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THE EFFECTIVENESS OF A VELOCITY CAP AND DECREASED FLOW
IN REDUCING FISH ENTRAPMENT

FINAL REPORT

to

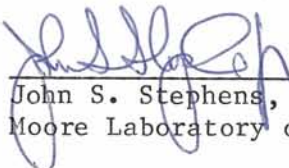
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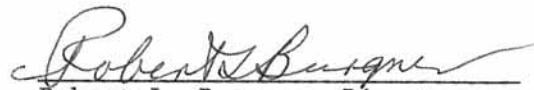
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ABSTRACT

Simultaneous measurements of the offshore fish density and inplant fish entrapment were made during surveys at four electric-generating stations along the southern California coastline in 1979-1980. Hourly estimates of the fish biomass in the vicinity of the cooling-water intake sites with state-of-the-art precision were made possible with hydroacoustic techniques. Synchronous hourly measurements of fish entrapment were made in order to describe the density dependence of fish entrapment. An entrapment vulnerability statistic, the ratio of the weight (kg) of fish entrapped in the plant (E) to the weight (kg) of fish offshore in the vicinity of the intake (B), i.e., E/B , was employed to describe the effect of water transparency, the velocity-cap and volume of flow on the entrapment of fish.

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1.0 INTRODUCTION

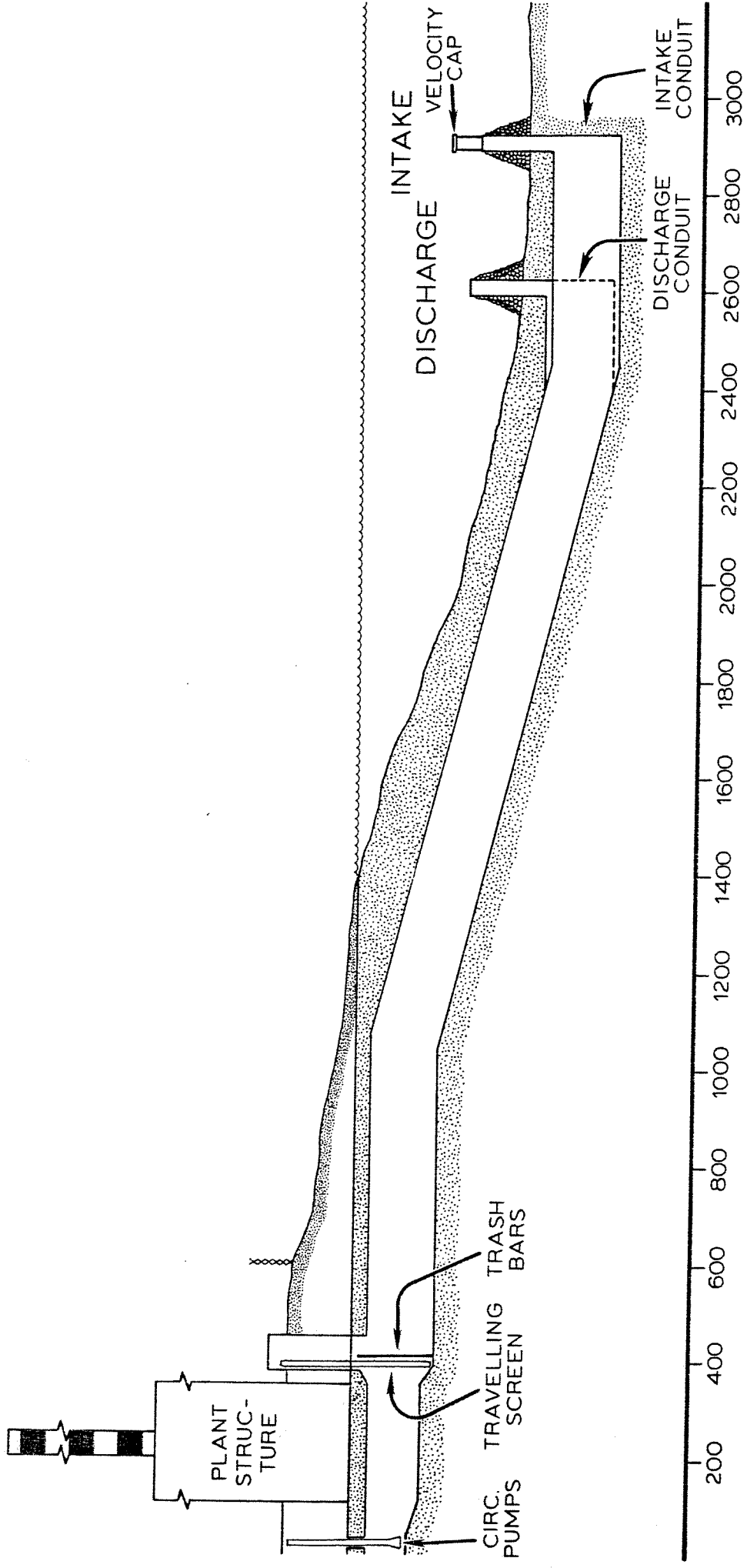
Southern California Edison Company (SCE) utilizes offshore-sited intake towers to provide once-through cooling water for a number of coastal thermal electric power plants. Cooling water is provided to the plants at flow rates of up to $52.4 \text{ m}^3/\text{s}$ (830,000 gpm). Large numbers of fish are also drawn into the cooling water intake systems. The fish eggs, larvae and a proportion of smaller fishes are entrained through the systems and returned offshore through the discharge outlets. Larger fish are entrapped by the systems since they are screened out of the cooling water flow at onshore screenwells. The larger fish do not return to the ocean and represent entrapment mortality. This study evaluates one existing (the velocity cap) and one potential way (reduced flow) to reduce entrapment mortality.

1.1 Velocity Cap

In the early 1950's, SCE installed a "velocity cap" on one of the El Segundo Generating Station (ESGS) intake towers in an effort to minimize fish entrapment (Fig. 1). The velocity cap structure consisted of a horizontal concrete slab supported 1 m above the open end of the intake's vertical riser bowl. The cap structure was designed to produce a horizontal flow field (as opposed to a vertical flow field) at the entrance to the intake tower. The incorporation of the velocity cap into intake tower design is the primary design feature of SCE's efforts to reduce fish entrapment.

Weight (1958) analyzed fish entrapment occurring before (1956) and after (1957) the installation of the velocity cap at ESGS. The annual fish entrapment was 210 and 10.5 m tons in 1956 and 1957, respectively. Therefore, Weight concluded that the installation of the velocity cap reduced annual entrapment by 95%.

The 1958 paper by Weight is the main field demonstration SCE utilizes to support the contention that the velocity cap is the best technology available to minimize fish entrapment. However, subsequent to Weight's analysis a number of researchers have suggested that the most important variables affecting fish entrapment are the density and distribution of fishes in the vicinity of the intake (Sharma, 1978; Haven and Ginn, 1977). Recently, variation in annual fish entrapment similar in magnitude to Weight's observations was documented at the Redondo Beach Generating Station (RBGS). The RBGS changes were presumed to be the result of natural fluctuations in fish abundance since there were no design or operational modifications of the station. Therefore the absence of information on offshore fish density at the ESGS during Weight's evaluation of the velocity cap raises questions as to the validity of his conclusions.



HORIZONTAL SCALE (FEET)

Fig. 1. Cross-sectional view of a "typical" cooling water circulation system for a Southern California Edison generating station with an offshore-site cooling water intake tower.

There is some controversy in the literature concerning the effectiveness of a velocity cap because of the absence of a valid field demonstration. Schuler and Larson (1975) demonstrated in the laboratory that a velocity cap can reduce anchovy entrapment by "85 to 90%." However, Stupka and Sharma (1977) suggest that the velocity cap at the San Onofre Nuclear Generating Station (SONGS) "may actually serve to enhance the entrapment of fish." If Stupka and Sharma are correct, then the velocity cap would not be acceptable as the primary treatment of fish entrapment on an industry-wide basis.

1.2 Reduced Flow

Secondary changes (post-velocity cap) in operational procedures and/or siting and design features added to reduce fish entrapment are generally expensive and difficult to apply. Therefore, it must first be demonstrated that alterations in existing conditions can be made that will result in feasible and cost effective reductions in fish entrapment. One potential alteration is to reduce flow during off-peak production hours. The amount of flow is determined by the number of circulating pumps in operation. Under current policy the flow at fossil fuel plants is not lowered during periods of normal load reduction. Fortunately, the off-peak production hours have been described as those intervals which also have the highest entrapment rates (Thomas et al. 1979). Therefore, secondary reductions (beyond installation of the velocity cap) in fish entrapment may be feasible without power loss. The reduction of flow during off-peak production hours is being considered as regulatory requirements for utilities elsewhere (Milburn and Ginsburg 1977).

At SCE's El Segundo Generating Station, Weight (1958) observed that entrapment rates appeared to be lower during periods of reduced flow. Johnson et al. (1976) reported lower entrapment rates of anchovy with two rather than four circulating water pumps operating at SCE's Redondo Beach Units 7 and 8. In addition, Schuler and Larson (1975) demonstrated that anchovy entrapment within model intake towers was positively correlated with entrance velocity, which is also proportional to the number of circulating pumps in operation.

1.3 Objectives

A total of 11 field surveys were conducted in 1979-80 at four generating stations, OBGs, ESGs, Huntington Beach Generating Station (HBGS), and SONGS (Table 1). Interim reports produced for the first three surveys provided preliminary evaluations of reduced flow (FRI-UW-7928), heat treatment (FRI-UW-8012), and the velocity cap (FRI-UW-8003). Surveys 4, 5, 6, and 8 were conducted at four generating systems and reported in the Multiple-station Comparison paper (FRI-UW-8023). Surveys 7, 9, 10 and 11 were conducted to provide additional reduced flow and velocity

Table 1. Survey dates, locations, and reports for the 1979-80 research effort.

Julian dates	Survey	Month/Yr	Location	Operational evaluation	Report number and date
156-159	1	6/79	Huntington	Reduced flow	FRI-UW-7928 (12/79), FRI-UW- (12/80)
176-180	2	6/79	Huntington	Heat treatment	FRI-UW-8012 (8/80), FRI-UW- (12/80)
198-203	3	7/79	Huntington	Velocity cap	FRI-UW-8003 (2/80), FRI-UW- (12/80)
219-221	4	8/79	Ormond Beach	Multiple station	FRI-UW-8023 (12/80)
225-227	5	8/79	E1 Segundo	Multiple station	FRI-UW-8023 (12/80)
233, 237, 238	6	8/79	Huntington	Multiple station	FRI-UW-8023 (12/80)
234-236	7	8/79	Huntington	Reduced flow	FRI-UW- (12/80)
249, 250	8	9/79	SONGS	Multiple station	FRI-UW-8023 (12/80)
309-311	9	11/79	Huntington	Seasonal	FRI-UW- (12/80)
119-122	10a*	4/80	Ormond Beach	Velocity cap (individual fish)	FRI-UW- (12/80)
119-122	10b*	4/80	Ormond Beach	Velocity cap (school fish)	FRI-UW- (12/80)
205-209	11	7/80	Huntington	Velocity cap	FRI-UW- (12/80)

*Large schools of jack and Pacific mackerel were present in the study area. The fish school data were removed for entrapment analyses because these schooling fish were not susceptible to entrapment. Both data sets are presented in the appendices.

cap data which are examined in a comprehensive manner in this final report. The combined data collected during all eleven surveys are presented in Appendices A-1 through A-4.

The objective of this report is to present the results of a series of field studies at HBGS and OBGS which evaluate the effects on fish entrapment of changes to the design, siting, and capacity of offshore cooling water intake towers. The major demonstrations were made with HBGS data with corroborating evidence from OBGS. The demonstrations reported herein include field evaluations of the effectiveness of a velocity cap in reducing fish entrapment and the possibility of lowering fish entrapment by reducing the number of cooling water circulating pumps operating during low electrical demand periods. These results are the product of a cooperative effort of interdisciplinary staffs at the University of Washington and Occidental College.

2.0 METHODS

The primary objectives of the field surveys were to monitor the vulnerability of fish to entrapment by simultaneously measuring offshore fish density and inplant fish entrapment. The measurement of offshore fish density involved the coordination between two separate sampling fractions. First, the biomass of fish was estimated by hydroacoustics. Second, as the fish assemblage was being measured acoustically, a lampara net sampling program was conducted in order to subsample a proportion of the acoustic fish targets for species composition. The measurement of fish entrapment involved incapacitating and removing all fish within the cooling water intake system. These techniques are described in detail in Thomas et al. (1979). A brief description of these techniques and selected underlying assumptions (the density-dependence relationship, the lampara/acoustic relationship, the echo integration technique, the vertical distribution effect, and length frequency analysis) are presented in Appendices B, C, D, E, F, and G, respectively.

2.1 Study Area

The majority of the field surveys examined in this paper were conducted along the southern California coastline at the Huntington Beach Generating Station (HBGS). Supplementary data were collected in two surveys at the Ormond Beach Generating Station (OBGS) in 1979-80. Data collected on one survey at the SONGS and ESGS were presented in Appendix H and addressed in the Multiple Station paper. A brief description of the study sites is presented in Appendix H and a more detailed version is available in McGroddy et al. (1979) (Fig. 2).

2.2 Sampling Schedule

Each survey was designed to last six to seven days. The first survey day of each study was devoted to screenwell clearing and the positioning of offshore gear. On subsequent days, as equipment and conditions permitted, simultaneous measurements of entrapment, offshore density, and physical conditions were taken hourly from approximately midnight until dawn (Fig. 3). In general, equal time was spent collecting control and treatment data. In addition, total entrapment was monitored during the remainder of the day.

2.3 Data Analysis

The ability to synchronously calculate real time entrapment rates and offshore fish density enabled the evaluation of the effects of an intake on a fish assemblage in a manner not previously possible. This ability allowed the following evaluations of the velocity cap and re-

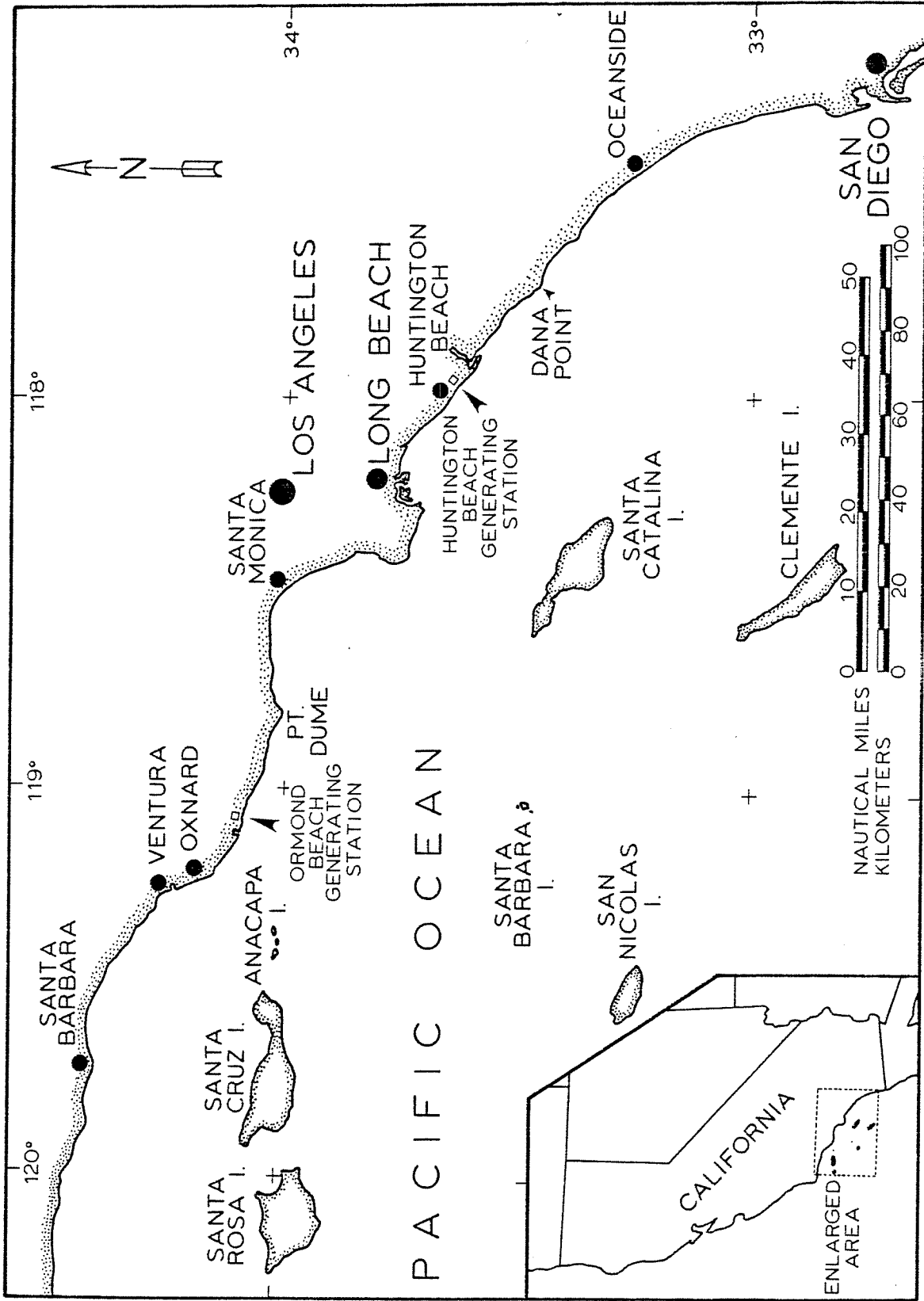


Fig. 2. The location of the Ormond Beach and Huntington Beach generating stations along the southern California coastline.

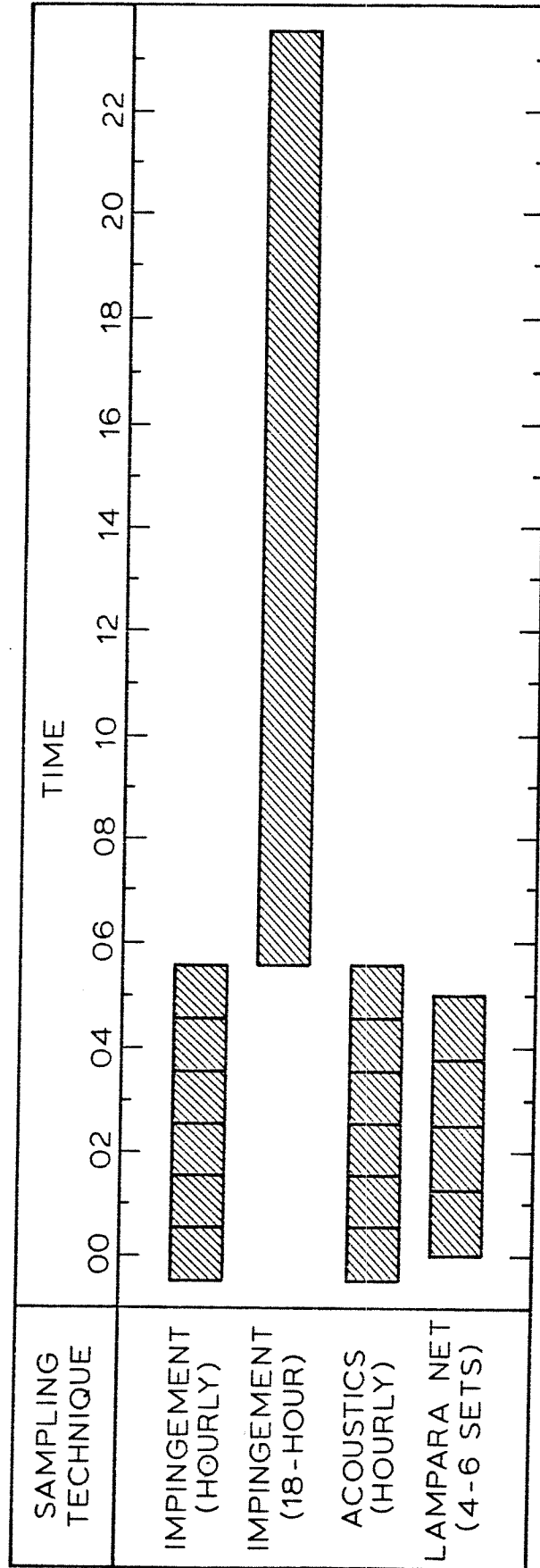


Fig. 3. Typical daily sampling schedule for a comparison of fish entrapment rates of four SCE cooling water intake systems.

duced flow effect on entrapment independent of changes in offshore density. The statistical technique for adjusting entrapment rates by offshore fish biomass was simply to form the ratio of entrapment to density (E/B). This ratio was assumed to represent the relative vulnerability of a fish assemblage to an intake. Therefore, by synchronously monitoring E and B through major changes in operational modes of an intake, it was possible to test several hypotheses.

The offshore fish samples collected at OBGS in 1980 contained large mackerel schools which were not entrapped by the intake in sufficient quantities to warrant examination. These school data were removed easily from the offshore measurements by superimposing a high density threshold. In this manner the background data which included the species of concern could be examined without being obscured by the large mackerel biomass present in the study area. Data are presented with and without school data in Appendix A. All analyses were conducted on the without-school data.

2.4 Hypothesis Testing

The experimental design used for hypothesis testing was that of control/treatment. Comparisons of E/B (for all species and by species) collected during experimental and control conditions were made with directional hypotheses using the Mann Whitney U test and $\alpha = 0.05$ (Siegel 1956). Directional hypotheses were used because laboratory evaluations suggested that the velocity cap and decreased flow may reduce fish entrapment and to conform to the 316(b) demonstration of minimizing fish losses. The control conditions (treatment 2) were full-flow-with-velocity-cap. The experimental conditions were: full-flow-without-velocity-cap (treatment 3), reduced-flow-with-velocity-cap (treatment 1), reduced-flow-without-velocity-cap (treatment 4), and "tunnel swapping" (treatment 5).

The first hypothesis tested was that E/B during full-flow-without-velocity-cap was larger than E/B during control conditions or $p(\text{E/B treatment 3} > \text{treatment 2}) > 1/2$. The control conditions were obtained by operating all of the circulation pumps with once-through flow from the velocity-capped intake to the uncapped discharge outlet. The full-flow-without-velocity-cap conditions were achieved by operating all of the circulation pumps with once-through flow through the uncapped discharge to the velocity-capped intake. As both structures are identical in configuration (except for the velocity cap) and are located close to each other offshore, these operating conditions allowed direct comparisons of with- and without-cap entrapment.

The second hypothesis tested was that E/B during reduced-flow-with-velocity-cap was lower than control conditions, or $p(\text{treatment 1} < \text{treatment 2}) > 1/2$. The reduced-flow-with-velocity-cap conditions were achieved by operating 4 of 8 circulating pumps with once-through flow from the velocity-capped intake to the uncapped discharge outlet.

The third hypothesis tested was that without-cap E/B was lower during reduced flow than during full flow or p (treatment 4 <treatment 3) >1/2. The reduced-flow-without-velocity-cap conditions were obtained during operation of all the circulation pumps with partial-recirculation and flow through the uncapped discharge to the velocity-capped intake (a heat treatment).

Three hours of entrapment vulnerability were collected during the "tunnel swapping" (treatment 5) event, a transitional period between normal and reverse flow conditions. Although three points were insufficient for hypothesis testing procedures they were included for discussion because of their magnitude.

2.5 Species of Concern

In this report hypothesis testing was confined to those species the techniques were designed to monitor: queenfish (Seriphus politus), northern anchovy (Engraulis mordax), and white croaker (Genyonemus lineatus). These three species comprise very large percentages of SCE's total entrapment and are on the SCE "key" species list (Wintersteen and Dorn 1979). Additional hypothesis testing was performed using data for "all-species-combined." Miscellaneous observations regarding the entrapment, abundance, and distribution of other fishes are presented in Appendix I.

3.0 RESULTS AND DISCUSSION

3.1 Water Transparency Effects on Entrapment

The maximum water transparency was plotted against the entrapment vulnerability coefficient for all-species-combined data collected at Huntington Beach under control conditions (Fig. 4). The indication was that the maximum entrapment vulnerability decreased in a linear fashion with increasing water clarity. However, a family of curves best describe the species specific relationships between water clarity and entrapment vulnerability (Fig. 5). The influence of water clarity on vulnerability appears to be more pronounced for the two sciaenids, queenfish and white croaker, than for northern anchovy.

3.2 Design and Operational Effects on Entrapment

There were 123 and 35 hourly estimates of entrapment vulnerability (E/B) for all-species-combined at Huntington Beach and Ormond Beach, respectively. These were plotted by treatment (Fig. 6). The 123 hourly estimates at HBGS were comprised of 21 estimates during reduced flow conditions (treatment 1), 70 during control conditions (treatment 2), 24 at normal flow without a velocity cap (treatment 3), 5 at reduced flow with no-velocity cap (treatment 4) and 3 during tunnel swapping conditions (treatment 6). The 35 hourly estimates at OBGS were comprised of 24 estimates of control and 11 estimates of normal flow without-velocity cap.

3.2.1 Velocity Cap Effectiveness

E/B Data. The entrapment vulnerability indices for all-species-combined were greater during without-cap full flow conditions than during control conditions (treatment 3 > 2 , Mann Whitney U, one-tailed $p < 0.0001$, $n_1 = 24$, $n_2 = 70$). This test was repeated on data collected in April 1980 at Ormond Beach. The Ormond Beach results presented in Fig. 7 corroborated those at Huntington Beach (Mann Whitney U, one-tailed $p = 0.0083$, $n_1 = 8$, $n_2 = 11$).

Vulnerability coefficients were also computed for queenfish, white croaker, and anchovy to evaluate the species-specific effectiveness of the Huntington Beach velocity cap in 1979-80. All three fishes displayed higher vulnerabilities under no-velocity-cap conditions (Table 2). The Ormond Beach results did not display the species-specific differences seen at Huntington Beach. However, the Ormond Beach data were treated differently in data reduction because of an unusually high relative abundance of mackerel schools (Scomber japonicus and Trachurus symmetricus) in the study area. The presence of large mackerel schools may have obscured the species-specific trends of "key" fishes because the "key" species were relatively low in abundance.

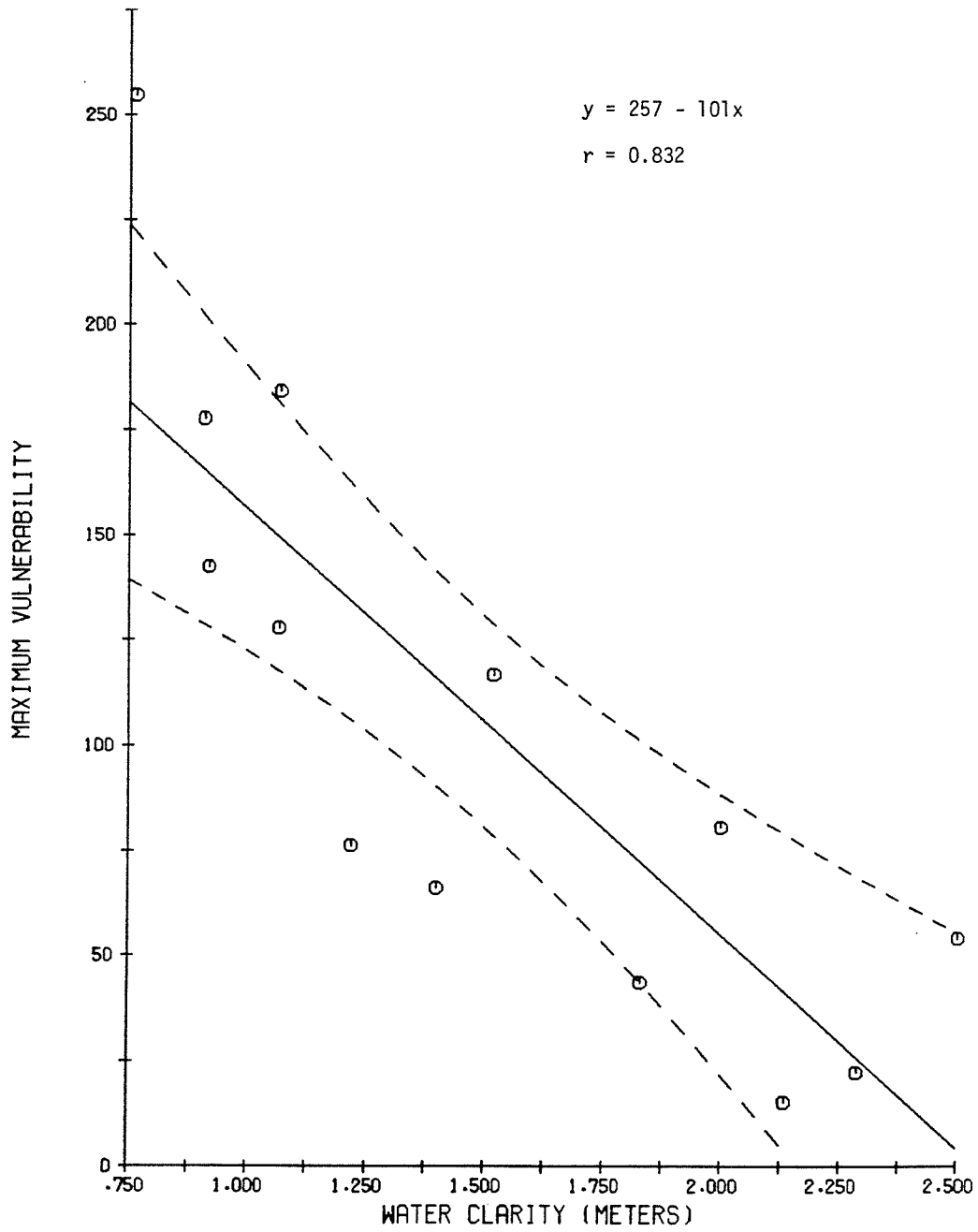


Fig. 4. The relationship (least squares regression line and 95% CI) between maximum entrapment vulnerability ($E/B \times 10^4$) of all species combined and water clarity. The data were collected at Huntington Beach in 1979-1980 under full-flow with-cap operational conditions.

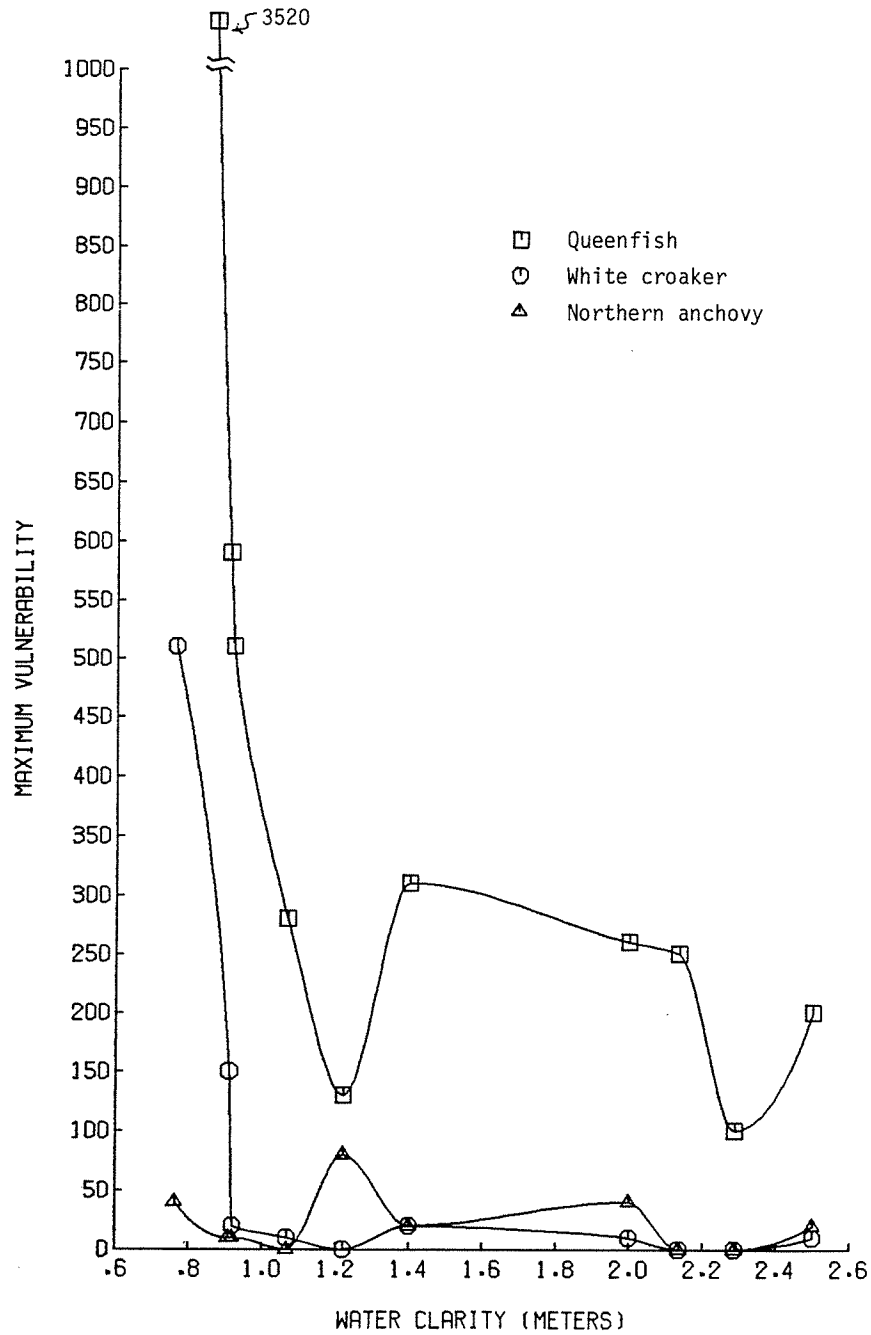


Fig. 5. Maximum vulnerability ($E/B \times 10^4$) versus water clarity (Huntington Beach, 1979-1980 data, full-flow with-cap) for queenfish, white croaker, and northern anchovy.

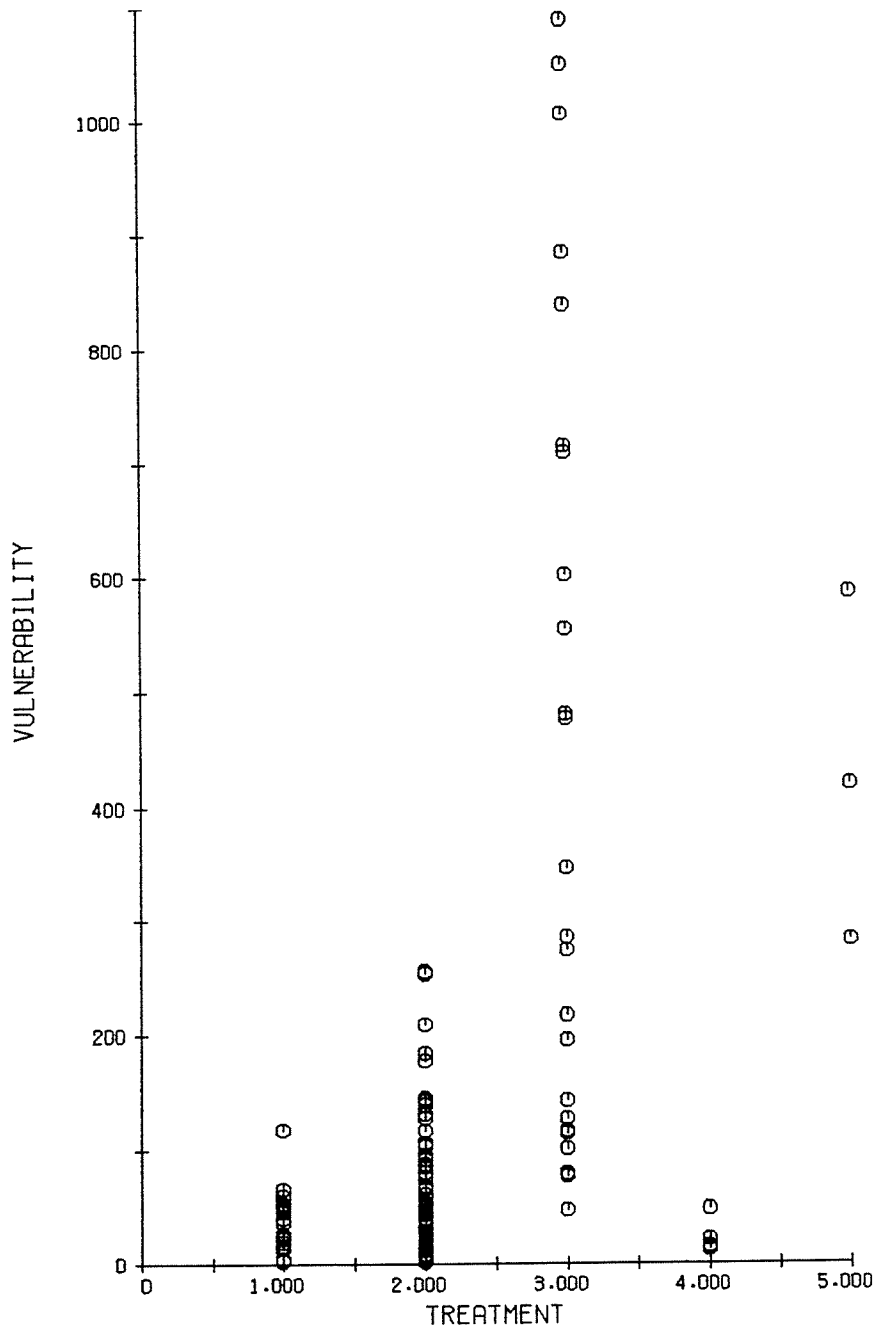


Fig. 6. Vulnerability ($E/B \times 10^4$) for all species combined by treatment (plant operational mode: 1 = reduced-flow with-cap; 2 = full-flow with-cap; 3 = full-flow without-cap; 4 = reduced-flow without-cap; and 5 = tunnel swapping, i.e., the transition period between reversed and normal flow directions). The data were collected at Huntington Beach in 1979 and 1980.

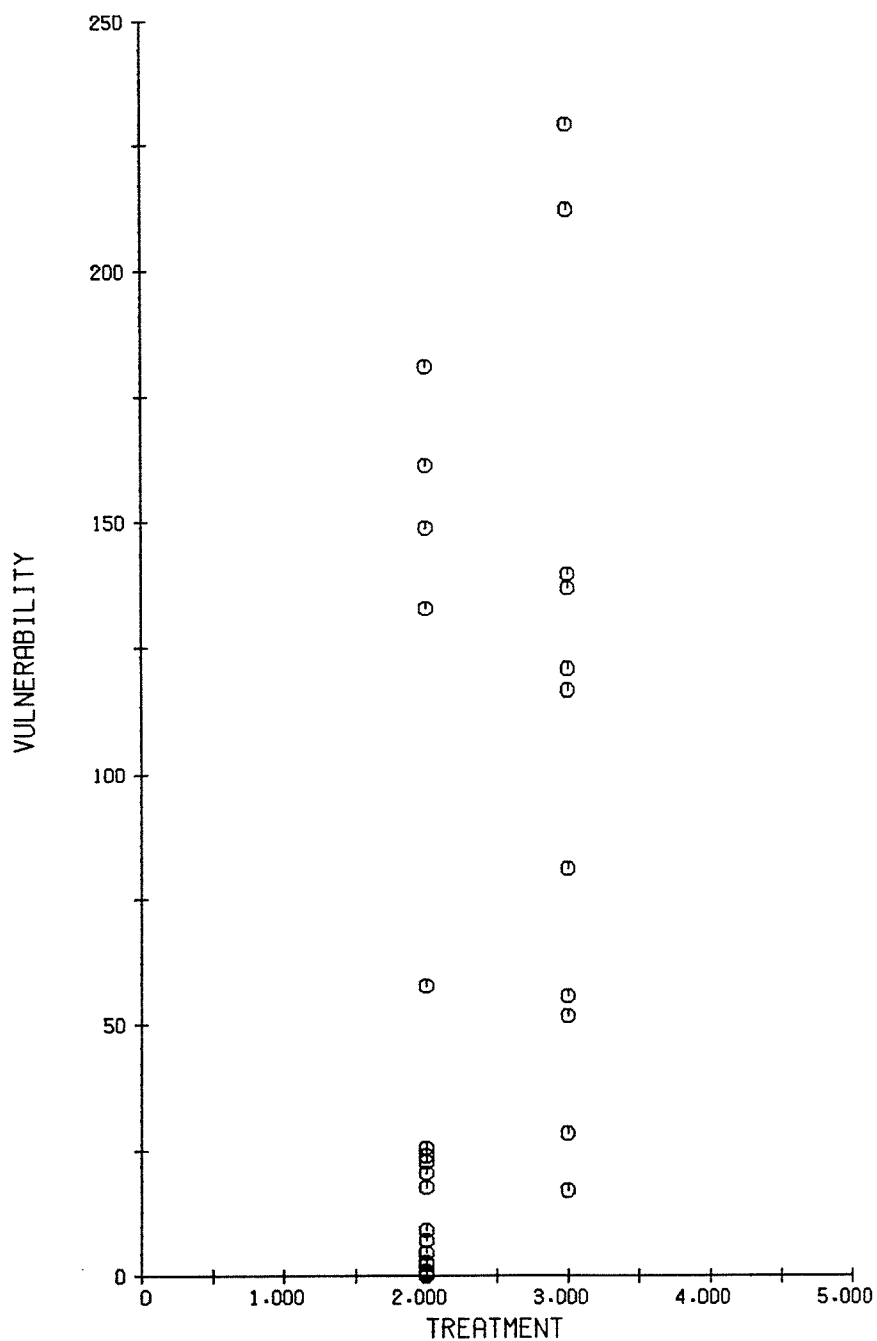


Fig. 7. Vulnerability ($E/B \times 10^4$) of all species combined under full-flow with-cap (treatment = 2) and without-cap (treatment = 3) conditions. The data were collected at Ormond Beach in 1979 and 1980.

Table 2. Results of Mann-Whitney U tests on the effectiveness of the velocity cap by species at Huntington Beach in 1979-80.

Species	Control n_1	Without cap n_2	U	Z	One-tailed P
Queenfish	53	13	174	-2.749	0.0030
White croaker	53	13	139	-3.3162	0.0005
Anchovy	53	13	2	-5.5222	< 0.0001

Entrapment Data. Entrapment data were analyzed for trends during with-and without-cap operations, and suggested a diel aspect in velocity cap effectiveness in reducing fish entrapment. The average hourly entrapment data during with-and without-cap measurement periods are presented by diel interval in Table 3. During daylight, without-cap entrapment was generally greater by at least an order of magnitude than with-cap entrapment. In contrast, at night, without-cap entrapment was generally only 2 to 3 times greater than with-cap entrapment. This result suggests that the velocity cap is more effective during daylight than at night. Although this hypothesis is intuitively acceptable in that the velocity cap probably presents a dramatic visual cue to fishes during daylight, the suggestion cannot be verified until fish density and entrapment data are simultaneously collected during daylight with- and without-cap operations.

3.2.2 Effects of Reduced Flow

Vulnerability data were collected during reduced flow to determine if fish entrapment would decline. The hourly vulnerability coefficients for all-species-combined during all surveys at Huntington Beach displayed a lower range in values during reduced flow conditions than in control flow conditions. However, a statistical difference between the two flow conditions was only demonstrated when data were examined from periods when water clarity was less than 1.5 m (Fig. 8, Mann Whitney U one-tailed $p = 0.0022$, $n_1 = 15$, $n_2 = 18$). This data stratification was necessary because during full flow velocity cap conditions the vulnerability of the fish assemblage already approached zero during clearer water conditions.

The computation of vulnerability coefficients for queenfish, white croaker, and anchovy allowed examination of the reduced flow data for species-specific trends (Table 4). Queenfish displayed lower vulnerability to entrapment with reduced flow (Table 3). The mean ranks of entrapment vulnerabilities of white croaker and anchovy suggested they were also reduced, but not at the $\alpha = 0.05$ acceptance level.

The heat treatment survey in June 1979 allowed the collection of treatment 4 data, i.e., reduced-flow-without-velocity-cap (Fig. 6). The 4 hourly estimates were lower than any full-flow no-velocity-cap data points, thus, independently corroborating the effect of reduced flow on entrapment.

An additional observation during the heat treatment was 1 hr of vulnerability data during "tunnel swapping" operations (treatment 5). Two additional hours of "tunnel swapping" data were collected during the velocity cap field studies (Fig. 6). These three "tunnel swapping" entrapment vulnerability measurements were presented here because they represented the highest vulnerabilities observed during full-flow with velocity-cap (control) conditions.

Table 3. Average hourly entrapment rates (kg/hr) for with- and without-cap conditions at HBGS in 1979 and 1980 and at OBGS in 1979.

Station	Date	Diel	Conditions	Entrapment			
				All species	Queen-fish	White croaker	Northern anchovy
HBGS	1980	night	with-cap	6.78	3.81	0.65	1.68
		night	without-cap	52.99	14.64	17.51	7.23
		day	with-cap	0.65	0.24	0.07	0.15
		day	without-cap	47.20	37.64	3.15	1.49
HBGS	1979	night	with-cap	15.53	8.71	3.39	0.31
		night	without-cap	32.93	6.98	13.52	1.02
		18 hr (day+night)	with-cap	1.97	0.92	0.30	0.06
		18 hr (day+night)	without-cap	20.45	10.01	3.08	1.96
OBGS	1980	night	with-cap	1.97	0.36	0.01	0.01
		night	without-cap	4.99	0.11	0.21	0.01
		day	with-cap	0.12	0.02	*	0
		day	without-cap	0.95	0.02	0.12	*

* Trace.

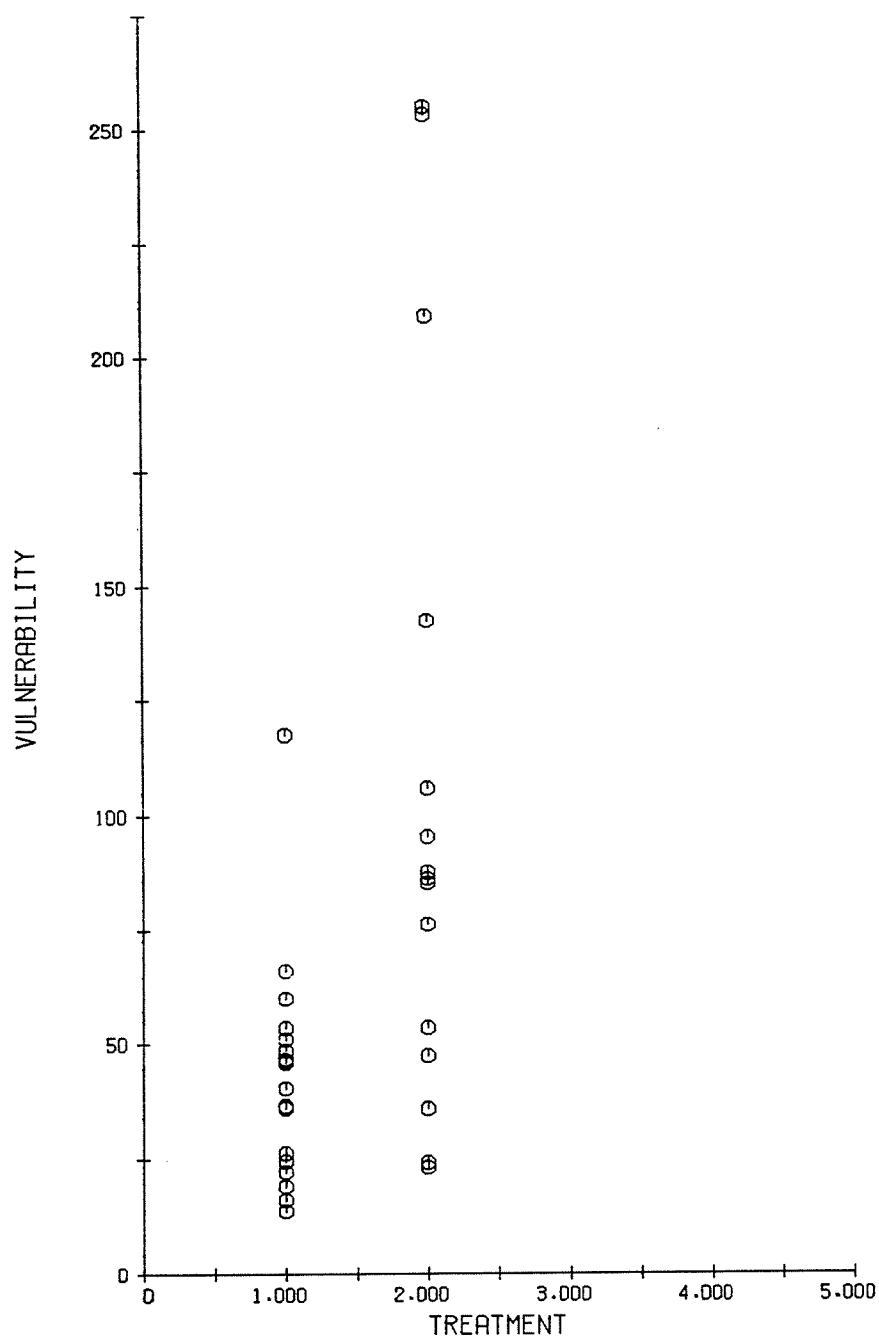


Fig. 8. Vulnerability ($E/B \times 10^4$) of all species combined under with-cap reduced-flow (treatment = 1) and full-flow (treatment = 2) conditions. The data were collected at Huntington Beach in 1979 and 1980 at water clarities $> 1.5m$.

Table 4. Results of Mann-Whitney U tests on the effectiveness of reduced flow by species at Huntington Beach in 1979.

Species	Normal n_1	Reduced		Mean rank	U	Z	One-tailed P
		Mean rank	flow n_2				
Queenfish	15	22.27	18	12.61	64	2.567	0.0052
White croaker	15	21.73	18	13.06	96.5	1.3961	0.0814
Anchovy	15	19.57	18	14.86	100	1.2654	0.1028

4.0 SUMMARY AND CONCLUSIONS

The rapid fluctuation in density and composition of the fish assemblage in the nearshore habitat has prevented accurate abundance measurements by traditional net sampling techniques. This unfortunately has delayed the evaluation of the role of density as a factor affecting fish entrapment. Hydroacoustic techniques have been demonstrated as the only technique to date that can effectively measure nearshore fish densities in the vicinity of intakes with the speed and accuracy required to diagnose the entrapment problem. Utilization of hydroacoustic techniques allowed the description of the density dependence of fish entrapment, the essential first step in the field evaluation of the effects on entrapment of changes to the design, operation, and siting characteristics of cooling water intake systems. This field study demonstrated that in spite of the large amount of natural variability in fish vulnerability to entrapment, the addition of velocity caps to the intake tower design represents an effective treatment for minimizing fish losses. Thus, under present conditions, further treatments for the reduction of fish entrapment would be secondary in nature.

One secondary treatment, that of reduced flow in off-peak electrical demand intervals, displayed some potential for reducing fish entrapment. Since this reduction is at a secondary stage, the total effect was not as large as the velocity cap effect.

Several studies have indicated relationships between water turbidity, reduced sunlight, sky cover, etc., and fish entrapment. A high negative correlation was also observed in this study between water clarity and entrapment. Since the effect of clarity was shown to overwhelm operational factors at the secondary treatment level it represents a very important physical consideration of site selection. The water clarity effect suggests that visibility of the intake to the fish may be a controlling mechanism. The fact that the major entrapment occurs at night when vision is reduced also supports this hypothesis.

The capture efficiency of fish larvae and adults by a variety of nets has been demonstrated in the literature to be related to light level and/or water clarity. The similarity between the controlling mechanisms for fish entrapment and net capture suggest the concept that the intake operates as a stationary fish sampler. If in fact the intake is considered a fish sampling mechanism, and its selectivity and efficiency can be described, as its density dependence has been, then there exists a potential to use intakes for future nearshore fish stock assessment.