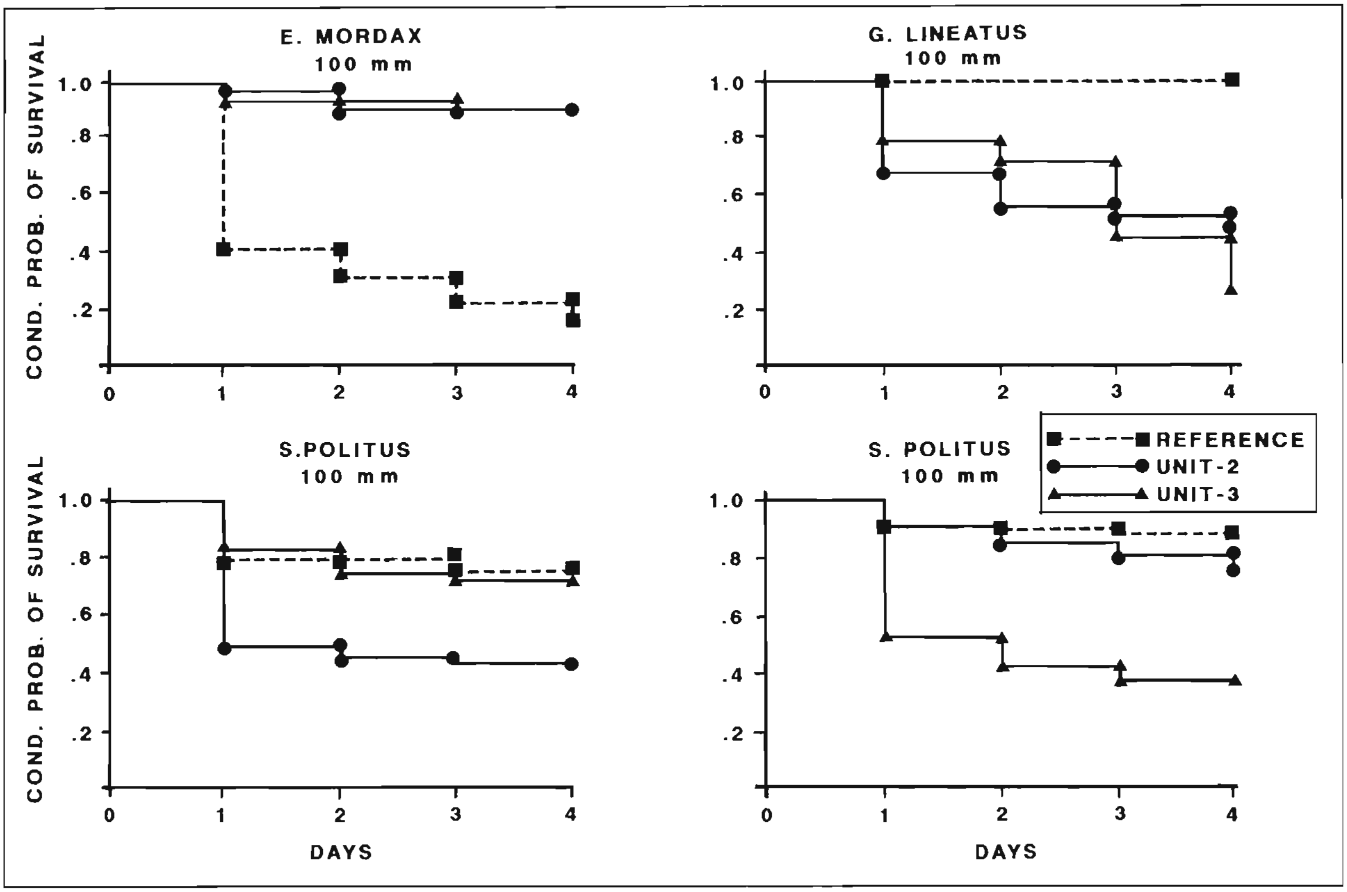

Figure 14
Conditional probability of survival of *Engraulis mordax*, *Seriphus politus*, and *Genyonemus lineatus* in the reference net and San Onofre Units 2 and 3 experiments.

(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.

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

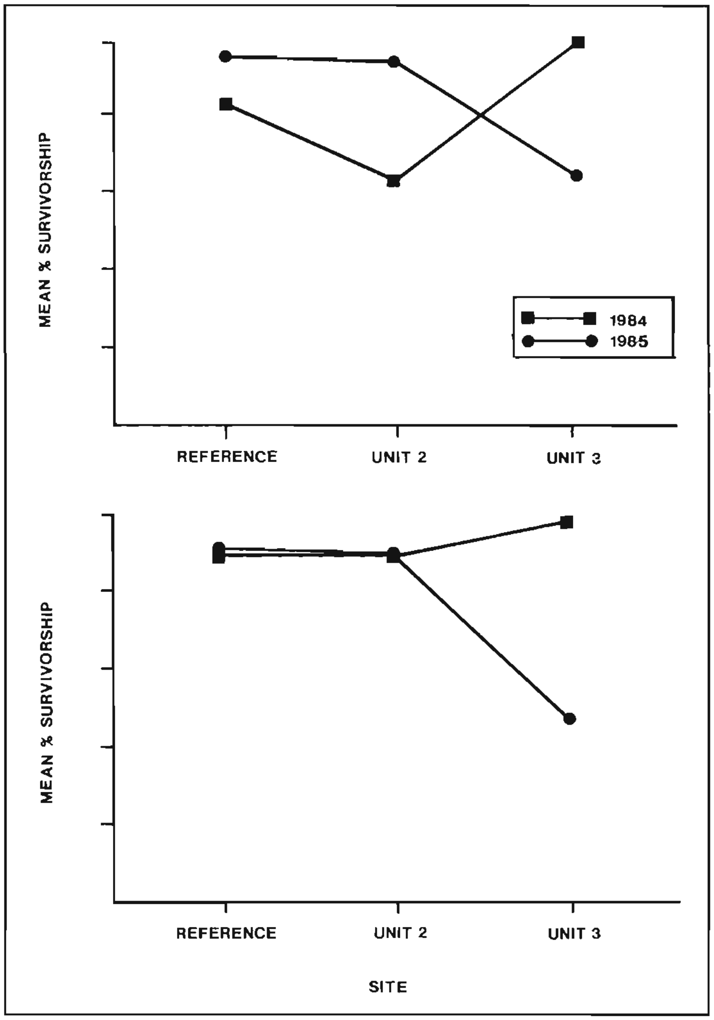
*Due to zero counts of total abundances at least once during the study, the interaction could not be considered in the model.

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.