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TECHNIQUES FOR ASSESSING THE RESPONSE OF FISH ASSEMBLAGES TO OFFSHORE COOLING WATER INTAKE SYSTEMS

by

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TECHNICAL REPORT

to Southern California Edison Company
with

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GENERAL INTRODUCTION

Fish impingement studies at steam electric power plants with offshore cooling water intake structures typically have two main objectives: 1) to determine the most suitable intake design, location, and operating procedure to minimize fish entrapment, and 2) to assess the "significance" of entrapment. Neither of these objectives can be met by providing data solely on the number of fish killed by entrapment. Their accomplishment requires the comparison of in-plant fish loss information to offshore fish density data. To meet the first objective, offshore fish density and distribution data must be known in the immediate area influenced by the intake structures. However, the second objective requires total population mortality and total entrapment to be known which extends the study area over the population's entire geographic range. This is particularly true in the marine environment where many of the species that are entrapped in large numbers are present within intake areas for only short periods of time. The Southern California Edison Company (SCE), which operates a number of power stations along the southern California coastline, contracted the Fish Encounter Studies (FES) group at Occidental College in conjunction with personnel from the Fisheries Research Institute (FRI) and Applied Physics Laboratory (APL) at the University of Washington, to develop sampling techniques for use in assessing "near-field" response of fish assemblages to design, operational, and siting parameters of their offshore cooling water intake systems. This contract was one element of a multiphase bioengineering research program sponsored by SCE in response to Federal Water Pollution Control Act 316(b) regulations. These particular regulations require that cooling water intake systems reflect the best design, construction, and capacity technology available for minimizing adverse environmental impact. For SCE this requirement can best be met by describing the best technology available for offshore intake systems, and applying it to siting, design, and operation decisions for each of its generating plants. Therefore, the sampling techniques developed and evaluated by FES, FRI, and APL personnel were designed to identify and evaluate intake system characteristics that influence entrapment. In brief, the techniques yield ratios of fish entrapment to density (E/D) for the abundant species which are used to test for differences between different key operating conditions (treatment/normal).

In 1976 the Marine Review Committee (MRC) of the California Coastal Zone Commission contracted the University of Washington Marine Acoustics Group to assess the feasibility of measuring fish density offshore of the San Onofre Nuclear Generating Station (SONGS). This study suggested that acoustic measurements of fish density were reliable enough to determine several aspects of spatial and temporal variability occurring in the fish assemblage there (Acker et al. 1977). A series of six field surveys was conducted to examine changes in fish density with respect to the shutdown and resumption of SONGS unit 1 operations. These results were presented in a series of reports to the MRC (Carlson et al. 1977; Thomas et al. 1977a, b, c, d, e, f, 1978).

In 1977, preliminary studies were conducted by Occidental College and the University of Washington to identify sampling methods to be used in future investigations of cooling water systems. These studies were conducted at the El Segundo and Redondo generating stations. The evaluations of sampling methods were based on ability to provide abundance, distribution, and entrapment data on the species most frequently impinged within SCE screenwells. These species were northern anchovy, white croaker, queenfish, shiner perch, walleye surfperch and white surfperch.

The result of the 1977 study suggested hydroacoustics, lampara seining, gillnetting, underwater television, and SCUBA techniques should be examined in greater detail to better determine their potential for use in monitoring offshore fish populations. The in-plant impingement monitoring methods selected for further examination of their ability to clear screenwells of fish were heat treatments (elevated temperatures) and sodium hypochlorite injections. These methods were evaluated in the FES program (Occidental College) at the Huntington Beach Generating Station during 1978. The primary objective of the FES 1978 program was to evaluate the feasibility of using the previously mentioned techniques to measure changes in fish abundance, distribution, and entrapment with respect to cooling water intake systems. The recommended techniques would then be used in 1979-1980 to study the relationships between entrapment and abundance, and station design, siting, and operational characters. As previously stated, the results of the 1979-80 studies will provide input into SCE's 316(b) "best intake technology" demonstration.

Foremost of the assumptions guiding the design and evaluation of the sampling methodology described in this report was that density and distribution of fishes in the immediate vicinity of an intake structure are the most important variables affecting the number of fish entrapped (Haven and Ginn 1978). Thus, the ability to provide reliable estimates of fish density in the offshore areas influenced by cooling water intake systems represents the singlemost critical problem in intake system assessment (Sharma 1978). This problem is addressed in this study, and a sampling methodology that reliably estimates offshore fish density and distribution is presented.

A second necessity for an understanding of the relationship between abundance and entrapment is the acquisition of accurate entrapment rate information. Estimating entrapment is difficult because actual entrapment can only be observed indirectly by impingement. Within SCE offshore cooling water intake systems there occurs a considerable delay between time of entrapment and time impingement. This entrapment monitoring problem is also addressed in this study.

PART I: ESTIMATION OF OFFSHORE FISH DENSITY

1.0 INTRODUCTION

The measurement of fish density is complicated by the diel (day, night), day to day, and seasonal changes in distribution and behavior of fish populations. This is particularly true in the southern California marine coastal environment where physical and biological parameters fluctuate rapidly in part because of the upwelling oceanic conditions and presence of a highly migratory fish assemblage. Thus, biological variability accounts for a large portion of the lack of precision observed in many estimates of fish density. This lack of precision in density estimation has impeded the determination of relationships between abundance, entrapment, and other parameters in past investigations. Therefore, a major consideration in the development of the fish sampling methodology reported on in this paper was that biological variability be minimized. The most direct method of minimizing biological variability is to limit temporal and spatial parameters. That is, collect data only during a single, short period of day,when fish behavior is relatively constant and limit data collection to as small a study area as required in order to increase the proportion of the area sampled. Documentation and collection of the background knowledge essential to this approach represented the tasks for FES in 1978. These tasks were: 1) to identify sampling equipment that in a short time interval collect sufficient data for making reliable estimates of fish abundance (sampling gear), 2) to determine the temporal and spatial parameters for data collections (data acquisition), and 3) to develop efficient processing techniques to prepare data for analysis (data processing). These tasks are addressed in the following chapters.

1.1 Identification of Sampling Equipment

Catch-per-unit-effort (CPUE) has been the most common means of determining fish density in fisheries management research. The major assumption in using CPUE measurements is that the size of the catch is proportional to the fish density. A necessary condition for this assumption is that catchability of a particular year is constant. Implicit in this is that selectevity, (the proportion of the fish by size class in the sample volume that are vulnerable to the net) and efficiency (the relative selectivity between species) is constant. Catchability, selectivity, and efficiency are not constant because of temporal changes in the distribution and behavior of fishes. The catchability of a gear type is also dependent on a fisherman's ability to use it and thus catchability may be reduced by many environmental conditions (i.e., weather, currents, etc.). These and many other biological and physical parameters may introduce bias and/or variance to CPUE measurements.

In limited situations, net or other catch removal techniques have provided estimates of absolute abundance. For example, mark and recapture techniques have been useful in small lakes and ponds, but a large number of recaptures are required to make a good estimate. The absolute size of fish populations in larger bodies of water has been estimated by decline in CPUE (Leslie Method). This latter technique, however, is obviously unacceptable in impact assessment. Due to these facts virtually all fisheries management is based upon deterministic measures of population size (unreasonably large confidence limits). Unfortunately, today, many of the objectives of successful fisheries management require more accurate measurements of population size. Even if the most expedient of the classical methods, net sampling, could collect an adequate sample fast enough, the difficult tasks of determining selectivity and efficiency would still have to be contended with. Since the determination of these parameters for a particular gear is difficult and costly, and the results of such past studies have not been universally accepted within the scientific community, we have promoted the use of hydroacoustic measurements of fish density under suitable conditions. Because of the sample volume and resolution obtainable in short time intervals, hydroacoustics cannot be matched with any other sampling gear type.

1.2 Hydroacoustic Techniques

In recent times, hydroacoustic techniques have provided an alternative to the traditional methods of mark and recapture and CPUE in the quantitative study of fish populations. Hydroacoustic data have several characteristics which make possible the rapid measurement of fish density with relatively small variance and bias. First, when collected at high repetition rates with a high degree of overlap between samples, it is continuous and therefore provides high resolution information on fish distribution, whereas net samples are discrete, requiring substantial interpolation to obtain similar information. This continuous nature of hydroacoustic data also allows the investigator much greater freedom in the selection of the experimental design than he would have with discrete samples obtained from a net. The sampling volume obtainable per unit of time with acoustical transecting methods is at least an order of magnitude larger than what is possible with a net. This additional coverage reduces the error which may be introduced from improper allocation of sampling effort within a study area. Hydroacoustic measurements can also provide continuous and simultaneous measurement of bottom hardness, structure, vegetation, plankton, etc. No other fishery assessment technique can provide the quantity of information, with the speed, precision, and cost that acoustical methods can.

In spite of the above, advantages care must be taken in selection of hydroacoustics as a sampling methodology. This is because hydroacoustic techniques, as stated above, have only recently been employed in quantitative studies of fish populations. Sources of bias or error in acoustic sampling methodologies are not widely understood by the present community of fisheries biologists. This is particularly true when hydroacoustics are proposed for employment in an area such as the Southern California nearshore marine environment where hydroacoustic techniques have not been evaluated thoroughly. Therefore, hypotheses initially proposed for evaluation using hydroacoustic techniques will represent the initial demonstration of this application.

The hypotheses SCE has requested to be analyzed meet this criterion (e.g., the effectiveness of the velocity cap in reducing entrapment is expected to be 90%). However, the hypotheses SCE requests to have studied cannot successfully be addressed using classical net sampling techniques. This is because analyses of relationships between entrapment and density must take into account the very swift and dramatic changes in abundance which occur in the nearshore environment of the intake structures.

The species of primary concern are highly mobile, transient fishes thought to exhibit marked diel shifts in distribution. The collection of an adequate sample of these fishes for meaningful determinations of density within the restricted area around an intake structure within single diel intervals using classical net methods is not practicable. Hydroacoustic techniques are, therefore, the best choice for a sampling method. Hydroacoustic techniques and their potential sources of error are introduced below.

Hydroacoustic techniques can be described in two phases: data acquisition and data processing. The acquisition procedures data can vary depending on study objectives. Usually when measuring offshore fish densities a boat echo sounds along transects through the study area using a calibrated high frequency transducer mounted in a downward-looking position. The collection of essentially continuous data is possible by increasing the repetition rate to the point where each acoustic sample overlaps. Qualitative target information is collected in real time on an echogram while quantitative data are recorded on magnetic tape. Acoustic data processing can be separated into two techniques, echo counting, and echo integration. At low fish densities ($<10^{-4}$ fish/m^3) echo counting has a smaller mean squared error than integration, but as densities increase above this level the error of echo counting increases, whereas the error for echo integration declines (Ehrenberg and Lytle 1972). Echo integration was the procedure for selected assessment of fish populations in the vicinity of southern California cooling water systems.

Echo integration techniques require the use of computers to analyze the volumes of information collected by this method. Recent advances in this area have greatly increased the complexity of analysis that is possible. One of the more sophisticated computer programs available for echo integration allows the water column to be stratified into as many as 50 depth intervals (Thorne 1977).

Moose and Ehrenberg (1971), and Ehrenberg and Lytle (1972) have developed mathematical models for abundance estimation by acoustics. Moose (1971) reviews many of the assumptions (sample volume, target strength, etc.) underlying the biology and the physics of these models. With regard to these assumptions Thorne (1977) concluded the major source of error in acoustic surveys is the result of the distributional characteristics of the fish and that this can be minimized by the appropriate choice of equipment and experimental design to be used.

Today the most widely accepted method for measuring the error associated with acoustics is survey replication. Thorne (1973), Johannesson and Losse (1977), and Thomas et al. (1978) used a replicated survey technique to measure variability in their estimates of fish density. Johannesson and Losse (1977) found that in a small survey area of 43 km^2, replicated surveys showed a precision of ±30% (95% CI) for the fish population there. Thorne (1973) found the standard deviation of the population estimate of hake in Port Susan, Washington, to be less than 10% of the estimated densities. Johannesson and Robles (1977) made estimates of the anchovy population off Peru with ±1% precision (95% CI). Even in a survey of strictly demersal fishes (demersal fishes are particularly difficult to estimate abundance of acoustically), on the Scotian Shelf near Nova Scotia, the precision of population estimates were 25% to 50% (90% CI, Nickerson and Dowd 1977).

Both echo counting and echo integration require knowledge of the mean back-scattering properties of fish in order to compute abundance. In echo counting, this information is needed to compute sample volume, whereas integration requires it to scale the integrated squared voltage output and obtain density measurements. A measure of fish back-scattering properties is the acoustic target strength. Target strength has been measured extensively by direct (Johannesson and Losse 1977) and in situ (Ehrenberg 1974; Ehrenberg et al. 1976) methods. The FAO/ACMRR working party on fish target strength concluded in their 1977 session that on the basis of information available that all fish with swimbladders may be grouped into one class with respect to mean target strength per unit biomass. This important conclusion was based on the similarity of mean target strength measurements made by a large number of independent investigators on several different species. Dunn and Forbes found that the target strengths of the gadoid species were practically identical when adjusted for differences in fish weight, and Johannesson and Burazynski obtained similar results for the many other species of fish studied during FAO field surveys (Anon 1978). Nakken found this generalization also applied to herring and sprat. As expected the fishes with no swimbladder had much lower target strengths; however, insufficient data were available to determine whether they also form a single group.

Biological components can be separated into two categories: distributional bias and variances. Distributional bias lies in the availability of the fish to the acoustic gear, in space and time. Conventional echo sounding techniqes are limited in their ability to survey the very near surface and bottom of the water column. In many surface-to-bottom facing transducers the first 2 m of water column are lost. Similarly, fish targets must be at least one-half the pulse length in distance above the bottom in order to be separated from the sea floor. In addition, boat avoidance is a commonly observed behavior of near-surface schooling fish. Of course, the importance of these limitations is largely dependent upon the species being studied and there are several ways in which to minimize these errors through choice of equipment and experimental design.

Variability in size and species composition may contribute bias to the general application of acoustics to fishery assessment because of the lack of definitive information on fish target strengths. In virtually all the previously mentioned applications the authors have claimed to have surveyed predominantly single species populations. In a nearshore marine environment, however, the fish composition can be complex and highly variable. Since the identification of species compositon depends primarily upon net capture techniques which are costly, inefficient, and of questionable performance, there have been few attempts to acoustically assess mixed species assemblages. However, the similarity in mean target strength per unit biomass among various species referred to above may mitigate this bias. Two promising studies on mixed assemblages have been the investigations of the nearshore fish populations in the vicinity of the San Onofre and Huntington Beach Power Generating Stations (Thomas et al. 1977a, 1978).

Distributional variances refer to the non-uniform spacial distribution of fish. The majority of this variance can be minimized by an appropriate sampling design. In the past, zig-zag survey patterns have been used to provide maximum coverage of an area for a given amount of ship time. Unfortunately, zig-zag transect patterns can produce serially correlated observations (Nickerson and Dowd 1977) which increase the variance of the density measurements. Recent studies have employed standard random and stratified random survey designs to reduce the variance in density measurements (Thomas et al. 1978).

It is realistic to expect considerable sophistication in the statistical treatment of hydroacoustic data in the next few years because of its rapidly increasing acceptance as a fishery assessment tool. Because hydroacoustic techniques can quickly provide information on large-scale changes in fish abundance, it is not surprising to find that acoustic techniques have been used extensively on a number of resource assessment surveys (Thorne 1973, 1977; Parrish 1975; Taylor and Barne 1976; Mathisen et al. 1977) and more recently for ecosystem studies (Blackburn and Thorne 1974; Thomas et al. 1978). The concept of collecting continuous data on the fish distribution and water temperature simultaneously with the aid of acoustics was first investigated at the Point Beach Nuclear Power Station on Lake Michigan (Spigarelli et al. 1973); later at Calvert Cliffs Nuclear Plant on Chesapeake Bay, Maryland (Zankel et al. 1978; Thorne, personal communication); at San Onofre Nuclear Power Station in California (Thomas et al. 1978) and on the Great Lakes (Minns et al. 1978). The data collected in these studies have proved the feasibility of large-scale synoptic investigations of fish distribution and behavior using hydroacoustic techniques.

1.3 Net Sampling Techniques

Hydroacoustic techniques are extremely useful to all types of fishermen in the location of "good" fishing grounds. However, the complexities of fish behavior have confounded the study of the difference in acoustic target properties between species. Thus, species identification with acoustic gear independent of information derived from nonacoustic sources is not yet possible. Because identification of echoes to a species level is required in this study a net sampling program was developed to subsample acoustic targets.

Several methods have been developed to identify acoustically monitored targets. Photography, direct observation, hook and line, electrical fishing, explosive charges, predator stomach content analysis, and numerous net fishing techniques have all been applied at some time to this problem. The most widely applied identification technique has been to capture targets with some appropriate fishing gear, normally a trawl or seine, or another type of net. The accuracy of these techniques is determined by the selectivity and efficiency of the gear. It is therefore important to choose a sampling gear that minimizes error due to selectivity and maximizes efficiency. In cases where several fish species are present, several gear types which are selective and efficient for those fishes may yield the highest quality of data. Direct observation should be made whenever feasible.

There are several important advantages which a combined hydroacoustic-net sampling program have over a net-only or an acoustics-only sampling program in addition to the high resolution of the acoustic information obtained. First, since hydroacoustics give a rapid picture of the distribution of fish over the study area through echogram traces, net sampling can be stratified by the "ideal" variate, fish density, which is the quantity to be measured in the survey. By stratifying the survey effort in this way, the variance within strata is much smaller than the overall variance (Cochran 1977) which results in the collection of higher quality data. Second, since the primary purpose of the net catch is now to determine species composition rather than to measure fish density, and since the calculated variance on relative abundance indices have been demonstrated to be lower than for density measurement, the number of samples required to obtain similar precision is reduced. These two advantages increase the effectiveness and reduce the cost of a net sampling program. In addition, the deployment of hydroacoustics and net sampling techniques simultaneously provide information from which some aspects of net selectivity and efficiency can be evaluated.

2.0 METHODS

The primary objective of measuring 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 net sampling program was conducted in order to subsample a proportion of the acoustic fish targets for species composition. The methods described below were developed through the cooperative efforts of Occidental College and the University of Washington in 1978 studies at the Huntington Beach Generating Station. The survey design reflects efforts to minimize the natural variability due to fish behavioral patterns in order that the response of fishes to plant operations may be described with some degree of accuracy. Such determinations of fish response are an integral part of SCE's 316(b) Demonstration Study.

2.1 Sampling Gear

The sampling gear employed to determine the offshore fish density consisted of two components: 1) the hydroacoustic equipment, i.e., echo sounder, chart recorder, magnetic tape recorder, etc. and 2) the sample fishing gear, i.e., lampara seine and vertical gillnets.

2.1.1 Hydroacoustic Gear

A block diagram of the data acquisition system used at Huntington Beach is shown in Fig. 1. This system was developed by the Marine Acoustics Group at the University of Washington, and has been used extensively to gather acoustic data on fish stocks. The chart recorder provides real-time output while the interface amplifier and magnetic tape recorder allow data to be stored for later detailed analysis. System parameters can be adjusted to optimize echo returns for particular applications. These parameters are discussed below.

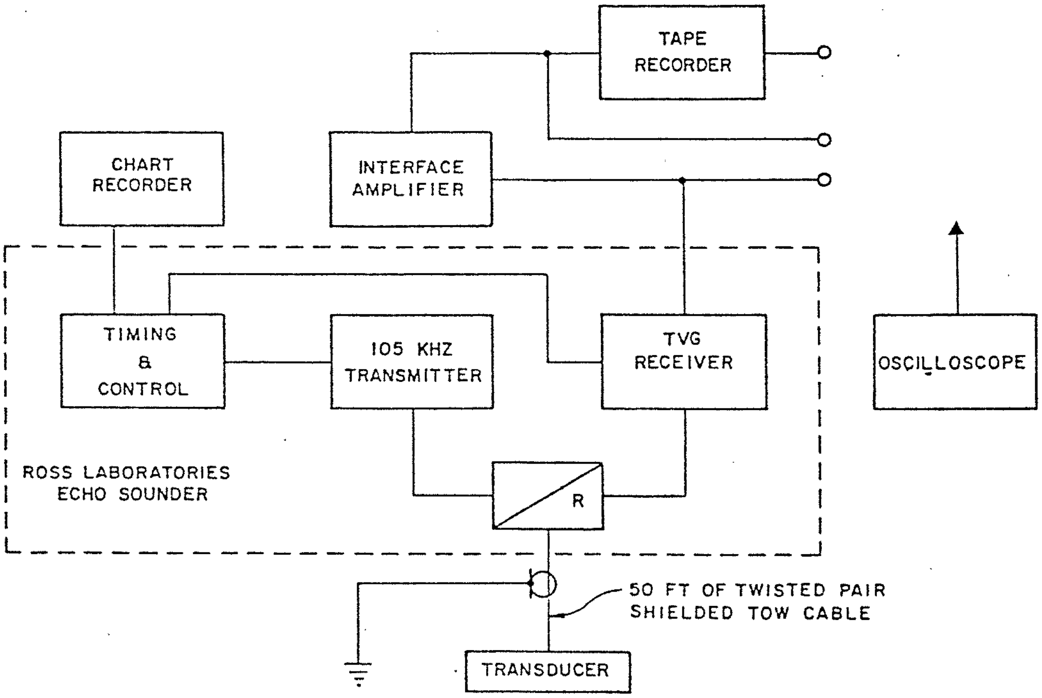


Figure 1. Block diagram of data acquisition system.

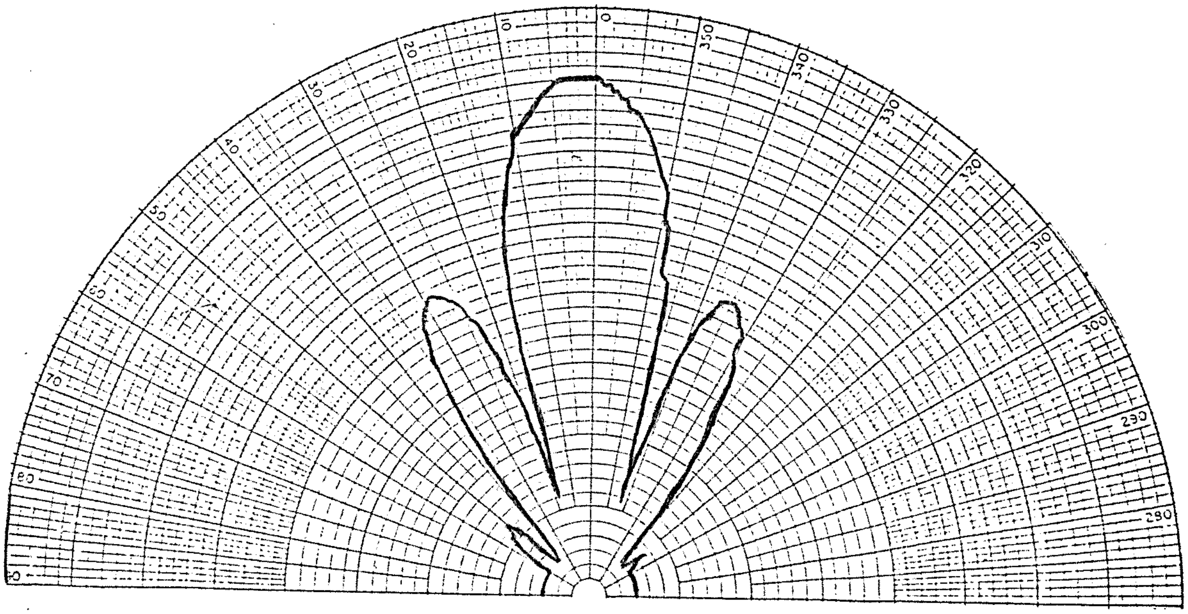


Figure 2. Transducer directivity pattern for Ross 105 kHz.

Echo Sounder. The echo sounder functions as a transmitter, receiver, and amplifier. The transmitter component provides power of a specific frequency and pulse length to the transducer when triggered by an electronic circuit, which in our case is provided by the chart recorder. The power output, sound frequency and pulse length are some important system characteristics used for selecting the echo sounder suited for particular applications. In general, the resolution of acoustic targets increases with frequency since shorter pulse lengths and narrower band widths may be employed; however, the range of target detection decreases with increasing frequency because of increased attenuation. In addition, while resolution of near-bottom, near-surface and vertical distribution of targets increase with shorter pulse lengths, the average power into the water decreases. The power output level of an echo sounder must be sufficient to detect a minimum size target within the desired sampling range which is a function of the physical properties of the water ensonified, i.e., temperature and salinity. For example, the detection range at any given power is less in salt water than in freshwater because the higher salinity causes more attenuation of sound. Attenuation in salt water increases with sound frequency and is one of the most important characteristics which limits the range of echo detection. Maximum power output is dependent upon transducer size, and is, therefore, limited by the practical size of the transducer that can be deployed in a particular field situation.

The echo signals received at the transducer are very weak. Therefore, before they can be recorded they must be increased in amplitude. This is accomplished by a receiver-amplifier. The amplifier must maintain a good signal-to-noise ratio because of the magnitude of amplification (sometimes as much as 10^6 to 120 dB). Noise due to interference is introduced by the amplification. There are several ways to minimize noise such as the selection of an appropriate band width. The noise voltage increases with band width; however, the band width must be chosen which is compatible with the pulse length to prevent original distortion. This is approximated by:

$$\text{Band width } (\text{KH}_z) = \frac{2}{\text{pulse length (milliseconds)}}$$

Two gain controls, one automatic and one manual, are fitted into the echo sounders by UW/FRI/APL employees. This modification is necessary for echo integration. First, the automatic form of gain is known as time-varied-gain (TVG). Time-varied-gain adjusts the amplitude of signals from different depths for the one or two-way loss of signal due to geometric spreading and frequency-dependent absorption. Therefore, targets of the same size but at different depths will show equal reflection on the recording systems. Second, a manual gain control is present for adjusting the amplitude of the echoes in order to optimally match the dynamic range of the recorders.

In conclusion, the selection of the appropriate sounder represents a compromise between several different system characteristics. Virtually all echo sounders available on the market today have a restricted choice of these limiting characteristics. In addition, there is a wide variety in the quality of the electronics used in "stock" echo sounders. Fortunately, the Marine Acoustics Group at the University of Washington has several high-quality sounders to choose these parameters from and has developed and is presently field-testing a new sounder with flexibility in all these parameters.

Chart Recorder. The chart recorder has two functions: 1) to provide a trigger for the transmitter, and 2) to record a real-time display of the echo signals. The characteristics important to selection of the appropriate chart recorder are: 1) the pulse repetition rate; 2) the type of chart record it produces, and i.e, its scale, depth range, etc.; 3) its compatibility with the echo sounder (many echo sounders come with their own chart recorder); and 4) its portability and cost. The Ross chart recorders, used in the Huntington 1978 surveys, were selected because of their 1) flexible trigger rate (an advantage in shallow water acoustic applications because it allows collection of a large and continuous sample volume; and 2) the high visual quality of the echogram.

Transducer. The transducers employed are of "electrostrictive" type which means they measure and produce sound by changes of dimensions related to an applied electrical field. Transducers are designed to operate at one frequency and considerable loss in power and distortion of the beam pattern occurs with small deviations from the designed frequency. The transducer is functionally an electroacoustic oscillator which directs sound within a well-defined beam pattern. The distribution of sound energy transmitted in different directions is described by its directivity pattern function:

$$b = b(\Theta,\phi)$$

where: Θ is the angle perpendicular to the transducer
ϕ is the angle from a certain reference direction in its plane

The directivity pattern of the Ross 105 kHz transducer is presented in Figure 2. The common description of a transducer beam pattern is its beam width given as the half-value angle. The half-value angle is the angle at which the sound intensity has dropped 1/2 the value it has on the acoustic axis, b = 1/2 and 10 log b = -3 dB. As we see from Figure 2 the half-value angle for the 105 kHz transducer is 17^o.

The quality of a transducer for echo integration technique is often the combination of its: 1) power capacity (proportional to its size), 2) the size of its side lobes (obviously large side lobes may severely distort sample volume and vertical distribution measurements), 3) the width of its beam pattern, half-value angle (a trade-off between sample volume and vertical resolution), and 4) the practicality of its deployment (size, cost, compatibility with sounder, etc.).

The transducers used at Huntington Beach were high power, with small side lobes (down more than 15 dB off acoustic axis), relatively moderate half-value angles, and easily deployed off the bow of the vessel in a Braincon 2 ft towed body (Figure 3) in order to minimize boat avoidance by the near surface fishes. This body can be towed through the water at speeds in excess of 10 knots while maintaining acceptable stability.

In 1979, the SIMRAD EK120 was matched with a 9^o half-value angle transducer. Taking into account the increase in power with the narrower beam the sample volume of the EK120 system was approximately 75% of the Ross system. A wider angle transducer may be more suitable for the present studies; however, one is not presently available and would have to be fabricated at the Applied Physics Laboratory (the approximate cost is 5K).

Magnetic Tape Recorder. The purpose of the magnetic tape recorder is to collect high-quality data on fish echoes for a later detailed computer analysis. Magnetic tape recorders often determine the effective linear dynamic range of the acoustic system. Both AM and FM recording systems are presently used to record acoustic reflections from fish targets. The general acceptance is that FM provides higher resolution and a larger linear dynamic range than AM recording. However, the cost benefit analysis of using FM over high speed AM recording has not yet been determined for the echo integration technique. The AM recording systems we presently employ provide 40 dB linear dynamic range, which means echoes between two orders of magnitude (i.e., 0.01 to 1 volt) are recorded without significant distortion. As previously described when fish target echoes exceed this range, the operator may use the manual gain control to "optimize" the echo strength range he wishes to record. Virtually all recorders have gain adjustments which may be used in addition to sounder gain adjustments. In echo integration this normally means that the manual gain is set to a level which allows recording of the largest targets present without saturating the acoustic system. When fish schools are present in an area, it has been demonstrated that the fish schools represent the largest proportion of the biomass present in the area (Hewitt et al. 1976). Since biomass is the "ideal" variate of an echo integration survey, to adjust the system to collect the largest targets normally results in biomass measurements of higher precision than if a mid-range target strength was selected for recording.

Fig. 3. Acoustic V-fin depressor deployed from bow boom.

Power Supply. Few ships have a power supply which does not introduce significant amounts of noise into the data collection. For this reason the use of an independent power supply is preferable. In the 1978 Huntington surveys the power supply consisted of two 12-volt car batteries connected in a series, a 24-volt inverter, and a voltage regulator.

2.1.2 Net Sampling Gear

The objectives of sample fishing were to measure the abundance and distribution of selected species. Selection of species was based on 1) the magnitude of the effect of the plant operations on them (entrapment), 2) their economic and/or recreational importance, and 3) their abundance and/or ecological importance (Cox 1970) to the area. These species included northern anchovy, queenfish, white croaker, shiner surfperch, walleye surfperch, and white surfperch. At certain stations other species (kelp bass, sargo, spotfin croaker, Pacific butterfish, black and pile surfperches) are impinged in numbers which may warrant concern as well. All of these species occur across the southern California bight, and the majority has bathymetric ranges from shallow water to at least 60 m. In shallow waters numerous size classes of each species are present. Each of the primary species is characterized by schooling habits. Several species are known or thought to exhibit movements daily or seasonally which may feature intake-discharge structures as an object of such movements for feeding or orientation purposes. Most of the species exhibit marked diel shifts in behavior, generally schooling tightly during daylight and dispersing at night. Several of the species are found throughout the water column, while others are oriented primarily to the bottom or to the surface. The species differn geatly in body size. In consideration of these behavioral and life history observations for the species of primary concern, optimal net sampling techniques were chosen to identify acoustic targets on the basis of the following characteristics: 1) to be able to fish the entire water column at the location of an observed acoustic target in the shortest period of time with the highest efficiency; 2) to have the ability to capture and retain the largest size range of fishes with a similar catchability; 3) to have the ability to capture the largest variety of species with the least difference in catchability; 4) to be able to fish effectively over the widest variety of habitats, 5) to be able to be deployed throughout different diel or seasonal periods with similar fishing power; and 6) to be cost/effective. Clearly, no existing single net sampling method possesses all these characteristics. Therefore, a combination of complementary gear types was evaluated for the feasibility of conducting a large scale synoptic fish survey at Huntington Beach. The methods considered were the lampara seine, gillnet, SCUBA diver operations and camera techniques. The visual methods were unsuccessful because of poor water transparency, while the net sampling methods were moderately successful and compliments in that selectivity parameters could be estimated by comparison of catch data.

Lampara Seine. In general, the least selective of fishing gear used in marine waters is the surrounding nets, i.e., purse ring and lampara seines. Their low selectivity results primarily because of the small mesh size. They are also relatively efficient for a large variety of species. The lampara seine probably requires the least amount of time of all the surrounding nets from deployment to closing on an observed fish target.

The lampara net was selected as a gear type to subsample acoustic targets in the offshore study area for the above reasons. When fished properly the lampara seine probably has the ability to capture a larger variety of species (highest relative efficiency) and a larger size range of individuals within a species (lowest relative selectivity) than any other single net which could be deployed to capture acoustic targets located throughout the entire water column.

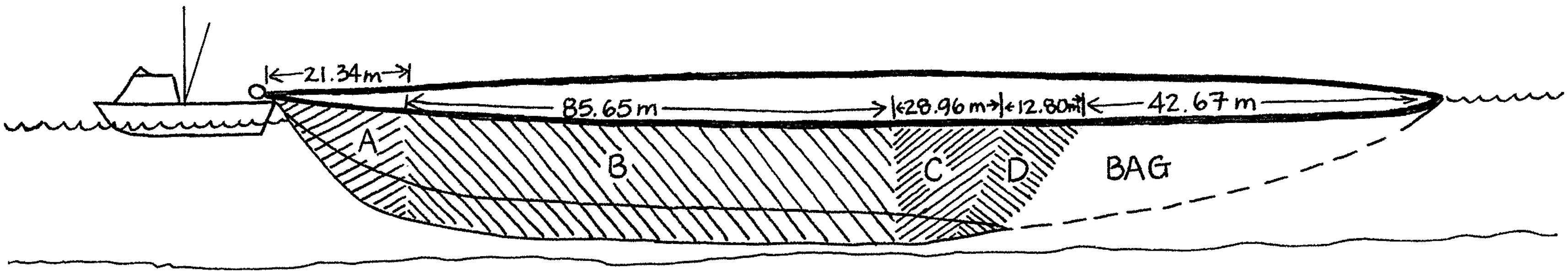
A commercial live-bait boat was chartered for lampara seining in the 1978 surveys. The seine used in our studies was constructed for commercial use in shallow water. The University of Washington, Fisheries Research Institute (FRI), has pioneered the use of lampara seine for scientific purposes (Thomas et al. 1978).

In the SONGS and Huntington 1978 studies, FRI used the lampara seine only for identification of acoustic targets. However, other researchers have recently used this gear for abundance estimates and have examined some aspects of selectivity and efficiency (E. DiMartini, personal communication).

The net consisted of an 85-m corkline at the bunt of the net (Figs. 4 and 5). The bag of the net measured approximately 60 m deep and was constructed from approximately 1.5 cm stretched mesh. The thread of the net (the section around the bag which represents the initial pursing sections) was constructed from heavy material with an approximate mesh size of 3.8 cm. Attached to the sides of the bag were two 148 m corkline wings which tapered into rope leads. A large float was attached to the primary lead rope and the secondary lead rope was fixed to the boat. The retrieval of the rope leads and wings was made with a dual-hydraulic drive system. Once the bag was retrieved the catch was processed manually.

There are two major disadvantages to lampara seining: 1) the lampara seine cannot be deployed safely closer than 60 m to an intake structure, and 2) it doesn't provide information on the vertical distribution of fishes in the water column. These two limitations prompted the complementary useage of gillnets.

Gillnets. Evaluation of gillnets during 1977 at the RB and ESGS and during 1978 at HBGS showed that they fished effectively near intakes, provided vertical position information, were relatively inexpensive, easy to handle, and did not require a specialized vessel for



LEGEND

A - 20.32 cm stretch mesh, floats 45.72 cm on center, tapered.

B - 17.78 cm stretch mesh, floats 40.64 cm on center, 30 fathoms vertically.

C - 15.24 cm stretch mesh, floats 35.56 cm on center, 30 fathoms vertically.

D - 3.81 cm stretch mesh, floats 35.56 cm on center.

Bag - 1.59 cm stretch mesh, floats 35.56 cm on center.

Fig. 4. Horizontal view of lampara net.

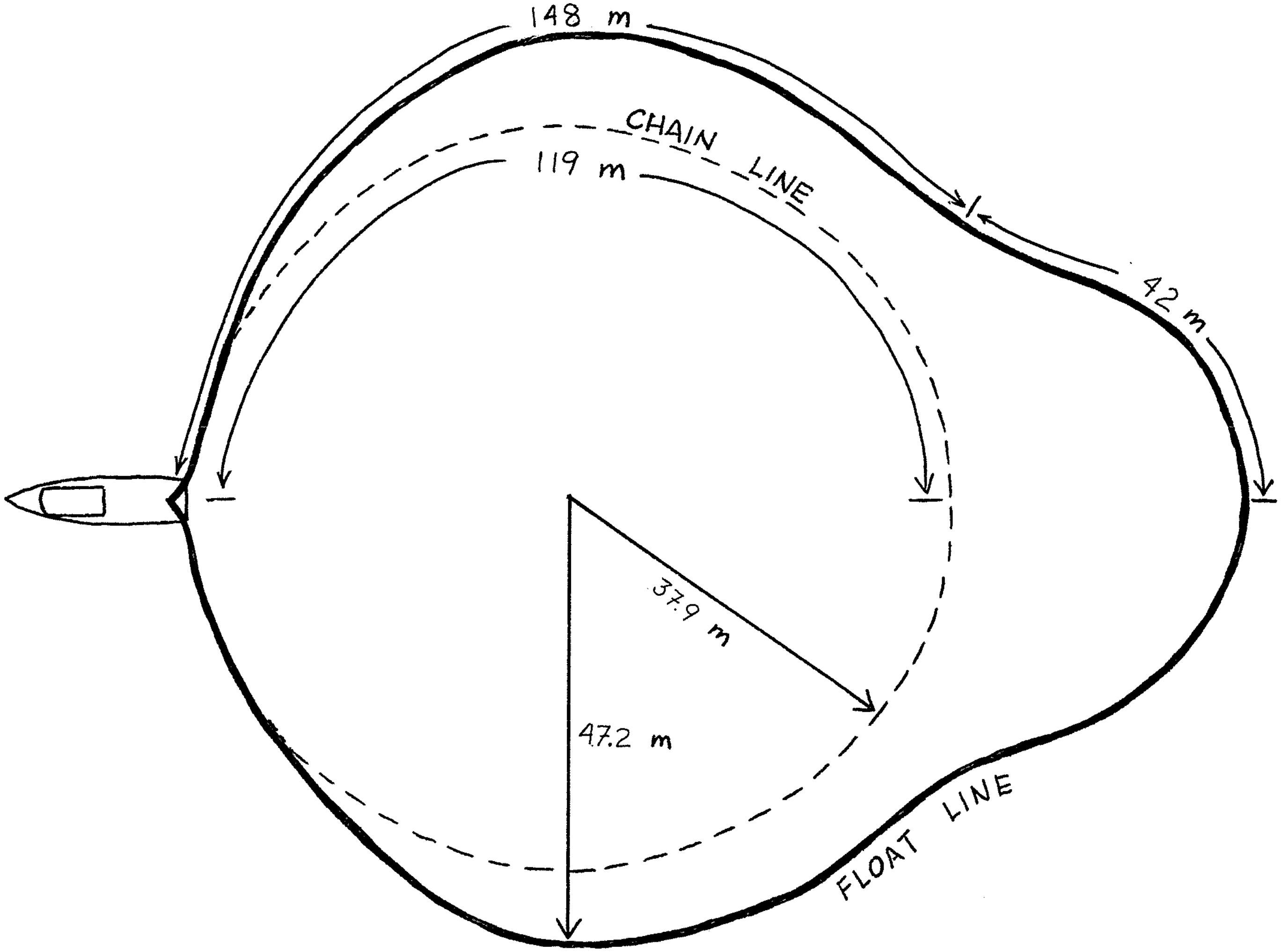
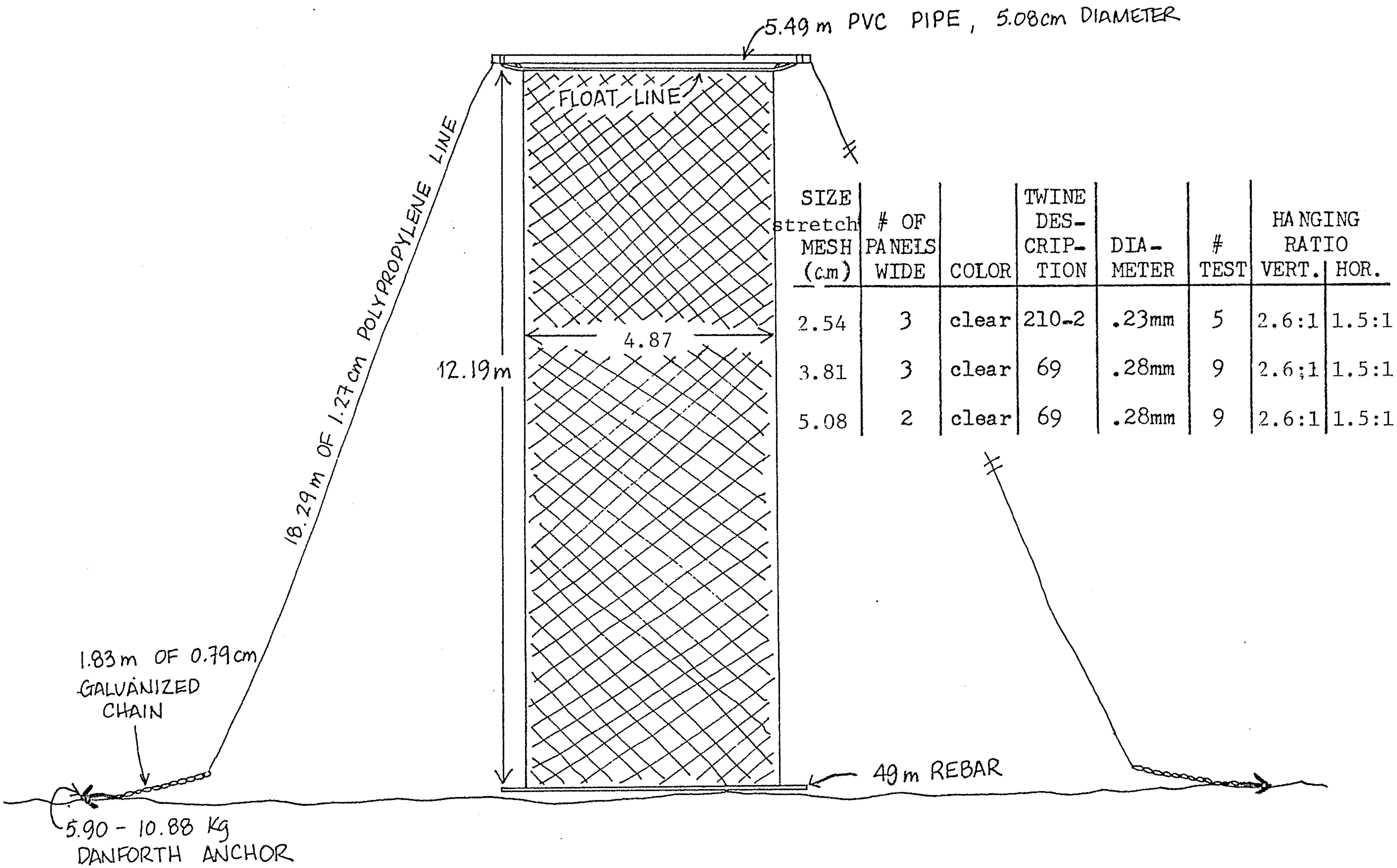


Fig. 5. Top view of lampara net.

their deployment. Their ability to provide species composition information, however, was limited because of problems of efficiency and selectivity. Gillnets of a single mesh size have high selectivity (they catch only a small size range of fish) and low efficiency (they catch relatively few species). Thus, in order to accurately determine the species composition of fish near an intake structure, many mesh sizes have to be employed. The deployment of many mesh sizes, however, reduces the CPUE. This is because the area in which the gillnetting is to be accomplished around an intake structure is limited and each additional mesh size reduces the total number of those panels fished which have the optimal selectivity for capturing the dominant species in the area. For example, at the El Segundo and Redondo Beach Generating Stations in 1977 a large number of mesh sizes were fished. This resulted in CPUE values too small for meaningful analysis. Thus, the decision was made to reduce the number of mesh sizes used, and to concentrate on catching those species and size classes constituting the majority of fish entrapped at a station. The catch data thus obtained will be used to provide information on the vertical distribution of these fishes and to make relative estimates of their abundance. A variety of net designs and mesh sizes were evaluated offshore of the HBGS in 1978. The evaluations were based on a net's ability to 1) catch those species and size classes which constituted the majority of entrapped fish and 2) to provide vertical distribution data. The designs and mesh sizes that most adequately resolved problems of efficiency and selectivity in fishing for these particular fish were chosen for use in 1979 FES studies. The vertical gillnets which were the most effective and selected for use in 1979-80 were each 4.87 x 12.19 m (16 x 40 ft) in size (Fig. 6). Each net was constructed of a single mesh size. Mesh sizes used were 2.54, 3.81, and 5.08 cm (stretched). These particular mesh sizes proved to be the most efficient and selective in capturing the species and size classes most frequently entrapped and/or most abundant offshore of the HBGS in 1978. Construction details for vertical gillnets are shown in Fig. 6.

A ratio of 1.5:1 was employed in attaching netting to lead lines and float lines. The rhombic shaped meshes of the netting were hung so that they were broader than high. This orientation minimized "pinching" of the netting, thus eliminating the need for horizontal spreader bars. A 2.6:1 ratio was employed in attaching netting to sidelines. Surface flotation was provided by sealed PVC pipes (5.49 m long x 5.08 cm dia). Nets were attached to the floating pipes with clips, thus allowing rapid deployment and retrieval of each net. The pipe attachment point on each net was adjustable. This allowed the nets to be fished in water of different depths. Anchor lines were attached to both ends of flotation pipes in order to keep the net in position and to minimize net twisting. The anchors were deployed so that net alignment in the water was generally parallel to currents. Each net lead line was attached to a 4.9 m long rod (concrete reinforcement bar) weighing approximately 1.4 kg. The additional weight at the lead line was utilized to prevent the lead line from "pinching," and also to prevent the nets from "walking" or shifting position. Since the bottom topography in the areas fished was flat, good bottom contact by the nets was maintained.



SIZE stretch MESH (cm)	# OF PANELS WIDE	COLOR	TWINE DES-CRIP-TION	DIA-METER	# TEST	HANGING RATIO VERT.	HOR.
2.54	3	clear	210-2	.23mm	5	2.6:1	1.5:1
3.81	3	clear	69	.28mm	9	2.6;1	1.5:1
5.08	2	clear	69	.28mm	9	2.6:1	1.5:1

Fig. 6. Vertical gillnet.

2.2 Survey Design

The selection of an appropriate survey design is dependent upon clearly defined objectives that are realistic in terms of the manpower and equipment available to carry them out. The obtainable objectives of a fishery resource survey are dependent upon 1) the ability to measure the fishery resource and 2) information available about the resource which tells you how to measure it. For example, in the Huntington 1978 surveys one of the major objectives was to measure offshore fish density. Therefore, the initial tasks were to examine the temporal and spatial characteristics of the fish density in order that information be available on how, when, and where to measure fish density.

2.2.1 Hydroacoustic Survey

Physical and biological patterns were taken into account when designing the survey of fish density around the intake. The physical environment around the intake was considered because it presented physical limitations and topographic boundary lines to sample around. Since the geographic or physical pattern of a study area is normally considered static in time and space, its characteristics are probably the first and easiest items to account for in a survey design. The most obvious physical factor influencing our survey design was the intake structure itself. Since our principal objective was to measure fish density around the intake, it was logical to use the intake as the focus (or center) of our survey area. Since the bottom substrate was fairly uniform and at the same depth for a considerable distance around the Huntington Beach Intake, the main physical factors influencing the survey design were: 1) the orientation to the shoreline (because up and down coast currents could affect fish distribution in the area), and 2) the closeness of the surf zone, which limited the distance that the acoustic survey could be extended inshore. In addition to these physical patterns, biological patterns in fish abundance were also considered in the survey design. For instance, the measurements of fish density at Huntington Beach in 1978 displayed important trends in spatial distribution and periodic diel variation. Determination of these patterns is viewed as an essential prerequisite to the meaningful measurement of fish density in intake study areas. These nonrandom characteristics of the fish populations suggested that systematic sampling would be better than simple random sampling. It has been demonstrated that if there is a trend in population distribution or abundances, stratification of sampling may lead to over 100% increase in relative precision (Cochran 1977).

In light of observations on physical and biological patterns in fish abundance (Appendices 1, 2, 3), a one-stage, line sample, stratified-random survey pattern was selected in order to achieve high precision biomass estimates in areas adjacent to intakes. Using the intake as a reference point, line sample areas were selected that extended equal distance from the intake in all directions (except the inshore direction if they entered the surf zone) (Fig. 7). Of these line study areas, several were found in 1978 studies at Huntington Beach to have different densities of fishes. These areas with different densities were up- and downcoast and in- and offshore. These variations resulted from alongshore currents and the thermal plume of the discharge (the discharge is located inshore from the intake). The area in which density and distribution were markedly influenced by the intake and discharge complex was within 300 m, the length of the line sample transect (Appendix 3). This distance also encompassed the area of the +Δ4°C thermal field (above ambient) surrounding the intake discharge structures. Water temperature is the most extensively described parameter which indicates the extent of the area affected by plant operations.

The fish biomass estimates were observed to exhibit a distinct diel periodicity, being lowest in the daylight hours and highest in the night hours (Appendices 1 and 2). This observation was due, in part, to artifacts and, in part, to real differences. The behavior of fishes causes daytime estimates of biomass measured using acoustics to be biased low for three important reasons: 1) the fish are more active during the day and are therefore more likely to avoid the survey boat, and 2) fish often school tightly during the day, therefore are more likely to be missed by the survey boat because of their distributional properties, 3) since schooling is a predator avoidance behavior, it is likely a school will respond and avoid a boat more readily than a single fish. These reasons are supported by 1) the mean biomass estimates observed (Appendices 1, 2, and 3), and 2) the clustered distribution of targets and large variance associated with the daytime surveys (Appendices 1 and 2). Some of the observations of the higher biomass in the water column at night are also due to the fact that several fishes which orient to the bottom during the day move upward into the water column at night. This was strongly supported by the comparison of day and night trends in the species composition of the lampara and gillnet catches (Appendix 3).

Because the biomass estimates were highest and the variances were lowest during the late night dark period, this period was selected as the best diel interval in which to make biomass measurements with hydroacoustics. In-plant observations indicate this was the time interval of greatest entrapment (Appendix 4).

Owing to the size of the study area the midnight to pre-dawn period allowed the collection of an ample number of hydroacoustic biomass measurements (as many as 24 legs in a series). This number of measurements allowed an adequate examination of the precision of the survey sampling techniques.

2.2.2 Net Sampling Survey

The following net sampling techniques were developed in order to subsample acoustic fish targets determine vertical distribution of the fishes, and measure near-intake fish densities.

Lampara Seine Procedures. The subsampling of acoustic targets required the charter of a live bait boat with crew and lampara net. The lampara net, when fished properly, can capture the fast-swimming fishes such as carangids, scombrids, engraulids, and athrinids which are seasonally abundant along the southern California coastline. In addition, it also allows the catches to be sampled and then released alive.

Allocation of lampara net fishing effort involved two stages: first, equal stratification of the effort by into four strata, and second, the sampling of strata in order of the density of fish within them (Fig. 7). In this allocation the strata of highest fish density was fished first, then the strata of second highest fish density was sampled second, etc., until all strata were fished. As time allowed the process was replicated.

The actual net sampling proceeded as follows: 1) the entire survey grid was acoustically sampled once and the relative density of fish in the four quadrants was determined from echogram and oscilloscope observations; 2) the order of net sampling was determined in order of quadrant density; 3) if the fish density was uniform on the transect, a random Loran C coordinate on the transect was chosen for the lampara boat to make the set on, or, if the fish distribution was contagious, then the area with the greater numbers of acoustic targets was chosen to set on. Since fish schools were not present at nighttime this subsample was considered to be proportional to the weight of all species within the study area. In both of these cases the lampara boat followed the acoustic boat. When the acoustic boat passed an area with a large number of acoustic targets or other areas to be fished a surface buoy was deployed to mark it; 4) the accompanying net boat then set the net in a manner determined by the lampara skipper to capture the fish which were directly under the surface marker.

Although the fish density was higher within 300 m of the intake (Appendix 3) the location of this fish concentration moved inshore to offshore and/or upcoast to downcoast depending upon the local current strengths, direction, and oceanic conditions (upwelling). Therefore, the stratification of the survey area into in-, off-, up-, and down-quadrants was necessary to measure the near-field fish densities.

Practical considerations, not statistical, determined the sample size of lampara sets obtained. The lampara net can be set and retrieved and prepared for another set in approximately one hour. Delays due to large catches and hanging the net on rocky bottom occurred, thereby reducing the number of sets which could be made in one day. Due to these limitations the number of sets that were made within one diel period was about five. This is just one more than the minimum number of sets needed to sample each of the quadrants of our study area, this effort provides adequate an adequate estimate of species composition.

Detailed examination of each catch was rarely feasible due to the large catches and limited vessel time. Therefore, the following sampling scheme was devised to estimate for each catch the total numbers, total weight, catch composition, and length-frequency distribution of each species.

First, the total weight of the lampara catch was measured directly. This was accomplished by manually scooping out and weighing the catch with a 1/4 scoop brail after the catch was crowded adequately in the bag. Often the catches were stratified inside the crowded bag, with "greenbait" (anchovy, smelt, butterfish, etc.) on the top stratum (surface) and "brown bait" on the lower stratum (bottom). In any case, strata observed inside the bag were subsampled systematically with equal effort for species parameters. Six subsamples of 1/4 scoop brails was adequate for representing the species composition of the total catch. The system for taking these 6 scoops was to take 2 at the start, two more when approximately half the fish had been scooped out, and then, the last two scoops in the net. All scoops not saved for subsample purposes were returned to the sea alive. The aliquot of scoops saved were sorted by species as suggested by Paloheimo and Dickie (1963). Fish in the aliquot were weighed and a randomly selected subsample of 100 individuals of each species was measured (standard length). Queenfish and white croaker in the aliquot were stratified into three size groupings which correspond to age group prior to data recording. The size groupings utilized for queenfish were less than 120 mm, 120-175 mm, and greater than 175 mm. For white croaker the size groupings were less than 80 mm, 80-140 mm, and greater than 140 mm.

Gill Netting Procedure. Six vertical gillnet stations (2 nets of each mesh size) were located within 30 m of the intake. The stations were approximately equidistant from each other. Six additional gillnet stations were divided between locations 1500 m up- and downcoast of the intake (*see* Fig. 7). Two vertical gillnets of each of the three mesh sizes were fished at the six stations located near the intake. Three of these six stations were somewhat offshore of the intake and three were somewhat onshore. A net of each mesh size was fished both offshore and onshore during each sampling interval. A net of each mesh size was also fished 1500 m up- and downcoast of the intake. The location of a particular net offshore, onshore, up-, or downcoast was randomly selected. Anchoring ground tackle for the nets was left in position throughout a study period. This insured that the nets were not accidentally set too close to the intake structure. Damaged nets were replaced. Weather permitting, each gillnet station was fished from about 2330 to 0430 hours daily.

The catch for each gillnet for each fishing interval was identified to species. Standard length, aggregate weight by species, entrapping mesh size, and vertical position in the gillnet (by 1 m interval) were determined for each specimen.

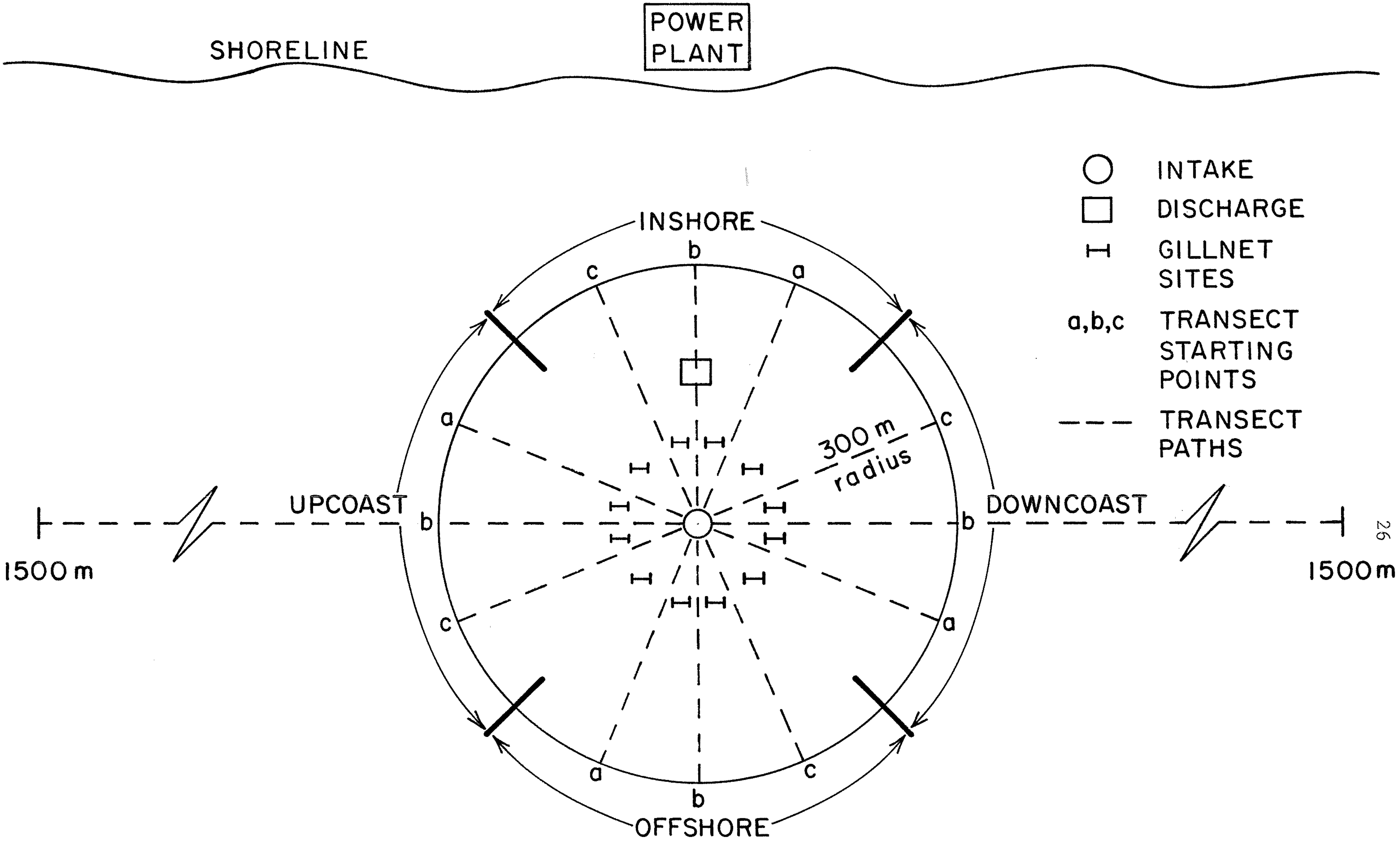


Figure 7. Schematic of Study Area illustrating stratification into four quadrants (inshore, offshore, upcoast and downcoast) in which the acoustic, lampara and gillnet sampling are allocated. Acoustic transect starting points are randomly selected with the effort being divided equally among strata. Net sampling is allocated by fish density until equally divided among strata. Acoustic sampling is completely replicated whereas net sampling is only partially replicated because of insufficient time.

2.3 Data Processing

2.3.1 Hydroacoustic Data Processing

Echo Integration. The technique used to convert the acoustic signal into biomass estimates was based on the principle that the acoustic intensity of a signal reflected fish targets is proportional to the mean individual scattering cross-section of the targets times the number of targets, i.e.,

$$\bar{I} \ \alpha \ N\bar{\sigma}$$

where $\bar{I}$ = mean echo intensity
N = number of targets
$\bar{\sigma}$ = mean individual scattering cross-section

The scattering cross-section may be expressed for an individual fish or for a given weight of fish. It is usually more convenient to express the scattering properties in terms of fish weight since fish biomass is generally the parameter one desires to estimate, and also it has been shown experimentally that the mean scattering cross-section of an individual fish is approximately proportional to its weight.

Therefore, in order to obtain a biomass estimate from a school of fish, it is necessary to determine the total intensity of the acoustic signal reflected from all the fish. This is done with a procedure called echo integration. It has been shown (Ehrenberg 1973):

$$P = \frac{\bar{I}_{R_1R_2}}{r_x^{\,2}\ P_o^{\,2}\ \overline{b^2(\theta,\phi)}\ \bar{\sigma}\ \frac{c}{4}\ T\ G_o^{\,2}\ \frac{1}{R_2-R_1}\int_{R}^{R_2}\frac{G^2(R)\ 10^{-2\alpha R}}{R^2}\,dR}$$

R_i = distance from transducer at point i

P = fish density per unit volume

r_x = transducer receiving sensitivity

P_o = roof mean square transmitted pressure level

$\overline{b^2(\theta,\phi)}$ = mean beam pattern factor

$\bar{\sigma}$ = mean scattering cross-section per single fish (or per unit biomass)

c = velocity of sound

T = acoustic pulse length

G_o = fixed gain factor

$G(R)$ = time varying gain factor

$\frac{10^{-2\alpha R}}{R4}$ = acoustic (loss due to spreading and attenuation)

The factors r_x, P_o, T, and G_o are parameters of the acoustic system that were measured during calibraton as described below. The time interval (t_1, t_2) was an input that determines the depth interval being surveyed. The beam pattern factor,

$$\overline{b^2(\theta,\phi)},$$

can be calculated from the acoustic transducer directivity function which was measured during calibration. As discussed previously, the scattering properties of fish varies from species to species and with size. However, all swimbladder fishes appear to have similar mean back-scattering strengths as a function of size (Anon 1978). Acoustic target strength and scattering cross-section are related by

$$TS = 10 \log_{10}\left(\frac{\sigma}{4\pi}\right),$$

A target strength of -33 dB/kg has been used during previous SCE studies to convert acoustic data to biomass estimates. Based on the literature discussed previously and our own experience, this value appears reasonable for swimbladder fishes if the mean length of the fish population is between 10 and 30 cm.

Calibration of the Acoustic Systems. As mentioned above, information on several parameters of the acoustic system was needed in order to derive biomass estimates. This information was obtained by calibration of the acoustic system utilizing facilities at APL. Calibration was accomplished by the use of test equipment including standard hydrophones which were calibrated at Naval test facilities in Orlando, Florida. General procedures for calibration have been described in Forbes and Nakken (1972). The purpose of calibration was to measure the source level (P_o), transducer receiving response (r_x), and the directivity pattern. These characteristics are relatively stable. Thus, only periodic calibration was needed. However, the echo sounder receiver as well as the magnetic tape recorder requires frequent calibration. This was accomplished by use of a built-in calibration oscillator which sent a signal of known strength into the echo sounder receiver bypassing the transducer. This allowed the rapid measurement of all of the system gain and allowed quick identification of system irregularities in the field by examination of the magnetic tape playback on an oscilloscope. The input level of the calibration oscillator, which is fairly stable, was also checked during the periodic calibration. The calibration served not only to provide the information necessary for the biomass estimation, but also provided a detailed check on the operating characteristics of each component of the acoustic system.

The acoustic data collected at Huntington in 1978 was processed with a digital echo integration system shown in Fig. 8, steps 1 to 5. At "Echo Integration" (step 5) the data are integrated by meter of water column and the relative fish biomass is calculated from the input calibration information. At this step, the minimum horizontal and vertical dimensions are determined for the biomass output, the TVG data are corrected to obtain a perfect TVG (electronic TVG are seldom perfect) with reference to a particular depth; and system gain, beam pattern, target strength, etc., are used to standardize the biomass data. Density values at Huntington Beach in 1978 were computed at 20 sec intervals along each transect (approximately 50 m).

Sample Volume. At Huntington Beach the water column was shallow enough to transmit at a rapid pulse rate (8 pings/sec) so that an almost continuous volume of water under the transducer was insonified. For purposes of illustration, the sample volume can be considered to be a cone of full angle width about the acoustic axis. In reality, however, it is much more complex. The volume sampled is not only a function of depth but is also dependent upon the interrelationships between depth, fish target strengths, and the overall gain of the echo sounder. These factors were taken into account in the echo integration equation which directly relates echo returns to fish density.

Data Editing and Computation. A block diagram (Fig. 8, steps 6-11) illustrates what occurs after the acoustic data were reduced to biomass information and stored on the PDP 11/45 disk. All erroneous data points (bottom and surface reverberation, kelp, air bubbles, etc.) were deleted from the data file with the use of a CRT editing routine. The echograms and integration logs were employed to identify measurements which were suspected to contain bottom and/or surface reverberation, etc. The edited data file was then emulated from PDP 11/45 disk space to magnetic tape storage at the University of Washington's Academic Computer (Terminal CDC 6400). Then, a permanent data file was created for detailed analysis. All pertinent data were time-linked and coded as appropriate. Variables (water temperature, dates, transect number, species composition, etc.) were introduced either by a computer program, a card deck, or on a CRT terminal.

Stratification was employed in the survey design to produce again in precision of the estimates of the midwater fish density (D_m). Previous studies have shown the fish population around the intake to be heterogeneous i.e., the fish assemblage orients to the intake with respect to the strength and directional characteristics of the local

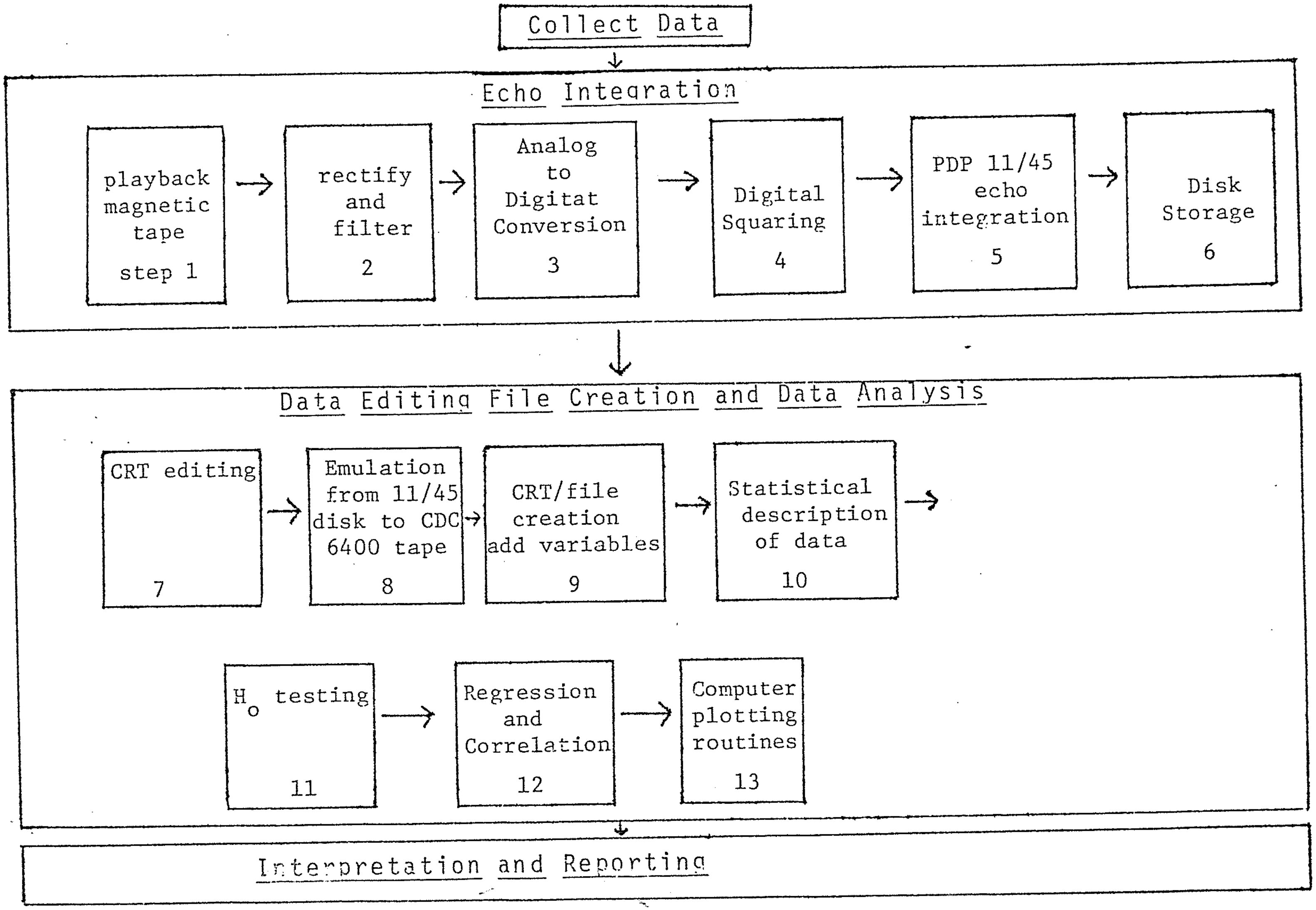


Figure 8. Block diagram at the reduction, editing, file creation, and statistical analyses of acoustic data.

along-coast and offshore currents (Thomas 1979). By dividing the fish population into sub-populations (in-offshore and up-down coast strata), which were believed to be homogeneous, precise estimates of each stratum were obtained with a small sample size. These estimates were then combined into a precise estimate for the whole population (D_m). To assure homogeneity of the stratum sample it was necessary that the transect pass over the intake since the gradient of fish density, if present, increased in the direction of the intake. The initial starting point for each transect was randomly selected from the pre-determined possible starting points on a 300 m radius from the intake. The following equation (Cochran 1977) was used to estimate the mid-water fish density (D_m):

$$D_m = \sum_{h=1}^{4} \bar{D}_h / 4$$

where:

$$\bar{D}_h = [\sum_{L=1}^{2} D_{hi}]/2$$

n_h = number of transects in stratum h (2)

$\bar{D}_h$ = mean fish density of stratum h

D_{hi}= mean fish density on transect i in stratum h

The number of transects were equal for each stratum, i.e., stratification with porportional allocation. If in every stratum the sample estimate $\bar{D}_h$ is unbiased, the $\bar{D}_h$ is an unbiased estimate of the population mean, $\bar{D}_m$ (mid-water fish density). Also if the samples are drawn independently in the strata:

$$\mathrm{Var}\ (\bar{D}_m) = \sum_{h=1}^{4} 16\ \mathrm{Var}\ (\bar{D}_h)$$

where $\mathrm{Var}(D_h)$ is the variance over repeated samples from stratum h.

2.3.2 Net Sampling Data Processing

Lampara Seining. The mean species composition (P_i) and its associated variance $\mathrm{Var}(P_i)$ of the lampara catch by day was determined as percent by weight. Therefore, each species component (P_i) was obtained by dividing the total weight of that species (i) in the catch by the total weight of all species in the catch. The species components (P_i's) and their associated variances were computed from the 4 to 6 lampara sets made within a survey day.

The vertical gillnet catches for all meshes were combined for the entire survey and the vertical distribution of fish was calculated by depth strata of the water column. Since the fish density (D_m) did not represent the fish present in the near-surface and bottom of the water column.

The vertical gillnet catch was used to calculate the relative fish density (D_{S+B}) not included in the calculation of D_m.

The percent of fish observed in the surface and bottom strata P_{S+B} and its associated variance Var(P_{S+B}) were calculated from the c/f by depth of the vertical gill. Since,

$$P_{S+B} = \frac{D_{S+B}}{D_M + D_{S+B}}$$

where:

D_{S+B} = density of fish in surface and bottom of water column not measured via acoustics

it follows that,

$$D_{S+B} = P_{S+B}\, D_M + P_{S+B}\, D_{S+B}$$

and,

$$D_{S+B} = \left[\frac{P_{S+B}\, D_M}{1-P_{S+B}}\right]$$

The assumption that the vertical gillnets catch by depth represented the true vertical distribution of the total fish density was obviously weak. This assumption should be strengthened by the calculation and adjustment of selectivity and efficiency characteristics of the gillnets.

The gillnet catches were also expressed in terms of catch per hour (CPH). This was for the purpose of comparing "far-field" abundance to "near-field" abundance as an independent check of acoustic estimates. CPH values were assumed to be proportional to activity and/or abundance in the area fished. However, because the volume sampled could not be defined and that gillnets are highly selective (Hamley 1975). The abundance estimate derived from the vertical gill nets are relative.

Selectivity and Efficiency. We propose to estimate selectivity and efficiency coefficients for the vertical gill nets to improve derived estimates of species composition. This evaluation will be part of the 1979 final report as insufficient data are currently available for necessary calculations. This is because the nets used during 1978 were being evaluated for design and similar nets were not fished throughout the entire year.

Selectivity is the traditional quantitative expression of selection by fish size (Lucas et al. 1960). Selectivity is not a single process; it includes availability of the fish to the net in time and space (the fish must encounter the net) and finally the fish must be caught and retained by the net. Selectivity for the nets used was defined as the proportion of fish captured and retained from those in the population. Size selectivity is best defined for each gear by a curve giving for each size of fish the proportion of the total population of that size which is caught by unit of effort. Therefore, selectivity is the proportionality constant, S_{kl}, and

$$C_{kl} = S_{kl} X_l N_k$$

where C_{kl} = catch of k size in l^{th} gear type

X_l = effort of l^{th} gear type

N_k = population size of k^{th} size class

In turn, the efficiency of a net is the area under its selectivity curve (Reiger and Robson 1966).

The gillnets and lampara seine have specific selectivity characteristics; therefore, the catches were not representative of the population as a whole. Extrinsic factors such as gear construction and mode of operation as well as intrinsic factors such as sex, size, behavior, diel time, season, etc., or the interaction of such factors, affect selectivity of a net.

The length frequency distributions of the catch of several gear types are used to evaluate selectivity. The selectivity of each gear was calculated by determining for each size of fish the proportion of the total population of that size which is caught and retained by one unit of effort with that gear. For instance, very large fish may escape capture by the gear by avoiding it while the smallest sizes of a fish species may not be retained by the mesh.

The method of estimating selectivity of the gillnets and lampara seine involved two steps: first, making an indirect estimate of the selectivity curves by mesh sized for the gillnets (Holt 1963; Thomas 1978). This step required no knowledge of the size distribution of the fish population but instead relied on intuitive assumptions about the nature of the selectivity curves. Second, with the known selectivity curve for the gillnets and the simultaneous fishing of gillnets with the lampara seine the direct calculation of the lampara seine selectivity curve was possible through comparison procedures.

The data we have collected using gillnets and lampara will provide information for application of several methods (Reiger and Robson 1966; Hamley 1975; Pope et al. 1975) for estimating selectivity parameters. Gillnet selectivity curves have been computed for several species of similar size and morphology to species found off Southern California. Comparisons with the literature and consistency between these results will be the criterion for evaluation of derived parameters.

Gillnets: the relative vulnerability of each size of fish to a given size of mesh of the gillnets will be computed for each species with the methods used by Thomas (1978). Briefly, selectivity curves will be determined by comparing the length frequency of the catches by mesh size. Assuming 1) selectivity curves were normal, 2) the variances were equal, 3) the amplitudes were equal, and 4) the modes were proportional to the mesh sizes, a straight line can be fitted to the data for each mesh size after plotting the cumulative percent length frequency histogram.

Estimates of the 50% points from the linear regressions of mesh size versus length were plotted against the mesh size and fitted by a straight line. The resulting linear regression was then utilized to estimate the 50% points for all mesh sizes, because not all individual meshes capture a sufficiently large sample. The complete selectivity exerted by the gillnets is then calculated by summing the relative mortality by predetermined length groups of fish in all mesh sizes. The development of this method and its assumption are presented in Holt (1963), Hamley (1975), and Thomas (1978).

A correction for gillnet efficiency will be computed by summing the relative selectivity of gillnets over the same length ranges of the principal species and standardizing them by one species, the queenfish. Assumptions of this technique are presented by Reiger and Robson (1966).

Prior to the 1979 final report the assumptions made on selectivity will be that net sampling captured the complete size range of fish entrapped within the intake. Length-frequency histograms will be presented for independent analysis in all E/D interim reports.

2.3.3 Offshore Relative Abundance, D_i

The mid-water fish density (g/m^2 surface), D_m, species composition (percent) from the lampara seine catches, P_i, and the relative fish density in near-surface and bottom strata of the water column, D_{S+B}, were used to compute the offshore relative abundance, D_i.

First, the total fish density was calculated:

$$D_T = \left[D_M + \frac{P_{S+B}\ D_M}{1-P_{S+B}} \right]$$

Let

$$\left[\frac{P_{S+B}}{1-P_{S+B}} \right] = V$$

where V and associated variance are computed from net sets.

Therefore,

$$D_T = D_M\ (1 + V)$$

and

$$\mathrm{Var}(D_T) = D_M^{\ 2}\ \mathrm{Var}\ V + (1+V)^2\ \mathrm{Var}\ D_M$$

The offshore density is then:

$$D_i = D_T \cdot P_i$$

The variance formula is:

$$\mathrm{Var}\ D_i = D_T^{\ 2}\ \mathrm{Var}\ P_i + P_i^{\ 2}\ \mathrm{Var}\ D_T$$

Practical considerations allowed us to compute D_m by hour of survey, P_i by day of survey and D_{S+B} by survey.

PART II: ESTIMATION OF FISH ENTRAPMENT

1.0 INTRODUCTION

The accurate determination of relationships between fish entrapment, offshore abundance, and other parameters is the primary goal of past and ongoing studies at SCE generating stations. A major factor complicating such determinations has been the inability to assess the time at which entrapment occurs. Entrapped fish can only be measured after they have been impinged on the traveling screens located in the screenwells. A screenwell is a large, rectangular, concrete-walled hole which allows access to the cooling water for the removal of entrapped material from the water prior to its entering the condensor tubing of the plant. The reduced water velocity as well as eddies created by the rectangular shape allow fish to survive in the screen well, sometimes for weeks, before being impinged. The time delay between initial entrapment and impingement must either be measured or estimated before accurate evaluations of causes and effects of entrapment can be undertaken.

The delay between time of entrapment and time of impingement was exemplified by a study conducted in 1976 at the Redondo Beach Generating Station (RBGS). In this study tagged fish of several different species were placed in the RBGS Units 7 and 8 screenwell. Of these fish, 50% were not impinged within the first hour, and 35% were not impinged within 24 hours. As the RBGS Units 7 and 8 screenwell has a relatively fast flow of water through it, it was suspected that other screenwells with slower flows would have even longer intervals between entrapment and impingement. It has been calculated that 72% of all fish entrapped at the Huntington Beach Generating Station, which has a slow-flow screenwell, were not impinged until the screenwell was heat treated (Critchlow, unpublished). Heat treatments at the Huntington Beach Station were conducted about every 6 weeks.

A number of survey techniques have been employed in attempts to monitor rates of entrapment independent of impingement observations. These techniques included observations by SCUBA divers, underwater television (UTV), and hydroacoustics. SCUBA diver observations of fish around the RBGS Units 7 and 8 cooling water intake structure have been performed routinely for several years. While this technique has proven valuable in describing some aspects of fish behavior around the 7 and 8 intake structure this technique is not precise enough to quantify rates of entrapment. Similarly, UTV efforts have provided valuable behavioral observations, but were not useful in monitoring entrapment. Hydroacoustic methods have provided useful behavioral as well as distribution data for fish around intake structures (Thorne et al. 1979). When used within screenwells to monitor entrapment, however, problems in identifying echo returns as fish, bubbles, or debris have discouraged the use of this technique to monitor entrapment. Other means of monitoring entrapment, such as electric fish shockers, nets within screenwells, and counting devices using either electric eye or wheat-stone bridge principles, were found unsuitable because of the confined configuration of SCE screenwells along with problems of high turbidity, salinity, flow, and debris. Because the above means of monitoring entrapment failed, or were not feasible to implement, the possibility of using heat treatments and/or chemical agents as means of inducing rapid fish impingement were evaluated at the El Segundo and Redondo Beach generating stations in 1977. The results of these 1977 evaluations were encouraging and led to the development during 1978 of a methodology for accurately monitoring short-term entrapment rates. This methodology is described in the following chapters.

2.0 METHODS

The methodology developed was aimed at reducing the time of residence by the fish in the screenwells, thereby making the rate of impingement equivalent to that of entrapment. This was accomplished by a combination of elevated water temperature and sodium hypochlorite injections. Both heat treatments and chlorine injections are described below.

2.1 Mini-heat Treatment

Heat treatments are routinely conducted at SCE generating stations. They are employed to remove organisms fouling the inner walls of cooling water conduit systems. All fish residing in screenwells during the heat treatments are also killed by the elevated water temperatures. During routine heat treatments screenwell water temperature is elevated and maintained at approximtely 40°C (104°F) for about 40 min. The temperature increase is obtained by recirculating a portion of the cooling water flow back through the station several times (the cooling water normally flows through the station only once). Recirculation of the water is accomplished by positioning gates within the cooling water conduit system. The fact that heat treatments are a standard operational procedure at SCE stations, and that they efficiently induce impingement of all fishes within a screenwell, prompted consideration of using them to assist in entrapment monitoring efforts. Unfortunately, routine heat treatments are costly because they severely restrict plant operating capabilities. The high cost factor led to the design and testing of a smaller scale heat treatment procedure which would be used solely for fish removal. This modified procedure was termed a "mini-heat treatment."

The reduction in magnitude of the treatment also reduced the quantity of fouling organisms discharged into the environment around the intake/discharge structures. Since the discharge of fouling organisms represents a potential food source and may attract fishes into the intake area the reduction of this effect was desirable. In any event, the mini-heat treatments lie within the normal operating limits of the power generating stations in that discharge temperatures during mini-heat treatments are similar to those observed during the daily cycle of plant generating demand (load cycle). For example, at the HBGS on October 25, 1978, the maximum discharge temperature observed during a mini-heat treatment was 34.7°C. During a high electrical demand period on the same day discharge conduit temperatures reached 32.3°C. Although mini-heat treatments have proven to be an effective method for inducing fish impingement during intervals of low plant demand, they are not adequate for determining hourly entrapment rates. This is because 1) less than normal flow occurs at the intake structure during periods of water recirculation, 2) mini-heat treatments require a large degree of station cooperation to conduct (i.e., personnel time, outages, etc.), and 3) they frequently take more than an hour to complete. These considerations prompted evaluation of the use of chlorine injections to induce fish impingement.

2.2 Chlorine Injection

Several chemical agents were considered for use in screenwells to induce fish impingement. Of those examined sodium hypochlorite (swimming pool chlorine) was chosen for use. Chlorine is routinely used at generating stations to control bio-fouling in condensor systems. Thus, its effects on plant personnel, plant equipment, the offshore environment, and its cost could be anticipated. The techniques developed for using chlorine in entrapment monitoring studies are described below.

Chlorine was injected into the upstream end of a screenwell. The injection was made from a large, portable chlorine storage tank. The chlorine was metered into the screenwell through reinforced vinyl tubes that were positioned within the dewatering gate slot. The tubes were positioned in the gate slot so that injection occurs about 1 m below the water surface and 1 m above the bottom of the screenwell. In screenwells with areas of low flow the upstream injections were supplemented with surface injections of chlorine into the areas of low flow.

Chlorine was injected into a screenwell in a quantity to induce impingement. Impingement resulted from 1) fish swimming downstream in efforts to avoid the noxious stimulant, and 2) partial impairment of swimming capabilities.

At the HBGS injections of 30 gal over a 5 min interval effectively cleared the species of concern from the screenwell. Injections of this dosage resulted in Total Free Chlorine readings at the discharge gate slot averaging 0.56 mg/liter. Chlorine concentrations measured at the gate slot can be expected to decay by as much as 50% before reaching the offshore discharge bubble. Thus, injections of 30 gal chlorine in 5 min probably resulted in discharge concentrations less than the allowed maximum of 0.5 mg/liter.

The effectiveness of chlorine in removing fish from a screenwell can vary by species. In July, at the HBGS, chlorine induced the impingement of only 70% of the walleye surfperch present in the screenwell. This contrasts with the over 90% impingement rate observed for all other species of concern. The above calculations of chlorine impingement success were based on the results of a heat treatment conducted after the chlorination surveys ended. Chlorine effectiveness in inducing impingement can be 100%. In October, when the HBGS screenwell was not crowded with fish, chlorine injections induced complete impingement of all the species of concern. This was determined by visual observations made in the screenwell using television. Thus, in order that maximum chlorine effectiveness is realized, a mini-heat treatment was utilized at the start of each survey day to empty the screenwell of fish. An underwater television was employed to check that impingement was 100% for the species of concern.

The amount of chlorine needed per injection to clear fish from the HBGS screenwell was approximately that amount the station normally uses during routine chlorinations. Thus, normal plant chlorinations were cancelled on days chlorine injections were utilized to remove fish from the screenwell.

The effect of chlorine on the offshore environment is poorly understood. Behavioral responses of marine fish to chlorinated seawater are species-dependent. The chlorine concentrations realized offshore during screenwell clearing injections were probably sufficiently high to induce fish avoidance responses. For example, Stober et al. (1978), reported shiner surfperch avoid chlorinated thermal seawater effluent when concentrations exceeded 0.175 mg/liter total residual oxidant. Fish avoidance responses in the field during screenwell clearing procedures, however, were probably similar to those they would execute in response to routine plant chlorinations. Visual observations of fish behavior around a discharge boil during chlorination periods indicate avoidance is limited (Herbinson, personal communication). Fish remain in the general area (approximately 80 ft from the discharge point) during chlorination periods and then move back into the boil area afterwards. This response was observed even though chlorine levels were quite high (>0.8 mg/liter total chlorine in the boil area).

2.3 Data Acquisition

Impinged fish were surveyed after each mini-heat treatment and hourly after each chlorine injection. Specimens surveyed were counted and identified to species. For each survey the total weight was measured for each species. Additionally, up to 100 randomly chosen individuals per species per survey were measured for standard length (2 mm). Queenfish and white croaker impinged were stratified into three size groupings prior to data recording. The size groupings utilized for queenfish were less than 120 mm, 120-175 mm, and greater than 175 mm. For white croaker the size groupings were less than 80 mm, 80-140 mm, and greater than 140 mm.

2.4 Data Processing

2.4.1 Length Frequency Analysis

Large catches of queenfish and white croaker in the screenwells prompted the use of the following procedures for estimating length frequency of each species. White croaker and queenfish entrapped were stratified by size and each stratum was weighed and counted. A random selection of 100 individuals from each stratum was then removed for measurement of standard length. The length frequency distribution from each stratum was expanded by the appropriate factor (derived from the total count of the strata). These strata were then combined for the examination of intake entrapment selectivity patterns.

Potential sources of error in entrapment estimates (E_i) may be incomplete removal of fish from the screenwell and the selectivity function of the traveling screen. Observations with the UTV suggest that the first error was insignificant. However, field observations indicated that a large proportion of some species was not retained by the traveling screens and was entrained through the system. Therefore, selectivity of the screen is thought to be significant and will be addressed in future studies. This task will follow the methods outlined for determination of the net sampling gear selectivity because the nets were fished simultaneously with the entrapment monitoring.

2.4.2 Calculation of Entrapment Rate

The total number of fish entrapped (E) for each species was counted and weighed. In order that E_i be comparable to D_i, E_i was determined on an hourly basis.

PART III: GENERAL DISCUSSION

The ability to calculate real time impingement rates and offshore fish density synchronously will enable us to evaluate the effects of an intake on a fish assemblage in a manner not previously possible. This ability minimizes the possibility than the results of field evaluations of several key aspects of intake design, location, and operation would be misinterpreted because of changes in either offshore density of physical parameters. The ability to measure offshore fish density synchronously with entrapment was made possible through the use of hydroacoustics.

The key aspects of SCE intake structure design, location, and operation that are presently being evaluated include the following:

1) Velocity caps - the key feature of SCE's defense of its offshore intake structures as environmentally acceptable and of the "Best Technology Available" is the velocity cap. SCE's claim that velocity caps reduce entrainment by 95% has been challenged and an updated field evaluation of their effectiveness is needed.

2) Maintenance of full flow during low electrical demand nighttime periods - preliminary survey information support the hypothesis that the reduction of flow (i.e., shut-down of circulator pumps) during nighttime periods would reduce entrapment. Such operational procedures have been suggested as regulatory requirements elsewhere and it is necessary to evaluate the biological aspects of implementing such procedures at SCE stations.

3) Heat treatments - previous studies have suggested that fish abundance around SCE intake structures may be influenced by the intakes proximity to the discharge outlet, particularly after heat treatments. The potential for a station's discharge to influence the fish population around an intake needs to be assessed because entrapment rates are thought to be density-dependent.

4) Comparison of entrapment rates of four representative intake systems - if a comparison of entrapment to density ratios of representative intakes demonstrated that there is little variation between the ratios, then SCE may avoid having to conduct intensive studies of entrapment at every station.

5) Evaluation of seasonal variation in entrapment to density ratios - examination of entrapment rates over a wide range of density values (Summer 1979 to Spring 1980) will allow definition of the relationship between entrapment and field density.

6) San Onofre Nuclear Generating Station (SONGS) Units 2 and 3 cooling water intake system - this system is prototype of SCE's latest intake technology. An evaluation of its effectiveness in reducing entrapment needs to be conducted after it comes on line in 1980. For purposes of comparing this intake's entrapment to density ratios to those observed at other sites, the same sampling techniques need to be employed.

Each of the above key aspects represents the research topic of a proposed 1979/1980 field task. The methods to be utilized, a complete description of each task, and the background information which justifies each task are being published in a series as F.R.I./UW technical reports.

The statistical technique for adjusting entrapment rates by offshore fish density has been simply to form the ratio of entrapment to density (E/D). This ratio is felt to represent the relative vulnerability of a fish assemblage to an intake. Therefore, by monitoring E and D through major changes in operational modes of an intake we hope to describe the "main" effects on fish entrapment. Refinement of the statistics used and assessment of the variability inherent in the technique will be addressed in the 1979 and 1980 F.R.I./UW technical reports. For example, the low selectivity of vertical gillnets for small fishes suggest that this bias has a relatively small effect because biomass estimation is influenced only slightly by smaller fishes. The E/D ratio may also be useful in determining differences in the fish assemblage's vulnerability to entrapment under differing conditions of temperature, flow, and water transparency.

The evidence is building which suggests that some abundant and comercially important species (i.e., northern anchovy) are not as vulnerable to entrapent as some commercially non-important species. For instance, in this study, the relative order of vulnerability to entrapment (E/D) was queenfish, white croaker, and then northern anchovy. In preliminary sutdies associated with this research there was some evidence that mackerels, bonita, and Pacific butterfish also had relatively low vulnerabilities to entrapment. This type of evidence will be closely examined in our upcoming studies as it may be a favorable point in the future evaluation of the effectiveness of SEC's intake design in minimizing fish entrapment.

PART IV: SUMMARY AND RECOMMENDATIONS

Questions addressed in huntington Beach 1978 Studies (Appendices 1, 2, and 3) consisted of describing the changes in the density of fish in the near- and far-field areas of the intake/discharge. In order to be rigorous in detecting changes in fish density, hypothesis testing (H_o) was conducted whenever sufficient sample size allowed.

The basic survey sedign used in 1978 examined fish density with respect to diel (day, night), day to day, and area variability. This was accomplished through comparison of fish density observations from "n" transect runs within four separate diel intervals during the day, over several days, and in several subareas within the survey area.

Diel variability was examined with the expectation that it was significant and pooling of the observations during separate periods in the day could not be justified. The findings indicated the late night period to be the best sampling interval. Second, density measurements within each diel period over several days were examined to decide whether days could be pooled. Often significant changes in fish density occurred between days; therefore each diel period of each day of the survey was considered to be an individual sample. Third, no significant difference among several transect runs within these periods were found and thus were used to estimate within-sample variance.

The density observations made with 1500 m in either up- or down-coast direction from the outfall were examined to determine the size of the study area. The fish density was higher within 300 m of the intake at Huntington Beach. Similar observations were also made at San Onofre (Thomas et al. 1978). Therefore, some part or all of the characteristics of plant operations or presence of the intake/discharge structures were concluded to have a general attracting influence on at least some of the fish for a 300 m radius around the intake. Therefore, measurements within 300 m of the intake were used to: 1) distinguish how the fish aggregations once attracted to the intake area were being affected, and, 2) for the examination of the ratio of entrapment to density (E/D).

The material presented in this report is based both upon the review of the literature and current field studies. References given include much of the theory behind the recommended fisheries assessment techniques presented in this report. The most notable techniques to incorporate into a monitoring program appear to be a combination of hydroacoustics, net sampling, and inplant entrapment data simultaneously collected. It is stressed that this kind of program is in the developmental stage and, although its full value will not be realized for some time, the immediate benefits far outweight what alternate methodologies provide. Therefore, it is recommended that SCE utilize the procedures described above to collect the information needed to assess whether or not its offshore cooling water intake structures meet the FWPCA 316(b) mandate for juvenile and adult fishes.

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APPENDIX 1

THE FISH DISTRIBUTION IN THE VICINITY OF SOUTHERN CALIFORNIA EDISON'S POWER PLANT AT HUNTINGTON BEACH, SPRING 1978

by

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INTRODUCTION

Acoustic data on fish density, along with ground truth information on species composition, were collected at the Southern California Edison Power Plant at Huntington Beach on 9 through 12 April 1978 to examine the plant's impact on the abundance and distribution of fishes in the area. Acoustic measurements and net sampling were conducted along line transects crisscrossing the intake structure; additional data were collected up to approximately 1 mile south of the intake (see Figure 1). This report presents the results of that survey.

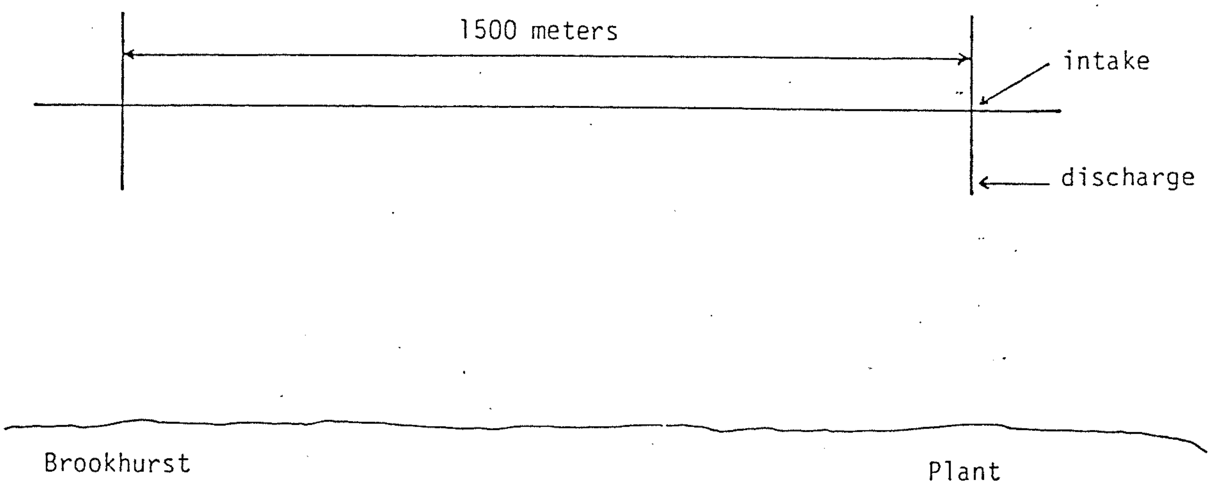

Figure 1. Schematic (not to scale) of the transect pattern for the acoustic survey in April 1978 at the Huntington Beach Generating Station.

Acoustic information is the best quantitative data on fish density that can be collected at sites such as Huntington Beach. Acoustic data provide both temporal and spatial information on the biomass of fish in an area. The sampling volume is at least an order of magnitude larger than that obtainable with a similar program using net sampling alone. In addition, the fish biomass obtained by a conventional net sampling program is only an estimate of an estimate. This is because (1) the volume sampled by the net (i.e., its efficiency) is an estimate and (2) the proportion of fish in the sampling volume that are vulnerable to the net (i.e., its selectivity) is also an estimate. Poor and often invalid assumptions are made about the selectivity and/or efficiency of a particular type of gear, since these characteristics are difficult if not impossible to measure. Acoustic sampling minimizes, if not eliminates, such problems.

Although total fish abundance and distribution are important information, interpretation requires data on species composition. Therefore, it becomes necessary to subsample the acoustic targets with nets to obtain ground truth data.

DATA-ACQUISITION SYSTEMS

A block diagram of the data-acquisition system used at Huntington Beach, along with the transducer beam pattern, is shown in Figure 2. A complete description of the system is presented in Reference 1. This system was developed by the Marine Acoustics Group at the University of Washington, and has been used extensively to gather acoustic data on fish stocks. The chart recorder provides real-time output, while the interface amplifier and magnetic tape recorder allow data to be stored for later analysis. System parameters can be adjusted to optimize returns for particular applications.

Continuous collection of acoustic data was made possible by installing the transducer in a 2-ft depressor body which was towed at approximately 4 kn along the line transects.

Both lampara seines and gillnets were used to collect the ground truth data. The lampara seine was chosen because of its relatively high efficiency and low selectivity. Gillnets were added to allow sampling near the intake structure.

DATA ANALYSIS PROCEDURES

The acoustic data were analyzed using a digital echo-integration technique. Density values were based on a target strength of -33 dB/kg (see appendix). The average fish density (in grams/meter^2 of surface area) was computed at 20-sec intervals along each transect. All unusual acoustic values recorded on the magnetic tape were cross-checked with the echograms, and erroneous values due to kelp, surface turbulence, etc., were edited out.

All depth strata were combined for the computation of statistics and the hypothesis-testing procedures. Nonparametric testing procedures were used exclusively to avoid making assumptions about the underlying distribution of the data. The rejection region for all testing procedures was determined using $\alpha = 0.05$.

RESULTS

Acoustic

The measurements were collected over three continuous 24-hour periods beginning with the predusk diel period on 9 April and ending with the postdawn diel period on 12 April 1978. Each sampling day was divided into four diel periods: predusk (noon to dusk); postdusk (dusk to midnight); predawn (midnight to dawn); and postdawn (dawn to noon).

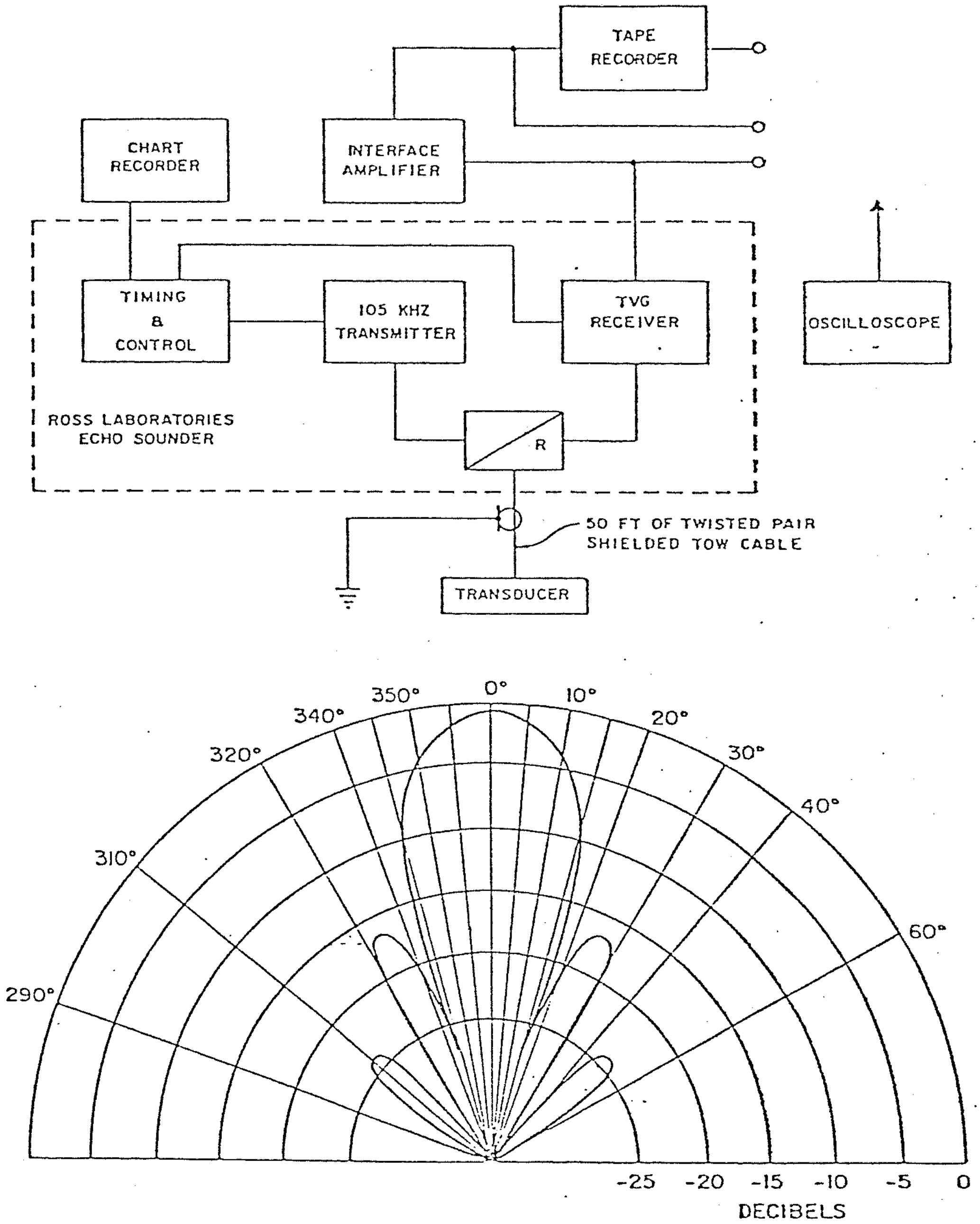

Figure 2. Block diagram of the data-acquisition system (top) and beam pattern of the transducer (bottom) used at Huntington Beach.

The density data from all survey periods were combined and then the mean, median, mode, kurtosis, skewness, and variance were calculated. The results are shown in Table I. These statistics suggest that the fish densities have a non-normal distribution.

Table I. The mean, median, mode, kurtosis, skewness, and variance of fish density values (in grams/meter^2 of surface area) from the acoustic survey at Huntington Beach, California, in April 1978.[a]

Mean	Median	Mode	Kurtosis	Skewness	Variance
6.640	0.756	0.302	79.993	7.454	542.985

---

[a] data include observations over intake

The mean fish density around the intake was indexed by day and diel period because these temporal characteristics are important in describing changes in abundance and distribution. The results are presented in Table II.

The survey was designed so that differences observed in the fish density between days and diel periods could be tested for their statistical significance. The results of these tests are presented in the following sections.

Diel Variability

A Kruskal-Wallis one-way analysis of variance by ranks[2] was used to test the null hypothesis:

H_0: There is no difference in average fish density between diel periods at $\alpha = 0.05$.

H_1: There is a significant difference in average fish density between diel periods.

For this test, and for all the other tests described in this report, the relevant test statistic and the significance level of the statistic (i.e., the probability under H_0 of obtaining values as large as those of the test statistic) were computed using the NPAR TESTS program of the Statistical Package for the Social Sciences.[3]

Table II. Mean fish density (in grams/meter^2 of surface area) in the vicinity of the Huntington Beach Power Generating Station during three consecutive 24-hour periods starting the afternoon of April 9 and ending the morning of April 12, 1978 (fish densities over intake excluded).

	Sample Day			All
	1	2	3	Days
predusk	10.15	1.63	4.30	4.28
postdusk	8.64	6.05	13.98	8.27
predawn	3.63	6.78	13.87	8.57
postdawn	6.48	11.57	5.02	7.70

When corrected for ties, the value of the Kruskal-Wallis H statistic computed under H_0 was 72.82 with a significance level greater than 0.0000. Therefore, H_0 was rejected at a level of $\alpha < 0.05$, and it was concluded that there were significant diel variations in the fish density.

The difference in fish density between days was examined for each of the four diel periods. A Kruskal-Wallis one-way analysis of variance was used to test the null-hypothesis:

H_0: There is no difference in fish density between days within one diel period at $\alpha = 0.05$.

H_1: There is a significant difference in fish density.

The test statistic values, corrected for ties, and the levels of significance are shown in Table III. The conclusion drawn from these tests was that there were significant changes in fish density between the three survey days within each diel period tested.

Table III. Values of the Kruskal-Wallis H statistic (corrected for ties) and the level of significance for testing the null hypothesis H_0 about differences in fish density between days for the four diel periods.

Data Set	Value of H	P
Predusk	130.317	0.000 *
Postdusk	--- insufficient data ---	
Predawn	24.150	0.000 *
Postdawn	17.580	0.002 *

* = significant

Fish Distribution near the Intake (within 300 m)

Fish aggregated at the intake during April, and the fish density appeared to be greater downcurrent from the intake (see Figure 3). These observations prompted testing for differences in fish density with respect to direction from the intake.

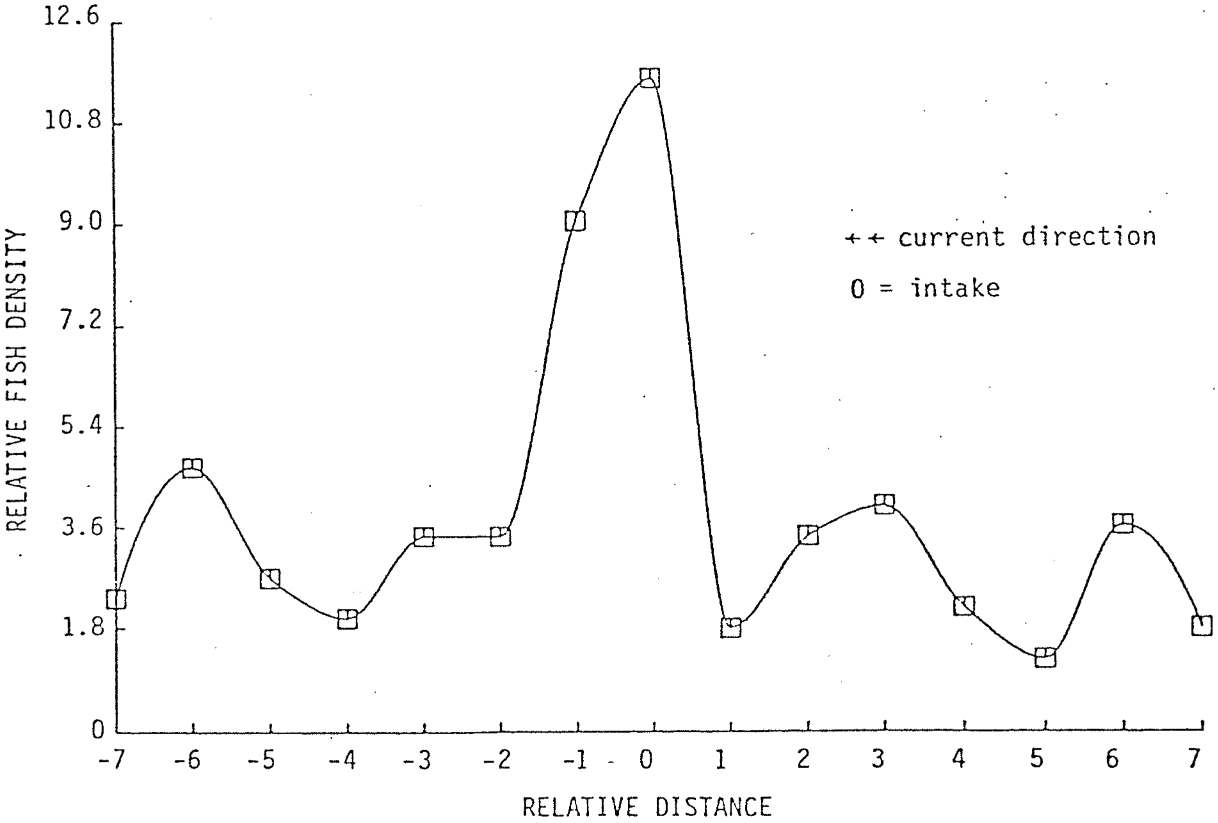

Figure 3. Density of fish (in grams/meter² of surface area) upcurrent and downcurrent from the intake at the Huntington Beach Generating Station in April 1978.

For the initial data analysis, the fish densities measured around the intake area were divided into four groups: inshore (toward the discharge outlet), downcurrent, upcurrent, and offshore.

The Mann-Whitney U procedure[2] was used to test the significance of differences in fish density between two areas. The values used for the tests were the average fish densities recorded on individual transects over each of the four areas of interest.

The general form of the null hypothesis tested was:

H_0: There is no difference in fish density between the inshore and offshore or the upcurrent and downcurrent areas of the intake site at $\alpha = 0.05$.

H_1: There is a difference in fish density between the inshore and offshore or upcurrent and downcurrent areas of the intake at $\alpha = 0.05$.

The test was conducted for each day and diel period separately.

The test statistic values and their levels of significance are given in Tables IV and V. The conclusions drawn from the tests were that there was often a significant difference in fish density between the inshore and offshore areas and the upcurrent and downcurrent areas. The highest fish densities were most often downcurrent and inshore of the intake, suggesting that operation of the discharge may have been influencing the density around the intake.

Fish Distribution Away from Intake (up to 1500 m downcoast)

Fish density decreased away from the intake (see Figure 4). Since the physiography of the Huntington Beach coastline is fairly uniform, the gradient in fish density was most likely due to the presence or operation of the Huntington Beach Generating Station. However, the fish density was also highest on the downcurrent side of the intake. Thus there may have been a general increase in fish density in the area northwest of the intake, which was not included in the survey.

Area Variability

The fish densities in an area 1500 m southeast of the intake (Brookhurst) and the area between there and the intake were arbitrarily selected for comparison with the fish density observed in the intake area. The differences in fish density between days were examined for all diel periods combined and for each diel period separately. A Kruskal-Wallis one-way analysis of variance was used to test the null hypothesis:

Table IV. Fish density 300 m inshore and offshore from the intake at Huntington Beach

Data Set	Date	Density Offshore	Inshore	P	
Predusk	4/9/78	5.96	34.47	0.0026	*
Postdusk	4/9/78	10.11	51.49	0.0771	N.S.
Predawn	4/10/78	1.93	34.11	-not tested-	
Postdawn	4/10/78	11.59	5.17	0.3000	N.S.
Predusk	4/10/78	0.23	8.30	0.0079	*
Postdusk	4/10/78	0.36	9.24	-not tested-	
Predawn	4/11/78	9.26	58.27	0.3092	N.S.
Postdawn	4/11/78	3.00	45.91	0.0000	*
Predusk	4/11/78	0.57	24.27	0.0000	*
Postdusk	4/11/78	1.04	47.88	0.0282	*
Predawn	4/12/78	2.54	117.90	0.0001	*
Postdawn	4/12/78	2.47	15.02	0.0000	*

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* = significant

N.S. = not significant

Table V. Fish densities 300 m upcurrent and downcurrent from the intake at Huntington Beach.

Data Set	Date	Density Upcurrent	Downcurrent	P	
Predusk	4/9/78	0.23	5.27	0.8067	N.S.
Postdusk	4/9/78	---	22.37	0.1626	N.S.
Predawn	4/10/78	1.49	1.49	0.7287	N.S.
Postdawn	4/10/78	8.53	1.30	0.4896	N.S.
Predusk	4/10/78	0.52	5.98	0.1862	N.S.
Postdusk	4/10/78	1.92	1.00	0.1910	*
Predawn	4/11/78	4.23	24.68	0.6407	N.S.
Postdawn	4/11/78	0.30	0.53	0.1850	N.S.
Predusk	4/11/78	1.00	1.14	0.3904	N.S.
Postdusk	4/11/78	1.41	2.36	0.0484	*
Predawn	4/12/78	0.32	15.98	0.0009	*
Postdawn	4/12/78	1.03	3.72	0.0000	*

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* = significant

N.S. = not significant

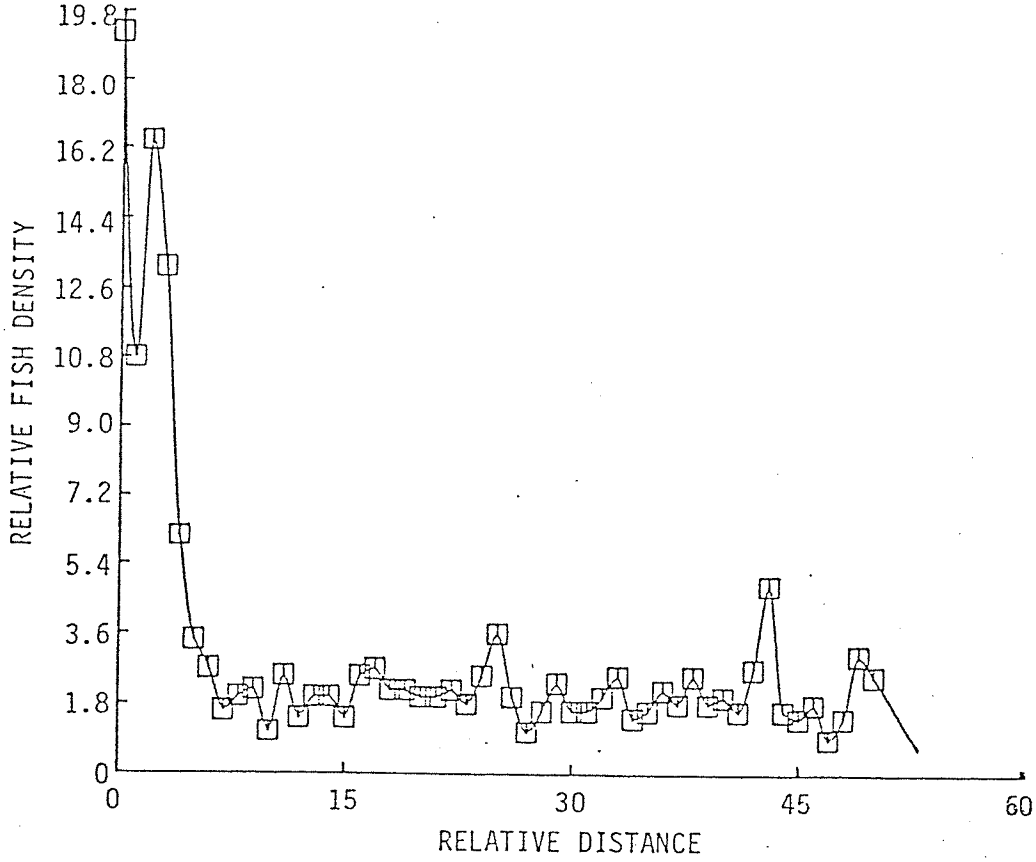

Figure 4. Relative density of fish (in grams/meter^2 of surface area) moving away from the intake in April 1978.

H_0: There is no difference in fish density between areas at $\alpha = 0.05$.

H_1: There is a difference.

The test statistics and levels of significance are shown in Table VI. The conclusion drawn from these tests was that there was often a difference in fish density between areas and that the average density was consistently highest at the intake area (see Table VI).

Ground Truth

Because of the significant changes in fish density between daily and diel periods, only the 10 lampara net sets and the 13 gillnet sets that were conducted simultaneously with the acoustic measurements were used in the data interpretation.

Table VI. The level of significance for hypothesis testing of variations in fish density between areas for each day and diel period, and the average fish density within each area.

Data Set	Date	Intake	Between Two Areas	Brookhurst	P	
Predusk	4/9/78	10.15	---	---	-- no test --	
Postdusk	4/9/78	31.22	2.26	7.23	0.0000	*
Predawn	4/10/78	9.27	3.83	1.04	0.0000	*
Postdawn	4/10/78	6.14	---	8.46	0.1642	N.S.
Predusk	4/10/78	4.15	0.46	0.18	0.0003	*
Postdusk	4/10/78	13.08	---	1.26	0.5089	N.S.
Predawn	4/11/78	30.59	1.32	1.60	0.0000	*
Postdawn	4/11/78	11.57	---	---	-- no test --	
Predusk	4/11/78	6.55	3.22	3.64	0.5633	N.S.
Postdusk	4/11/78	13.98	---	---	-- no test --	
Predawn	4/12/78	37.87	1.54	1.84	0.0005	*
Postdawn	4/12/78	5.02	---	---	-- no test --	

* = significant

N.S. = not significant

The average total weight of the lampara catch in the intake area was compared with the average acoustically-measured fish density at the intake for three diel periods: predawn of day 2 and day 3 and postdawn of day 2. The results are shown in Figure 5. There was no correlation between the lampara net catch and the acoustic measurements until the atherinid component of the net catch was removed. That the difference was due to the atherinids is probably a valid assumption since, at least during darkness, the atherinids are surface oriented, and the acoustic system does not sample near the surface. However, this assumption will have to be tested in the future with data on the vertical distribution of species. Once the atherinid component was removed, not only the total catch, but the catch of the three major species of fish, directly correlated with the results of the acoustic measurements (see Figure 5). This observation suggests that the acoustic fish densities observed at the intake area were due to queenfish, butterfish, and white croaker.

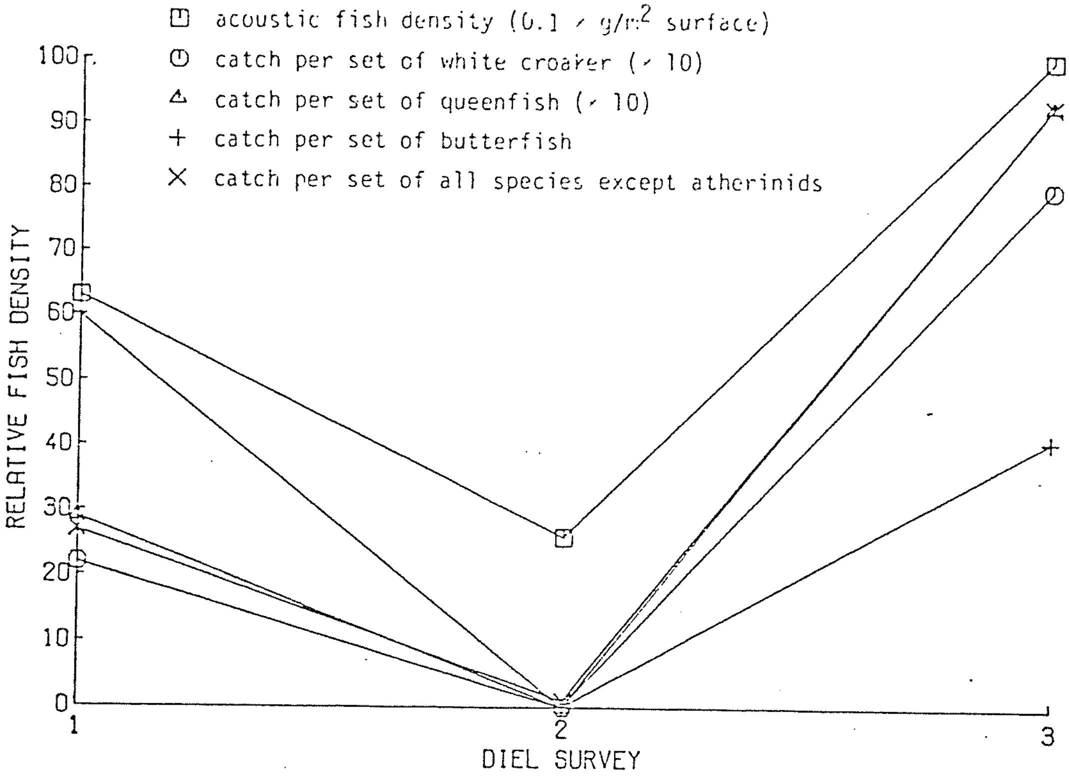

Figure 5. Acoustic fish density and the catch per set of white croaker, queenfish, butterfish, and all species (excluding atherinids) for two night and one morning surveys in April 1978 at the intake area of the Huntington Beach Generating Station.

The catch per hour (CPH) for the 13 gillnet sets, which corresponded to seven diel survey periods, is presented on Table VII. No trends were observed between the gillnet catch and the fish density measured acoustically.

DISCUSSION

Acoustic Measurements

The acoustic measurements of fish density were observed to have a nonnormal distribution. Mathisen et al.[4] found that the variance of acoustic measurements of fish density was proportional to the mean (Poisson distribution), and normalized the data by performing a square root transformation. Gallucci (personal communication) recommended the avoidance of such transformations because of the unknown characteristics of the variance after transformation. Therefore, the data were left intact and nonparametric hypothesis-testing procedures were employed exclusively.

Table VII. Gillnet catch per hour (grams) of white croaker, queenfish, butterfish, and corbina at the intake and Brookhurst sampling areas during the acoustic survey in April 1978.

	White Croaker			Queenfish			Butterfish			Corbina		
		Day			Day			Day			Day	
	1	2	3	1	2	3	1	2	3	1	2	3
Afternoon												
Intake	---	---	379	---	---	38	---	---	167	---	---	167
Brookhurst	---	---	451	---	---	22	---	---	5	---	---	57
Evening												
Intake	99	---	344	5	---	12	0	---	52	62	---	52
Brookhurst	18	---	624	20	---	65	12	---	133	20	---	0
Night												
Intake	65	1031	205	48	190	35	0	0	217	34	0	217
Brookhurst	48	240	32	10	9	19	0	20	42	0	0	0
Morning												
Intake	---	2400	---	---	440	---	---	0	---	---	317	---
Brookhurst	---	397	---	---	0	---	---	0	---	---	153	---

Diel Variability

In other studies, changes in the schooling behavior and vertical distribution of fishes have proven to contribute a large amount of variability to acoustic density estimates.[4,5] Often nighttime density estimates are considerably higher than daylight estimates.[5] The data collected in April at Huntington Beach display a similar pattern, with the estimates of fish density made during darkness being significantly larger than those made during daylight hours.

Daily Variability

Changes may occur in fish distributions from day to day because of tides, weather, feeding, reproductive movement of the fish, etc. Mathisen et al.[4] found that the pelagic biomass off the Spanish Sahara was constantly shifting, with significant changes in distribution occurring within 1 day.

The fish densities measured acoustically at Huntington Beach also displayed significant changes between days. Visual observations indicate there were large concentrations of anchovy in the study area during the first day of the survey but not during the following days. Anchovy schools have been observed to cause significant daily variations in the fish density at San Onofre.[6] This daily variability disappeared when anchovy schools did not dominate the fish biomass in the area. It appears that anchovy are highly mobile, and when they are absent from the inshore area in the spring, the remaining fish assemblage is dominated by sciaenids.

Near Field and Far Field

The larger densities of fish observed downcurrent and inshore of the intake suggest that operation of the discharge may be influencing the density of fish around the intake. Thomas et al.[7] found a similar concentration of fish around and downcurrent of the discharge outlets at the San Onofre Nuclear Generating Station (SONGS). Three physical properties of the discharge have a high potential as fish attractants: (1) the elevated temperature, (2) the discharge of small prey items, and (3) the higher water velocity.

Most of the daily variability in the inshore/offshore and upcurrent/downcurrent trends observed around the intake occurred in two consecutive diel periods, the morning and afternoon of the first survey day. This was the interval when the fish biomass of the area was probably dominated by anchovy. Since anchovy are primarily a cold-water species that prefers water temperatures of 12-14°C (Leong, personal communication), they may avoid the general area of the thermal plume. Therefore, their presence may have obscured the usual downcurrent gradient in fish density. Thomas et al.[6] observed fine-scale negative correlations between water temperature and fish density near SONGS when large concentrations of anchovy were present in the study area.

The fish density continued to decrease 1500 m from the intake. However, these data were collected primarily upcurrent from the discharge; additional data are needed farther downcurrent of the discharge to identify any natural gradients in fish density that may be present in the Huntington Beach area. The study at SONGS[7] showed that the discharge influenced the fish density within 2250 m (1.5 miles) downcurrent of the outlet.

Ground Truth

A positive correlation was observed between the total weight of the lampara catch and the acoustic density measurements at the intake once the atherinid component was removed from the net data. This was a reasonable adjustment, since the acoustic survey does not sample the top 2 m of the water column, the major habitat of the atherinids especially at night.

The lampara catch of white croaker, queenfish, and butterfish in the intake area displayed a direct correlation with the acoustic fish density. This suggested that the high acoustic densities of fish observed in the intake area were composed of these species.

The density of queenfish has been observed to increase near the outfall at the Huntington Beach Generating Station.[8] Thomas et al.[7] found queenfish densities to increase toward the SONGS discharge outlet in 1976-77.

Since white croaker, queenfish, butterfish, and corbina comprise most of the fish (by weight) entrapped in the Huntington Beach intake in April (ignoring Rajiformes), the combined acoustic/net-sampling program has given valuable information about the impact of plant operations on the fish community in the Huntington Beach area.

Based on the results of the SONGS study[7] and this first survey at Huntington Beach, it is apparent that (1) acoustic data on fish densities, net data on species composition, the entrapment rates, and information on the environmental conditions must be collected simultaneously, and (2) such information will make it possible to compare the impact of the operations and/or structures of different plants.

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APPENDIX I-A

The technique used to convert the acoustic signal into biomass estimates is based on the principle that the acoustic intensity of a signal reflected from an underwater target is proportional to the scattering cross section of the target. The scattering mechanism of a fish is very complex, and varies from species to species. However, for each species the scattering cross section is approximately proportional to biomass. For example, studies carried out by Dr. Richard Thorne in Puget Sound and Alaska in 1972 indicated that the average target strength for a 90-gram herring (approximately 20 cm long) was -38 dB. The target strength and the scattering cross section, σ, are related by

$$\text{Target strength} = 10 \log_{10} \left(\frac{\sigma}{4\pi}\right) .$$

For a target strength of -38 dB,

$$\frac{\sigma}{4\pi} = 10^{-3.8} = 1.585 \times 10^{-4} \text{ m}^2 .$$

Therefore the scattering cross section per gram of herring, σ_g, is

$$\sigma_g = \frac{4\pi \ (1.585 \times 10^{-4})}{90} = 2.2.3 \times 10^{-5} \text{ m}^2/\text{g} .$$

In order to obtain a biomass estimate from a school of fish, it is necessary to determine the total intensity of the acoustic signal reflected from all the fish. This can be done with a procedure called echo integration. It has been shown* that the mean output of an echo integrator, $\overline{I}$, is given by

$$\overline{I} = \rho \ r_x{}^2 p_o{}^2 \ \overline{b^2(\theta,\phi)} \ \sigma_g \ T \ G_o \ \frac{(t_2 - t_1)}{c} ,$$

where

p_o = rms transmitted source level at 1 m

r_x = transducer pressure-to-voltage conversion ratio

$\overline{b^2(\theta,\phi)}$ = average value of the transducer beam pattern factor

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*Ehrenberg, J.E., "Echo Integrator Analysis," notes presented at a series of courses taught at the University of Washington during 1973.

G_o = gain factor for the system

c = velocity of sound in water ~ 1500 m/sec

(t_1,t_2) = time interval over which acoustic returns are processed

ρ = biomass density

T = effective pulse length.

The factors r_x, p_o, T and G_o are parameters of the acoustic system that can be easily measured. The time interval (t_1,t_2) is an input that determines the depth interval being surveyed. The beam pattern factor, $\overline{b^2(\theta,\phi)}$, can be calculated from the acoustic transducer directivity function. The scattering cross section per gram, σg, can be evaluated for a particular species (as was done for herring earlier in this appendix). Therefore, the proportionality constant between integrator output, I, and biomass density can be evaluated. The biomass density estimate is given by

$$\rho = \frac{I}{r_x{}^2 \rho_o{}^2 \ \overline{b^2(\theta,\phi)} \ c_g \ T \ G_o \ (t_2-t_1)/c} \ .$$

APPENDIX 2

THE FISH DISTRIBUTION IN THE VICINITY OF THE SOUTHERN CALIFORNIA EDISON POWER PLANT AT HUNTINGTON BEACH, SUMMER 1978

by

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October 1978

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INTRODUCTION

Acoustic data on fish density, along with ground truth information on species composition, were collected at the Southern California Edison power plant at Huntington Beach on 18 through 22 July 1978. This report presents the results of that survey.

METHODS

Data Acquisition

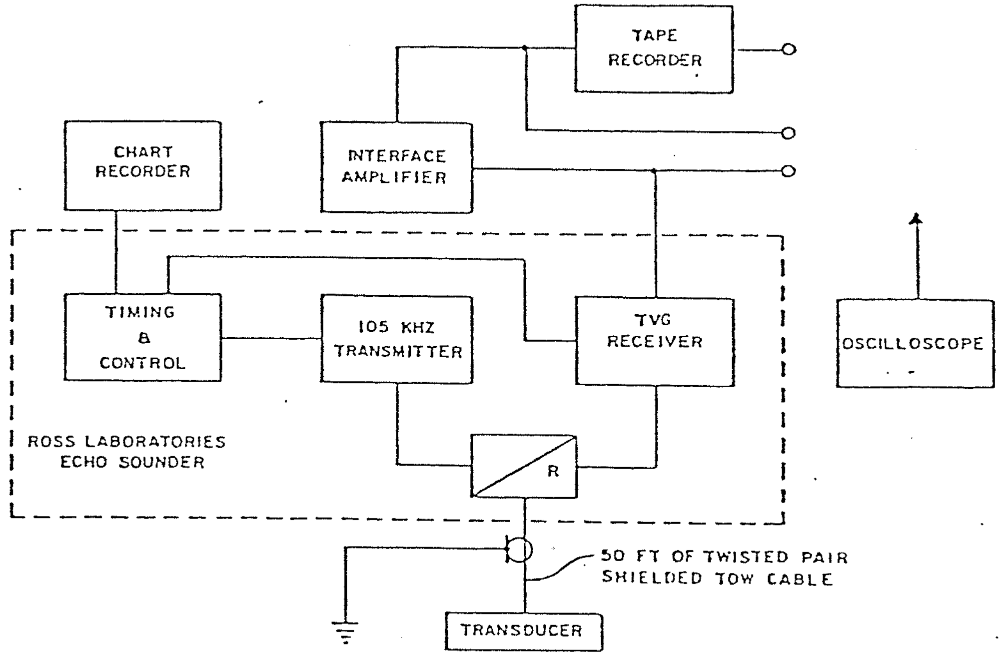
A block diagram of the data-acquisition system used at Huntington Beach, along with the transducer beam pattern, is shown in Figure 1. A complete description of the system is presented in Reference 1. This system was developed by the Marine Acoustics Group at the University of Washington, and has been used extensively to gather acoustic data on fish stocks. The chart recorder provides real-time output, while the interface amplifier and magnetic tape recorder allow data to be stored for later analysis. System parameters can be adjusted to optimize returns for particular applications.

Acoustic measurements and net sampling were conducted along line transects run over the intake and discharge structures. Four transect configurations were employed: a 600 m transect was run approximately parallel to the shoreline over the intake structure; a 3000 m transect was run approximately parallel to the shoreline over the intake structure; a 400 m transect was run perpendicular to shore over the intake and discharge structures; and a 600 m transect was run approximately parallel to the shoreline over the discharge structure (see Figure 2). The transects within 300 m of the intake and discharge structures were designed to examine near-field effects, and those >300 m from the structures were designed to examine far-field effects. Shallow water prevented running the perpendicular transect an equal distance from both structures.

For convenience we have designated the areas from 300 m - 1500 m up the coast and down the coast from the intake area as the Huntington and Brookhurst areas, respectively.

Continuous collection of acoustic data was made possible by installing the transducer in a 2-ft depressor body which was towed between 4 and 5 kn along the transects.

Both lampara seines and gillnets were used to collect the ground truth data. The lampara seine was chosen because of its relatively high efficiency and low selectivity. Gillnets were added to allow sampling near the intake structure, and to provide information on the vertical distribution of fishes by species.



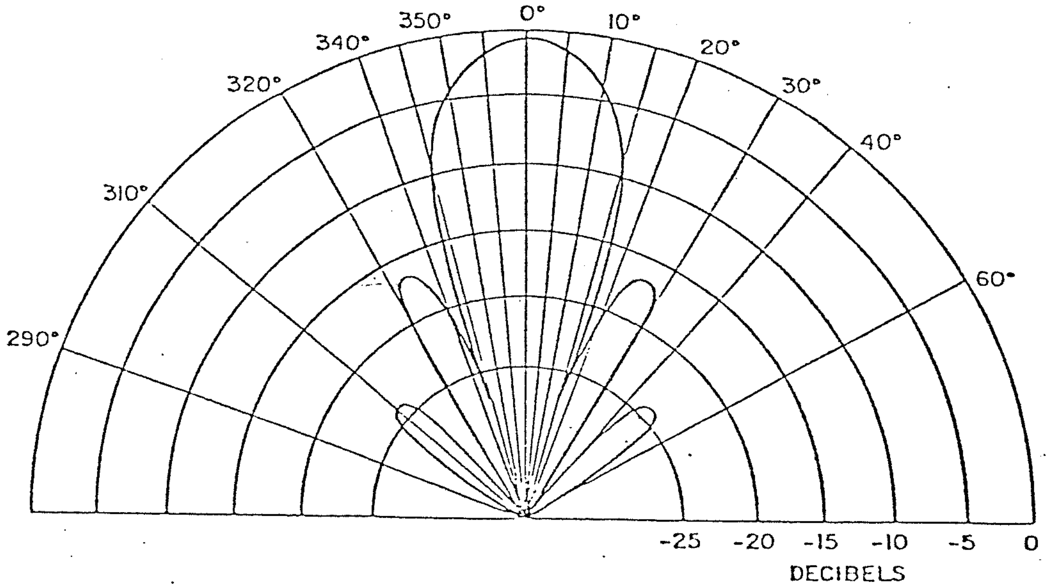


Figure 1. Block diagram of the data-acquisition system (top) and beam pattern of the transducer (bottom) used at Huntington Beach.

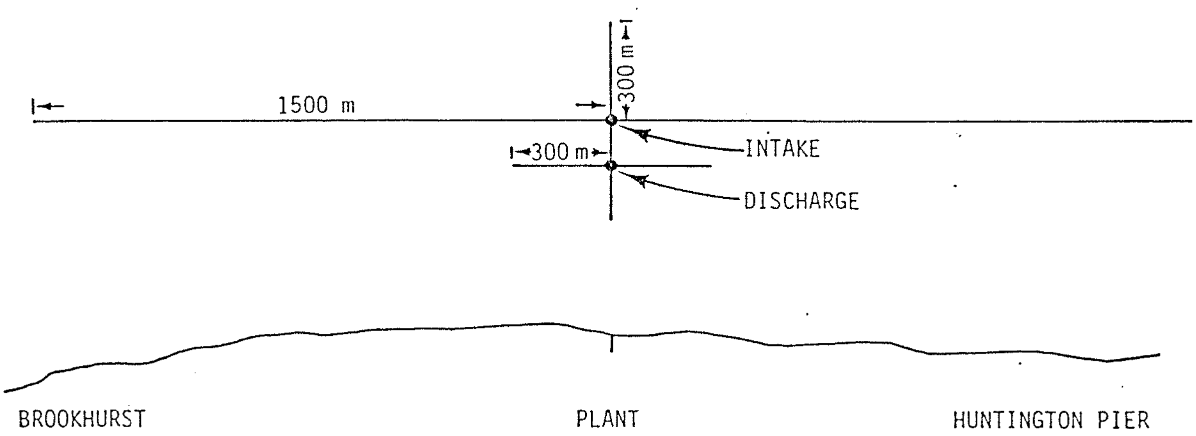


Figure 2. Schematic (not to scale) of the transect pattern for the acoustic survey in July 1978 at the Huntington Beach Generating Station.

DATA ANALYSIS

The acoustic data were analyzed using a digital echo-integration technique. Density values were based on a target strength of -33 dB/kg. The average fish density (in grams/meter^2 of surface area) was computed at 20-sec (approximately 50-m) intervals along each transect. All unusual acoustic values recorded on the magnetic tape were cross-checked with the echograms, and erroneous values due to kelp, surface turbulence, etc., were edited out.

All depth strata were combined for the computation of statistics and the hypothesis-testing procedures. Nonparametric testing procedures were used exclusively to avoid making assumptions about the underlying distribution of the data. The rejection region for all testing procedures was determined using $\alpha = 0.05$.

Although the fish densities in this report are expressed in absolute units (grams/meter^2), both the target strength and the calibration data are provisional. Consequently, the measurements should be considered relative values that are comparable only within the survey. Detailed examination of the calibration data, conversion to absolute values, and inter-survey comparisons will be presented in the final report.

RESULTS

Acoustic

The measurements were divided into four diel periods: predawn (midnight to dawn); postdawn (dawn to noon); predusk (noon to dusk); and postdusk (dusk to midnight). Five predawn and postdawn periods and one predusk and postdusk period were sampled during the 5-day sampling period. Inclement weather interfered with afternoon and evening sampling. Measurements directly over the intake were excluded from analysis because a diver's float bag was observed in mid-water above the intake.

The density data from all survey periods were combined and then the mean, median, mode, kurtosis, skewness, and variance were calculated. The results are shown in Table I. These statistics suggest that the fish densities have a nonnormal distribution.

Table I. The mean, median, mode, kurtosis, skewness, and variance of fish density values (in grams/meter^2 of surface area) from the acoustic survey at Huntington Beach, California, in July 1978.

Mean	Median	Mode	Kurtosis	Skewness	Variance
65.640	26.765	18.733	72.355	6.882	19418.987

The mean fish density around the intake was indexed by day and diel period because these temporal characteristics are important in describing changes in abundance and distribution. The results are presented in Table II.

Table II. Mean fish density (in grams/meter^2 or surface area) in the vicinity of the intake at the Huntington Beach power generating station between 18 and 22 July 1978.

	Date					
Diel Period	7/18/78	7/19/78	7/20/78	7/21/78	7/22/78	All Days
Predawn	105.895	55.254	44.687	73.511	180.863	83.091
Postdawn	41.929	91.733	55.225	45.147	62.485	58.005
Predusk	---	---	---	22.136	---	22.136
Postdusk	---	---	---	46.788	---	46.788

The survey was designed so that differences observed in the fish density between days and diel periods could be tested for their statistical significance. The results of these tests are presented in the following sections.

Diel Variability

A Kruskal-Wallis one-way analysis of variance by ranks[2] was used to test the null hypothesis:

H_0: There is no difference in average fish density between diel periods at $\alpha = 0.05$.

H_1: There is a significant difference in average fish density between diel periods.

For this test, and for all the other tests described in this report, the relevant test statistic and the significance level of the statistic (i.e., the probability under H_0 of obtaining values as large as those of the test statistic) were computed using the NPAR TESTS program of the Statistical Package for the Social Sciences.[3]

When corrected for ties, the value of the Kruskal-Wallis H statistic computed under H_0 was 269.75 with a significance level greater than 0.0000. Therefore, H_0 was rejected at a level of $\alpha < 0.05$, and it was concluded that there were significant diel variations in the fish density. A diel difference in fish density was expected because of diel changes in fish distribution relative to available light.

Daily Variability

The difference in fish density between days was examined for each of the night and morning periods. A Kruskal-Wallis one-way analysis of variance was used to test the null hypothesis:

H_0: There is no difference in fish density between days within one diel period (predawn, postdawn) at $\alpha = 0.05$.

H_1: There is a significant difference in fish density.

The test statistic values, corrected for ties, and the levels of significance are shown in Table III. The conclusion drawn from these tests was that there were significant changes in fish density between days within each diel period tested.

The differences in fish density observed between days were attributed to movement of fish in and out of the study area.

Table III. Values of the Kruskal-Wallis H statistic (corrected for ties) and the level of significance for testing the null hypothesis H_0 about differences in fish density between days for the night and morning periods.

Data Set	Value of H	Level of Significance	Decision for H_0
Predawn	172.99	0.0000	reject
Postdawn	118.97	0.0000	reject

Area Variability

The fish densities observed within 300 m of the intake were compared to the fish densities between 300 m and 1500 m up and down the coast line. Because of prior test results, the data tested were restricted to one diel period of each day. A Kruskal-Wallis one-way analysis of variance was used to test this null hypothesis:

H_0: There is no difference in fish density between areas at $\alpha = 0.05$.

H_1: There is a difference.

The mean fish densities, test statistics, and levels of significance are shown in Table IV. The conclusion drawn from these tests was that there was a difference in fish density between areas during the predawn periods. However, this difference did not always persist into postdawn periods.

The differences in fish density between areas were attributed to the higher densities observed near the intake.

Table IV. Values of the Kruskal-Wallis H statistic (corrected for ties) and their level of significance for hypothesis testing of variations in fish density between areas for diel periods combined and separate.

		Fish Density (g/m^2 of surface area)				
Diel Period	Date	Intake	Brookhurst	Huntington	Value of H	Level of Significance
Predawn	7/18/78	157.35	18.23	36.30	44.23	0.0000 *
Postdawn	7/18/78	52.39	32.19	6.64	3.65	0.1610 N.S.
Predawn	7/19/78	57.85	72.94	27.09	23.58	0.0000 *
Postdawn	7/19/78	126.77	22.81	18.42	20.64	0.0000 *
Predawn	7/20/78	66.98	30.13	15.24	70.02	0.0000 *
Postdawn	7/20/78	55.23	---	---	---	---
Predawn	7/21/78	94.49	33.24	31.11	13.71	0.0011 *
Postdawn	7/21/78	66.51	13.04	9.66	17.26	0.0002 *
Predusk	7/21/78	26.42	15.23	7.29	7.52	0.0233 *
Postdusk	7/21/78	49.64	35.62	46.05	9.32	0.0093 *
Predawn	7/22/78	205.69	39.06	178.25	25.78	0.0000 *
Postdawn	7/22/78	59.67	32.90	49.80	5.61	0.6070 N.S.

---

* = significant

N.S. = not significant

Fish Distribution Near the Intake (within 300 m)

The fish aggregated at the intake during July often appeared to be more numerous downcurrent from the intake. These observations prompted testing for differences in fish density with respect to direction from the intake.

For the initial data analysis, the fish densities measured within 300 m of the intake area were divided into four groups: inshore (toward the discharge outlet), downcurrent, upcurrent, and offshore.

The Mann-Whitney U procedure[2] was used to test the significance of differences in fish density between two areas. The values used for the tests were the average fish densities recorded on individual transects over each of the four areas of interest.

The general form of the null hypothesis tested was:

H_0: There is no difference in fish density between the inshore and offshore or the upcurrent and downcurrent areas of the intake site at $\alpha = 0.05$.

H_1: There is a difference in fish density between the inshore and offshore or upcurrent and downcurrent areas of the intake at $\alpha = 0.05$.

Because of prior test results, the data tested were restricted to one diel period of each day.

The fish density was in general higher inshore from the intake (see Table V). The density of fish was also higher downcurrent from the intake on 19 July when visible surface currents were present (see Table VI). The results of these tests suggest that the presence and/or operation of the intake and/or discharge may have been influencing the distribution of fish in the area.

Fish Distribution Far From the Intake (300 to 1500 m)

The fish density was often higher on one side of the intake (see Figure 3). The fish densities in the Brookhurst and Huntington areas were compared to see if these trends persisted over 300 m from the intake. The testing procedures were described in the previous section.

The fish density was usually higher downcurrent from the discharge (see Table VII). Although a significant difference in fish density observed in the near field (within 300 m of the intake) did not always persist into the far field (300 to 1500 m from the intake) and vice versa, when a difference was detected in both areas, the direction of the difference was always the same.

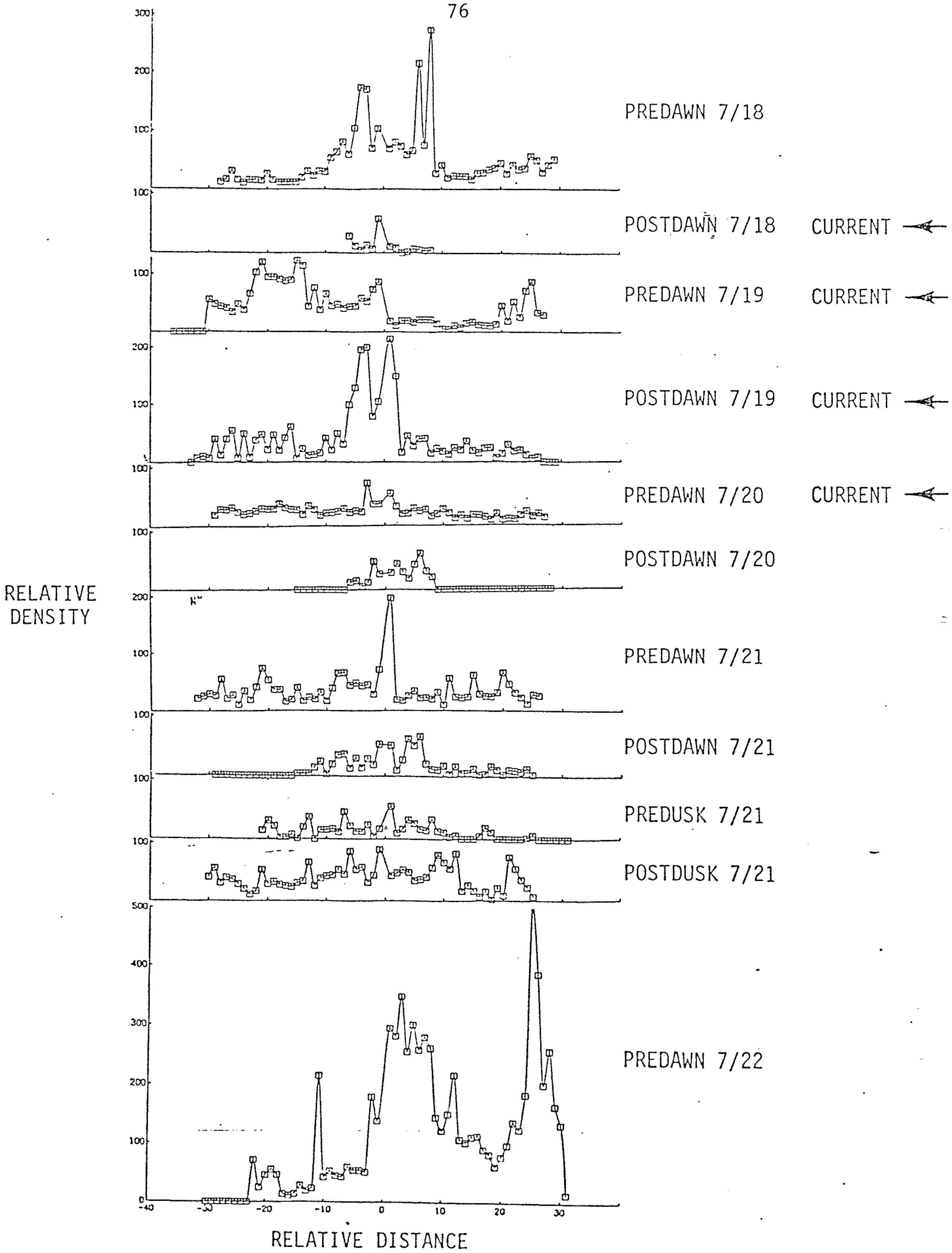


Figure 3. Density of fish up and down the coast from the intake at Huntington Beach, July 1978.

Table V. The mean fish density and significance level (P) at which the inshore and offshore density observations within 300 m of the intake were found to be different.

		Fish Density (g/m^2 of surface area)			
Diel Period	Date	Offshore	Inshore	P	
Predawn	7/18/78	132.23	301.76	0.0026	*
Postdawn	7/18/78	6.85	323.51	0.0029	*
Predawn	7/19/78	69.45	272.63	0.0041	*
Postdawn	7/19/78	145.68	485.17	0.0607	N.S.
Predawn	7/20/78	74.24	224.29	0.2138	N.S.
Postdawn	7/20/78	14.80	366.89	0.0000	*
Predawn	7/21/78	26.10	374.90	0.0010	*
Postdawn	7/21/78	53.10	467.55	0.0000	*
Predusk	7/21/78	14.29	90.44	0.0010	*
Postdusk	7/21/78	14.29	62.43	0.3151	N.S.
Predawn	7/22/78	105.71	361.87	0.7853	N.S.
Postdawn	7/22/78	13.92	405.54	0.0000	*

* = significant

N.S. = not significant

Table VI. The mean fish density and the significance level (P) at which the up-coast and down-coast density observations within 300 m of the intake were found to be different.

		Mean Fish Density (g/m^2 of surface area)				
Diel Period	Date	Up Coast	Down Coast	Current Direction	P	
Predawn	7/18/78	146.20	109.01	---	0.6531	N.S.
Postdawn	7/18/78	65.08	29.66	down	0.2025	N.S.
Predawn	7/19/78	18.35	52.56	down	0.0005	*
Postdawn	7/19/78	55.84	95.35	down	0.0008	*
Predawn	7/20/78	31.61	35.41	down	0.8501	N.S.
Postdawn	7/20/78	35.21	20.41	negligible	0.0528	*
Predawn	7/21/78	53.60	44.65	negligible	0.0176	*
Postdawn	7/21/78	55.78	28.53	negligible	0.8575	N.S.
Predusk	7/21/78	23.63	20.96	negligible	0.3783	N.S.
Postdusk	7/21/78	42.31	55.72	negligible	0.0676	N.S.
Predawn	7/22/78	273.37	84.02	---	0.0000	*
Postdawn	7/22/78	32.16	40.73	---	0.9150	N.S.

* = significant

N.S. = not significant

Table VII. The mean fish density and significance level (P) at which the up-coast and down-coast density observations at the intake were found to be different.

Diel Period	Date	Mean Fish Density (g/m^2 of surface area) Up Coast	Down Coast	Current Direction	P	
Predawn	7/18/78	36.30	18.23	---	0.0000	*
Postdawn	7/18/78	6.64	32.19	down coast	0.2829	N.S.
Predawn	7/19/78	27.09	72.94	down coast	0.0000	*
Postdawn	7/19/78	18.42	22.81	down coast	0.8855	N.S.
Predawn	7/20/78	15.24	30.13	down coast	0.0000	*
Postdawn	7/20/78	---	---	negligible	---	
Predawn	7/21/78	31.11	33.24	negligible	0.6614	N.S.
Postdawn	7/21/78	9.66	13.04	negligible	0.4477	N.S.
Predusk	7/21/78	7.29	15.23	negligible	0.0532	*
Postdusk	7/21/78	46.05	35.62	negligible	0.7805	N.S.
Predawn	7/22/78	178.25	39.06	---	0.0000	*
Postdawn	7/22/78	49.80	32.90	---	0.0424	*

* = significant

N.S. = not significant

Fish Distribution Near the Discharge (within 300 m)

There were several indications that the fish distribution in the study area was influenced by the discharge. Therefore, the fish densities up and down the coast from the discharge and between the intake and discharge areas were tested using the Mann-Whitney U procedure. The general form of the null hypothesis was similar to that in the preceding section. The fish densities up and down the coast from the discharge were examined for the predawn 7/21, postdawn 7/21, and postdawn 7/22 survey periods. The fish density was higher down the coast from the discharge during the predawn 7/22 survey period and not different during the postdawn 7/21 period (see Table VIII). The fish density was higher at the discharge than at the intake during the postdawn 7/22 survey period and not different during the predawn 7/21 and postdawn 7/21 survey periods (see Table IX).

Table VIII. Mean fish density (g/m^2 of surface area), sample size, and significance level (P) at which the up-coast and down-coast density observations at the discharge were found to be different.

		Up Coast		Down Coast			
Diel Period	Date	Fish Density	n	Fish Density	n	P	
Predawn	7/21/78	71.73	25	85.83	28	0.011	*
Postdawn	7/21/78	31.27	29	35.37	18	0.4975	N.S.
Postdawn	7/22/78	146.11	17	48.99	14	0.0621	N.S.

* = significant

N.S. = not significant

Table IX. The mean fish density (g/m^2 of surface area) at the intake and discharge, the sample size, and the significance level at which the two observations were found to be different.

		Intake		Discharge			
Diel Period	Date	Fish Density	n	Fish Density	n	P	
Predawn	7/21/78	94.99	20	79.18	53	0.1417	N.S.
Postdawn	7/21/78	66.51	57	32.84	47	0.8317	N.S.
Postdawn	7/22/78	59.67	55	102.25	31	0.0019	*

* = significant

N.S. = not significant

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Ground Truth

The changes in fish density between days and diel periods stress the importance of collecting net samples simultaneously with the acoustic measurements. Sixteen lampara sets were made during the July survey. Eight sets were made on 19 July, one on 21 July, and seven on 22 July. As a rule, half the sets were made during the predawn period and half during the postdawn period. The one exception was the postdusk set on 21 July.

The net samples corroborated the acoustic measurements by indicating that there were more fish near the intake, and, for specific survey periods, more fish in the Brookhurst area, which was downcurrent from the intake (see Table X).

Table X. The average catch per set (kg) of the lampara seine, the mean fish density (grams/meter^2 of surface area) determined from acoustic echo integration, and the time elapsed (hours) between sample collection by area, day, and diel period.

Diel Period	Date	Area	Average CPS (kg)	No. of Net Sets	Fish Density (g/m^2)	Time Elapsed (hours)
Predawn	7/19/78	Huntington	17	1	27	3
Predawn	7/19/78	Brookhurst	49	1	73	3
Predawn	7/19/78	Intake	64	2	58	0
Postdawn	7/19/78	Intake	148	4	127	0
Postdusk	7/21/78	Huntington	5	1	46	2
Predawn	7/22/78	Brookhurst	49	1	39	2
Predawn	7/22/78	Intake	110	2	206	2
Predawn	7/22/78	Intake	42	1	60	1
Predawn	7/22/78	Discharge	627	3	102	1

The catch per set (CPS) of the lampara net tended to increase throughout the postdawn period. This may have been the result of the fish aggregating in larger schools as the light intensity increased (see Ref. 4) and the fact that the operator of the seine boat was using an echo-sounder to locate school-sized targets to set the net on. These factors as well as the time elapsed between our survey and the net set introduced some error into the correlation between the two measurements. However, a Spearman correlation coefficient (r_s) of 0.78 ($n = 9$, $p = 0.05$) was obtained between the CPS and the acoustic density. The fact that this correlation improves when the daylight samples are removed ($r_s = 0.83$, $n = 6$, $p = 0.05$) suggests that the efficiency of echo-location lampara seining changes with light intensity (i.e., by diel period).

The coefficients of variability of the lampara CPS were examined for the four dominant species (see Table XI). An important observation was that the variability in the CPS was lowest for butterfish, queenfish, and white croaker during the night and lowest for northern anchovy during the day. It was expected that the variability would be lower for nighttime net sampling because the fish are more uniformly distributed. The fact that the variability was lowest for anchovy during the daylight sampling was probably due to the net sets being targeted acoustically on anchovy schools. The variability in the nighttime CPS was much lower for butterfish, queenfish and white croaker than for northern anchovy. This suggests that the anchovy were less uniformly distributed and perhaps were more transient to the study area.

DISCUSSION

Acoustic Measurements

The fish densities measured acoustically were observed to have a nonnormal distribution. Mathisen et al.,[5] found that the variance of acoustic measurements of fish density was proportional to the mean (Poisson distribution), and normalized the data by performing a square root transformation. Gallucci (personal communication) recommended the avoidance of such transformations because of the unknown characteristics of the variance after transformation. Therefore, the data were left intact and nonparametric hypothesis-testing procedures were employed exclusively.

Diel Variability

In other studies, changes in the schooling behavior and vertical distribution of fishes have proved to contribute a large amount of variability to acoustic density estimates.[5,6] Often nighttime density estimates are considerably higher than daylight estimates.[6] The acoustic data collected in July at Huntington Beach display a similar pattern, with the estimates of fish density made during darkness being significantly larger than those made during daylight hours.

The net catches supported the acoustic measurements in that the species diversity decreased with light intensity while variability of the net catches tended to increase with light intensity, indicating that the fish distribution was more contagious during the day. Acoustic observations confirmed this indication in that fish schools are only observed during daylight surveys.

Daily Variability

Changes may occur in fish distributions from day to day because of tides, weather, feeding, reproductive movement of the fish, etc. Mathisen et al.[5] found that the pelagic biomass off the Spanish Sahara was constantly shifting, with significant changes in distribution occurring within one day.

Table XI. The mean ($\bar{x}$), sample size (n), estimated standard deviation (s), and coefficient of variation (C) of butterfish, queenfish, white croaker, and northern anchovy in the lampara catches at Huntington Beach during July 1978.

	Predawn 7/19/78				Predawn 7/22/78				Postdawn 7/19/78				Postdawn 7/22/78			
	$\bar{x}$	n	s	C ($s/\bar{x}$)	$\bar{x}$	n	s	C ($s/\bar{x}$)	$\bar{x}$	n	s	C ($s/\bar{x}$)	$\bar{x}$	n	s	C ($s/\bar{x}$)
Butterfish																
all areas	1.75	4	0.51	0.29	6.77	4	3.65	0.54	---	-	---	---	---	-	---	---
intake only	1.38	2	0.10	0.07	8.22	2	2.79	0.54	13.18	4	22.77	0.98	28.56	4	25.57	0.90
Queenfish																
all areas	8.67	4	4.85	0.56	7.10	4	5.30	0.75	---	-	---	---	---	-	---	---
intake only	8.38	2	3.73	0.45	11.57	2	0.50	0.04	98.25	4	191.05	1.44	61.38	4	101.73	1.66
White croaker																
all areas	5.50	4	4.26	0.77	2.98	4	2.59	0.87	---	-	---	---	---	-	---	---
intake only	9.13	2	1.39	0.15	5.13	2	0.65	0.13	4.00	4	7.05	1.76	6.56	4	10.30	1.57
Northern anchovy																
all areas	25.56	4	26.30	1.03	41.18	4	66.72	1.62	---	-	---	---	---	-	---	---
intake only	35.64	2	38.70	1.09	76.15	2	91.76	1.20	15.33	4	12.98	0.85	382.99	4	333.27	0.87

The fish densities measured acoustically at Huntington Beach also displayed changes between days. The data suggest that a large amount of this variability was due to northern anchovy moving into and out of the study area. Anchovy schools were also found to cause significant daily variations in the fish density at San Onofre.[7]

The species composition of the lampara catches with anchovy removed was dominated by butterfish, queenfish, and white croaker. In so far as these fishes appeared to be the resident fishes in the area in July, it is not surprising that they represent the most common entrapped species.

The fish densities up and down the coast from the intake suggested that fish were orienting to the intake/discharge area in two specific ways. First, when strong coastal currents were absent, fish aggregated near the intake. Second, when strong currents were observed, the fish appeared to concentrate on one side of the intake only. Thomas et al.[8] found similar fish distributions around the discharge outlet at San Onofre. In addition to the physical presence of intake and outlet structures, which create substrate and eddies which provide more habitat for fish, the discharged effluent has several properties with a high potential as fish attractants: (1) the elevated temperature, (2) the small prey items discharged, and (3) the higher water velocity. Studies at SONGS[8] suggest that elevated water temperature is the major attractant; however temperature may interact with the discharge of food resources.

Ground Truth

A positive correlation was observed between the total weight of the lampara catch and acoustic density measurements in the intake area. This indicates that the species composition of the net catches represents the species observed acoustically.

The net catches suggest that the species composition of the study area in July was dominated by one highly transient species, the northern anchovy (63%), and three resident species, queenfish (24%), white croaker (3%), and butterfish (8%).

The lampara catch of white croaker, queenfish, and butterfish in the intake area suggests that the high acoustic densities of fish observed in the intake area were composed of these species.

The density of queenfish has been observed to increase near the outfall at the Huntington Beach generating station.[9] Thomas et al.[8] found queenfish densities to increase toward the SONGS discharge outlet in 1976-77.

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APPENDIX 3

THE FISH DISTRIBUTION IN THE VICINITY OF THE SOUTHERN CALIFORNIA EDISON POWER PLANT AT HUNTINGTON BEACH, FALL 1978

by

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INTRODUCTION

Acoustic data on fish density, along with ground truth information on species composition, were collected at the Southern California Edison power plant at Huntington Beach on 23 through 27 October 1978. This report presents the results of that survey.

METHODS

Data Acquisition

A Simrad EK 120 sounder and Ross 200A chart recorder were used to collect acoustic data at Huntington Beach in October. This system was developed by the Marine Acoustics Group at the University of Washington, and has been used extensively to gather acoustic data on fish stocks.[1] The chart recorder provides real-time output, while the interface amplifier and magnetic tape recorder allow data to be stored for later analysis. System parameters can be adjusted to optimize returns for particular applications.

Acoustic measurements and net sampling were conducted along line transects run over the intake and discharge structures. Four transect configurations were employed: a 600 m transect was run approximately parallel to the shoreline over the intake structure; a 3000 m transect was run approximately parallel to the shoreline over the intake structure; a 400 m transect was run perpendicular to shore over the intake and discharge structures; and a 600 m transect was run approximately parallel to the shoreline over the discharge structure (see Figure 1). The transects within 300 m of the intake and discharge structures were designed to examine near-field effects, and those >300 m from the structures were designed to examine far-field effects. Shallow water prevented running the perpendicular transect an equal distance from both structures.

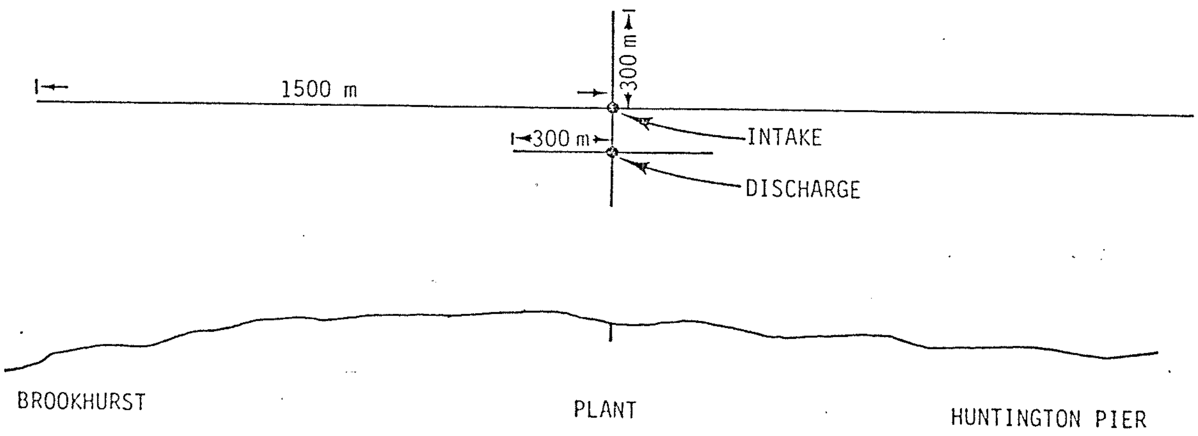

Figure 1. Schematic (not to scale) of the transect pattern for the acoustic survey in October 1978 at the Huntington Beach Generating Station.

For convenience we have designated the areas from 300 m - 1500 m up the coast and down the coast from the intake area as the Huntington and Brookhurst areas, respectively.

Continuous collection of acoustic data was made possible by installing the transducer in a 2-ft depressor body which was towed between 4 and 5 kn along the transects.

Both lampara seines and gillnets were used to collect the ground truth data. The lampara seine was chosen because of its relatively high efficiency and low selectivity. Gillnets were added to allow sampling near the intake structure, and to provide information on the vertical distribution of fishes by species.

DATA ANALYSIS

The acoustic data were analyzed using a digital echo-integration technique. Density values were based on a target strength of -33 dB/kg. The average fish density (in grams/meter^2 of surface area) was computed at 20-sec (approximately 50-m) intervals along each transect. All unusual acoustic values recorded on the magnetic tape were cross-checked with the echograms, and erroneous values due to kelp, surface turbulence, etc., were edited out.

All depth strata were combined for the computation of statistics and the hypothesis-testing procedures. Nonparametric testing procedures were used exclusively to avoid making assumptions about the underlying distribution of the data. The rejection region for all testing procedures was determined using $\alpha = 0.05$.

RESULTS

Acoustic

The measurements were divided into two diel periods: predawn (midnight to dawn) and postdawn (dawn to noon). Five predawn and four postdawn periods were sampled during the 5-day survey. Measurements directly over the intake were excluded from analysis.

The density data from all survey periods were combined and then the mean, median, mode, kurtosis, skewness, and variance were calculated. The results are shown in Table I. These statistics suggest that the fish densities have a non-normal distribution.

Table I. The mean, median, mode, kurtosis, skewness, and variance of fish density values (in grams/meter^2 of surface area) from the acoustic survey at Huntington Beach, California, in October 1978.

Mean	Median	Mode	Kurtosis	Skewness	Variance
1.634	0.615	0	155.970	10.554	13.928

The mean fish density in the study area was indexed by day and diel period because these temporal characteristics are important in describing changes in abundance and distribution. The results are presented in Table II.

The survey was designed so that differences observed in the fish density between days and diel periods could be tested for their statistical significance. The results of these tests are presented in the following sections.

Table II. Mean fish density (in grams/meter^2 of surface area) in the vicinity of the intake at the Huntington Beach power generating station between 23 and 27 October 1978.

	Date					
Diel Period	10/23/78	10/24/78	10/25/78	10/26/78	10/27/78	All Days
Predawn	2.992	3.307	3.673	2.663	3.236	2.393
Postdawn	1.972	---	0.879	0.011	0.593	0.499

Diel Variability

A Kruskal-Wallis one-way analysis of variance by ranks[2] was used to test the null hypothesis:

H_0: There is no difference in average fish density between diel periods at $\alpha = 0.05$.

H_1: There is a significant difference in average fish density between diel periods.

For this test, and for all the other tests described in this report, the relevant test statistic and the significance level of the statistic (i.e., the probability under H_0 of obtaining values as large as those of the test statistic) were computed using the NPAR TESTS program of the Statistical Package for the Social Sciences.[3]

When corrected for ties, the value of the Kruskal-Wallis H statistic computed under H_0 was 799.7271 with a significance level greater than 0.0000. Therefore, H_0 was rejected at a level of $\alpha < 0.05$, and it was concluded that there were significant diel variations in the fish density. A diel difference in fish density was expected because of diel changes in fish distribution.

Daily Variability

The difference in fish density between days was examined for each of the night and morning periods. A Kruskal-Wallis one-way analysis of variance was used to test the null hypothesis:

H_0: There is no difference in fish density between days within one diel period (predawn, postdawn) at $\alpha = 0.05$.

H_1: There is a significant difference in fish density.

The test statistic values, corrected for ties, and the levels of significance are shown in Table III. The conclusion drawn from these tests was that there were significant changes in fish density between days within each diel period tested.

The differences in fish density observed between days was attributed to movement of fish in and out of the study area.

Table III. Values of the Kruskal-Wallis H statistic (corrected for ties) and the level of significance for testing the null hypothesis H_0 about differences in fish density between days for the night and morning periods.

Data Set	Value of H	Level of Significance	Decision for H_0
Predawn	200.49	0.0000	reject
Postdawn	478.96	0.0000	reject

Area Variability

The fish densities observed within 300 m of the intake were compared with the fish densities between 300 m and 1500 m up and down the coast line. Because of prior test results, the data tested were restricted to one diel period of each day. A Kruskal-Wallis one-way analysis of variance was used to test this null hypothesis:

H_0: There is no difference in fish density between areas at $\alpha = 0.05$.

H_1: There is a difference.

The mean fish densities, test statistics, and levels of significance are shown in Table IV. The conclusion drawn from these tests was that there was a difference in fish density between areas during the predawn periods. However, this difference did not always persist into postdawn periods.

The differences in fish density between areas were attributed to the higher densities observed near the intake.

Table IV. Values of the Kruskal-Wallis H statistic (corrected for ties), the level of significance for hypothesis testing of variations in fish density between areas, and the average fish density within each area for diel periods combined and separate.

Diel Period	Date	Fish Density (g/m^2 of surface area) Intake	Brookhurst	Huntington	Value of H	Level of Significance	
Predawn	10/23/78	2.992	2.450	2.856	7.0921	0.5792	N.S.
Postdawn	10/23/78	1.972	0.132	0.323	46.4956	0.0000	*
Predawn	10/24/78	3.307	1.870	2.628	11.1400	0.0038	*
Predawn	10/25/78	3.673	0.681	0.692	6.3213	0.0424	*
Postdawn	10/25/78	0.879	0.237	0.101	1.4559	0.4829	N.S.
Predawn	10/26/78	2.663	1.505	1.819	7.4554	0.0240	*
Postdawn	10/26/78	0.011	0.058	0.070	21.4600	0.0000	*
Predawn	10/27/78	3.236	2.232	1.730	11.8830	0.0026	*
Postdawn	10/27/78	0.593	0.329	0.289	70.5517	0.0000	*

* = significant

N.S. = not significant

Fish Distribution Near the Intake (within 300 m)

The fish aggregated at the intake during April and July often appeared to be more numerous downcurrent from the intake. These observations prompted testing for differences in fish density with respect to direction from the intake.

For the initial data analysis, the fish densities measured within 300 m of the intake area were divided into four groups: inshore (toward the discharge outlet), downcurrent, upcurrent, and offshore.

The Mann-Whitney U procedure[2] was used to test the significance of differences in fish density between two areas. The values used for the tests were the average fish densities recorded on individual transects over each of the four areas of interest.

The general form of the null hypothesis tested was:

H_0: There is no difference in fish density between the inshore and offshore or the upcurrent and downcurrent areas of the intake site at $\alpha = 0.05$.

H_1: There is a difference in fish density between the inshore and offshore or upcurrent and downcurrent areas of the intake at $\alpha = 0.05$.

Because of prior test results, the data tested were restricted to one diel period of each day.

A difference in the inshore and offshore density of fish was detected for the predawn periods of 25 and 26 October and the postdawn period of 27 October. The mean fish density during these periods was highest inshore (see Table V).

A difference in the near-field density of fish upcoast and downcoast was observed for the postdawn periods of 23 and 27 October. The mean density of fish in the near field during these periods was higher on the downcurrent side of the intake (see Table VI). The fact that coastal currents were not particularly strong may have influenced the distribution of fishes up and down the coast from the intake.

Fish Distribution Far From the Intake (300 to 1500 m)

The far-field fish density was often higher on the downcurrent side of the intake in the spring and summer surveys, but in October currents along shore were weak and coastal differences in fish density were minimal. However, significant differences were observed for the postdawn periods of 23 and 27 October and the predawn period of 25 October, when the far-field fish density was highest downcurrent from the intake (see Table VII).

Table V. The mean fish density and significance level (P) at which the inshore and offshore density observations within 300 m of the intake were found to be different.

		Fish Density (g/m^2 of surface area)			
Diel Period	Date	Offshore	Inshore	P	
Predawn	10/23/78	3.6173	3.6255	0.5715	N.S.
Postdawn	10/23/78	1.5935	5.6833	0.1301	N.S.
Predawn	10/24/78	4.0359	6.4719	1.0000	N.S.
Predawn	10/25/78	1.6890	22.7866	0.0040	*
Postdawn	10/25/78	0.0091	12.0110	1.0000	N.S.
Predawn	10/26/78	2.3145	11.8029	0.0109	*
Postdawn	10/26/78	0.0092	0.2520	0.7320	N.S.
Predawn	10/27/78	5.1771	3.4281	0.2204	N.S.
Postdawn	10/27/78	0.5320	1.5599	0.0001	*

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* = significant
N.S. = not significant

Table VI. The mean fish density and the significance level (P) at which the upcoast and downcoast density observations within 300 m of the intake were found to be different.

Diel Period	Date	Mean Fish Density (g/m^2 of surface area) Upcoast	Downcoast	Current Direction	P	
Predawn	10/23/78	2.4265	2.9324	upcoast	0.2127	N.S.
Postdawn	10/23/78	2.1094	1.0301	upcoast	0.0069	*
Predawn	10/24/78	2.2890	3.0302	upcoast	0.2007	N.S.
Predawn	10/25/78	2.1755	1.2611	upcoast	0.6247	N.S.
Postdawn	10/25/78	0.1265	0.0334	upcoast	0.3393	N.S.
Predawn	10/26/78	1.8305	1.8592	downcoast	0.2028	N.S.
Postdawn	10/26/78	0.0089	0.0101	negligible	0.5291	N.S.
Predawn	10/27/78	2.2485	2.6356	downcoast	0.9624	N.S.
Postdawn	10/27/78	0.4402	0.4924	downcoast	0.0324	*

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* = significant
N.S. = not significant

Table VII. The mean fish density and significance level (P) at which the upcoast and downcoast density observations greater than 300 m from the intake were found to be different.

Diel Period	Date	Mean Fish Density (g/m^2 of surface area) Upcoast	Downcoast	Current Direction	P	
Predawn	10/23/78	2.856	2.450	upcoast	0.4350	N.S.
Postdawn	10/23/78	0.323	0.132	upcoast	0.0185	*
Predawn	10/24/78	2.628	1.870	upcoast	0.2717	N.S.
Predawn	10/25/78	0.692	0.681	upcoast	0.0423	*
Postdawn	10/25/78	0.101	0.237	upcoast	0.1398	N.S.
Predawn	10/26/78	1.819	1.505	downcoast	0.4499	N.S.
Postdawn	10/26/78	0.070	0.058	negligible	0.7234	N.S.
Predawn	10/27/78	1.730	2.232	downcoast	0.8277	N.S.
Postdawn	10/27/78	0.289	0.329	downcoast	0.0026	*

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* = significant
N.S. = not significant

Fish Distribution Near the Discharge (within 300 m)

There were several indications that the fish distribution in the study area was influenced by the discharge. Therefore, the fish densities up and down the coast from the discharge and between the intake and discharge areas were tested using the Mann-Whitney U procedure. The general form of the null hypothesis was similar to that in the preceding section.

The fish density upcoast and downcoast from the discharge and between the intake/discharge did not display any consistent trends (see Tables VIII and IX). The weak currents along shore and low fish densities probably account for these results.

Ground Truth

The changes in fish density between days and diel periods suggested the collection of lampara samples should be conducted simultaneously with acoustic measurements. However, because fish densities were very low, lampara sets were made at randomly selected points in the acoustic transects. Nineteen lampara sets were made during the October survey. Usually, half the sets were made during the predawn period and half during the postdawn period.

The small net catches (the average catch per set (CPS) was ~ 1 kg) corroborated the acoustic measurements by indicating a low density of fish relative to the July survey (avg. CPS ~ 123 kg).

The composition of the lampara seine catches was dominated by atherinids (46%) and northern anchovy (22%). The low catch of queenfish and white croaker relative to July indicated that the species with higher entrapment rates were not abundant in the study area.

Table VIII. Mean fish density and significance level (P) at which the upcoast and downcoast density observations at the discharge were found to be different.

		Mean Fish Density (g/m^2 of surface area)		
Diel Period	Date	Upcoast	Downcoast	P
Predawn	10/23/78	---	---	not enough cases
Postdawn	10/23/78	---	---	not enough cases
Predawn	10/24/78	1.0625	1.9667	0.0030 *
Predawn	10/25/78	2.2268	3.6328	0.3446 N.S.
Postdawn	10/25/78	0.0198	0.0248	0.8551 N.S.
Predawn	10/26/78	0.9328	0.8644	0.4139 N.S.
Postdawn	10/26/78	---	---	not enough cases
Predawn	10/27/78	1.7895	3.3175	0.0019 *
Postdawn	10/27/78	0.6301	0.6327	0.2718 N.S.

* = significant
N.S. = not significant

Table IX. The mean fish density at the intake and discharge and the significance level at which the two observations were found to be different.

		Mean Fish Density (g/m^2 of surface area)		
Diel Period	Date	Intake	Discharge	P
Predawn	10/23/78	---	---	not enough cases
Postdawn	10/23/78	---	---	not enough cases
Predawn	10/24/78	2.666	1.450	0.0000 *
Predawn	10/25/78	1.763	2.715	0.0034 *
Postdawn	10/25/78	0.083	0.022	0.0246 *
Predawn	10/26/78	1.845	0.901	0.0000 *
Postdawn	10/26/78	---	---	not enough cases
Predawn	10/27/78	2.430	2.510	0.7508 N.S.
Postdawn	10/27/78	0.467	0.631	0.0000 *

* = significant
N.S. = not significant

DISCUSSION

Acoustic Measurements

The fish densities measured acoustically were observed to have a nonnormal distribution. Mathisen et al.[4] found that the variance of acoustic measurements of fish density was proportional to the mean (Poisson distribution), and normalized the data by performing a square root transformation. Gallucci (personal communication) recommended the avoidance of such transformations because of the unknown characteristics of the variance after transformation. Therefore, the data were left intact and nonparametric hypothesis-testing procedures were employed exclusively.

Diel Variability

In other studies, changes in the schooling behavior and vertical distribution of fishes have proved to contribute a large amount of variability to acoustic density estimates.[4,5] Often nighttime density estimates are considerably higher than daylight estimates.[5] The acoustic data collected in October at Huntington Beach display a similar pattern, with the estimates of fish density made during darkness being significantly larger than those made during daylight hours.

The net catches supported the acoustic measurements in that the species diversity decreased with light intensity while variability of the net catches tended to increase with light intensity, indicating that the fish distribution was more contagious during the day. Acoustic observations confirmed this indication in that fish schools are only observed during daylight surveys.

Daily Variability

Changes may occur in fish distributions from day to day because of tides, weather, feeding, reproductive movement of the fish, etc. Mathisen et al.[4] found that the pelagic biomass off the Spanish Sahara was constantly shifting, with significant changes in distribution occurring within one day.

The fish densities measured acoustically at Huntington Beach also displayed changes between days. The data suggest that a large amount of this variability was due to northern anchovy moving into and out of the study area. Anchovy schools were also found to cause significant daily variations in the fish density at San Onofre.[6]

Since the composition of the lampara catches was dominated by atherinids and anchovy in October, these species were probably the cause of the high daily variability in fish density.

The October results were similar to those in July in that higher fish densities were observed in the intake/discharge area when strong coastal currents were absent, and that when the currents increased fish appeared to concentrate on the downcurrent side of the intake. Thomas et al.[7] found similar fish distributions around the intake/discharge area at San Onofre. In addition to the physical presence of the intake and outlet structures, which create substrate and eddies which provide more habitat for fish, the discharged effluent has several properties with a high potential as fish attractants: (1) the elevated temperature, (2) the small prey items discharged, and (3) the higher water velocity. Studies at SONGS[7] suggest that elevated water temperature is the major attractant; however temperature may interact with the discharge of food resources.

Ground Truth

The size of the lampara net catches supported the acoustic observations of low fish density in the study area. The species composition indicated that those fishes most vulnerable to entrapment were in low abundance, which was corroborated with entrapment measurements.

Gillnet measurements made after the survey indicated a substantial movement of queenfish and white croaker into the study area. This coincided with a major heat treatment. A similar change in the abundance of fishes was observed to coincide with the discharge of heated effluent at SONGS.[7]

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)

April, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

QUEENFISH

Diel Period	DATE					ALL DAYS
	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	
Pre-Dusk		25.0 / .55	8.7 / .17	44.8 / .63	11.8 / .13	22.6 / .37
Dusk		8.0 / .23	4.0 / .06	10.0 / .23	8.5 / .06	7.6 / .15
Post-Dusk		126.0 / 2.11	16.7 / .20	32.2 / .43	5.7 / .06	45.2 / .70
Pre-Dawn		319.0 / 8.77*	18.7 / .45	20.7 / .31	20.2 / .40	19.9 / .39
Dawn	296.5 /	- / -	15.5 / .23	84.5 / 1.42	106.0 / 2.95	125.6 / 1.53
Post-Dawn	20.2 / .23	17.8 / .34	36.7 / .59	13.2 / .23		22.0 /

* Includes dawn, therefore not used in ALL DAYS average.

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)

April, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

WHITE CROAKER

Diel Period	DATE					ALL DAYS
	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	
Pre-Dusk		2.8 / .29	0.5 / -	16.5 / .11	50.2 / .17	17.5 / .15
Dusk		2.0 / .06	2.0 / .11	30.0 / .11	25.5 / .06	14.9 / .09
Post-Dusk		6.9 / .06	18.2 / .09	58.7 / .17	20.2 / .06	26.0 / .10
Pre-Dawn		21.3 / .40*	47.2 / .34	80.7 / .25	17.0 / .09	48.3 / .23
Dawn	22.5 /	- / -	33.0 / .06	84.5 / .23	16.0 / .17	39.0 / .15
Post-Dawn	8.0 /	2.5 / .11	0.8 / -	6.3 / -		4.4 /

* Includes dawn, therefore not used in ALL DAYS average.

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)

April, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

WALLEYE SURFPERCH

Diel Period	DATE					ALL DAYS
	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	
Pre-Dusk		1.0 / .06	1.8 / -	0.8 / -	4.7 / .06	1.9 / -
Dusk		2.5 / .23	0.5 / -	2.5 / -	0.8 / .11	1.6 / -
Post-Dusk		26.0 / 1.02	10.2 / .11	10.7 / .11	6.7 / -	13.4 / -
Pre-Dawn		19.5 / .45*	1.75/ -	7.2 / -	11.0 / .06	6.7 / -
Dawn		- / -	4.0 / .06	16.5 / .13	17.0 / .06	12.5 / -
Post-Dawn	0 / 0	4.3 / .06	0.7 / -	4.5 / .50		2.4 / -

* Includes dawn, therefore not used in ALL DAYS average.

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)

April, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

ALL SPECIES COMBINED

Diel Period	DATE					ALL DAYS
	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	
Pre-Dusk		59.3 / 4.82	11.8 / .30	62.2 / .66	68.0 / .44	50.3 / 1.56
Dusk		23.5 / 2.21	7.5 / .45	43.0 / .34	56.5 / .63	32.6 / .91
Post-Dusk		133.3 / 2.57	50.2 / 2.21	104.0 / .71	34.2 / .11	80.4 / 1.40
Pre-Dawn		367.0 / 12.45*	81.7 / 7.31	111.2 / 1.25	52.7 / .77	81.9 / 3.11
Dawn	399.0 /	- / -	54.5 / .91	190.5 / 1.76	147.0 / 3.40	197.7 / 2.02
Post-Dawn	72.2 / 4.31	27.3 / 1.19	38.3 / .47	25.5 / .49		40.8 /

* Includes dawn, therefore not used in ALL DAYS average.

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)

July, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

QUEENFISH

Diel	DATE			ALL
Period	19 - 20	20 - 21	21 - 22	DAYS
Pre-Dusk		0.3 / .02	21.3 / 1.27	10.8 / .64
Dusk		1.5 / .11	19.0 / 1.08	10.2 / .60
Post-Dusk		283.7 / 16.27	44.2 / 1.87	163.9 / 9.07
Pre-Dawn		93.2 / 1.70	39.7 / 2.27	66.4 / 1.99
Dawn		27.0 / 1.02	47.5 / 2.83	37.2 / 1.93
Post-Dawn	2.7 / .13	99.2 / 6.54	7.25/ .45	53.2 / 3.50

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)

July, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

WHITE CROAKER

Diel Period	DATE			ALL DAYS
	19 - 20	20 - 21	21 - 22	
Pre-Dusk		10.2 / .06	3.8 / .06	7.0 / .06
Dusk		86.0 / .23	9.5 / .05	47.7 / .14
Post-Dusk		174.5 / .85	171.8 / .65	173.1 / .75
Pre-Dawn		130.0 / .79	100.0 / .57	115.0 / .68
Dawn		14.0 / .05	19.0 / .34	16.5 / .20
Post-Dawn	9.2 / .08	45.5 / .71	6.5 / .17	26.0 / .44

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)

July, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

WHITE SURFPERCH

Diel Period	DATE			ALL DAYS
	19 - 20	20 - 21	21 - 22	
Pre-Dusk		5.3 / .10	1.5 / .02	3.4 / .06
Dusk		9.5 / .17	1.0 / .06	5.2 / .12
Post-Dusk		70.2 / 2.95	39.2 / .82	54.7 / 1.89
Pre-Dawn		25.5 / .25	37.0 / .20	31.2 / .23
Dawn		2.0 / .06	3.0 / .06	2.5 / .06
Post-Dawn	8.0 / .17	13.5 / .23	1.5 / .06	7.7 / .12

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)
July, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

WALLEYE SURFPERCH

Diel	DATE			ALL
Period	19 - 20	20 - 21	21 - 22	DAYS
Pre-Dusk		3.0 / .06	1.2 / .08	2.1 / .07
Dusk		0 / 0	1.0 / .06	0.5 / .03
Post-Dusk		4.2 / .17	10.5 / .17	7.3 / .17
Pre-Dawn		6.0 / .06	4.0 / .09	5.0 / .07
Dawn		1.0 / .06	11.5 / .06	6.2 / .06
Post-Dawn	2.2 / .13	4.2 / .23	3.0 / .11	3.1 / .13

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)

July, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

SHINER SURFPERCH

Diel Period	DATE 19 - 20	20 - 21	21 - 22	ALL DAYS
Pre-Dusk		45.5 / .36	7.5 / .11	26.5 / .24
Dusk		139.0 / 1.25	6.0 / .06	72.5 / .65
Post-Dusk		44.0 / .40	62.0 / .63	53.0 / .51
Pre-Dawn		21.5 / .20	20.7 / .25	21.1 / .06
Dawn		7.5 / .06	14.5 / .17	11.0 / .12
Post-Dawn	122.8 / 2.58	20.0 / .21	35.5 / .34	59.4 / .28

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)

July, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

ALL SPECIES COMBINED

Diel Period	DATE			ALL DAYS
	19 - 20	20 - 21	21 - 22	
Pre-Dusk		69.3 / .72	38.7 / 1.46	54.0 / 1.09
Dusk		244.0 / 3.97	40.0 / 1.31	142.0 / 2.64
Post-Dusk		596.5 / 21.34	421.0 / 4.85	508.7 / 13.10
Pre-Dawn		296.0 / 3.32	304.5 / 5.47	300.2 / 4.39
Dawn		66.0 / 1.31	154.0 / 3.85	110.0 / 2.58
Post-Dawn	162.0 / 2.61	204.0 / 8.32	71.0 / 1.36	145.7 / 4.10

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)

October, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

QUEENFISH

Diel Period	DATE					ALL DAYS
	23 - 24	24 - 25	25 - 26	26 - 27	27 - 28	
Pre-Dusk	13.33/ .34	2.33/ .11	.33/ .02	.67/ .01	.33/ <.01	3.40/ .10
Dusk	15.0 / .50	4.0 / .13	2.0 / .04	3.0 / .02	2.0 / .03	5.2 / .14
Post-Dusk	32.5 / .35	27.5 / 1.09	4.5 / .02	5.0 / .03	54.0 / 1.30	24.7 / .56
Pre-Dawn	11.33/ .47	1.0 / .04	15.67/ .09	3.0 / .02		7.75/ .16
Dawn	4.0 / .23	0 / 0	5.0 / .03	1.0 / .01		2.5 / .07
Post-Dawn	6.0 / .24	0 / 0	1.0 / .01	0.5 / <.01		1.88/ .07

APPENDIX 4

Table 1. Impingement per hour averages for each diel period.

October, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

WHITE CROAKER

Diel Period	DATE					ALL DAYS
	23 - 24	24 - 25	25 - 26	26 - 27	27 - 28	
Pre-Dusk	2.0 / -	0 / 0	0 / 0	0 / 0	0 / 0	0.4 / 0
Dusk	5.0 / .02	0 / 0	0 / 0	0 / 0	0 / 0	1.0 / .00
Post-Dusk	1.0 / .01	1.0 / .04	0 / 0	0 / 0	0 / 0	0.4 / .01
Pre-Dawn	.33/ .02	0 / 0	0 / 0	0 / 0		0.08/ .00
Dawn	0 / 0	0 / 0	0 / 0	0 / 0		0 / 0
Post-Dawn	0 / 0	0 / 0	0 / 0	0 / 0		0 / 0

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)

October, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

NORTHERN ANCHOVY

Diel Period	DATE					ALL DAYS
	23 - 24	24 - 25	25 - 26	26 - 27	27 - 28	
Pre-Dusk	1.00/ -	1.33/ <.01	.67/ <.01	6.33/ .04	0.67/ <.01	2.00/ .01
Dusk	2.00/ <.01	0 / 0	0 / 0	4.0 / .02	3.0 / .02	1.8 / .01
Post-Dusk	11.5 / .07	16.0 / .08	35.0 / .23	7.5 / .04	76.5 / .41	29.3 / .17
Pre-Dawn	67.67/ .32	138.0 / .23	226.0 / 1.51	16.0 / .16		111.92/ .56
Dawn	10.0 / .05	1.0 / <.01	223.0 / 1.47	1.0 / .01		58.75/ .39
Post-Dawn	2.0 / .01	.5 / <.01	18.5 / 1.13	0 / 0		5.25/ .29

APPENDIX 4

Table 1. Impingement per hour averages for each diel period. (Cont.)

October, 1978, Huntington Beach Generating Station (Number per hour/Kg. per hour)

ALL SPECIES COMBINED

Diel Period	DATE					ALL DAYS
	23 - 24	24 - 25	25 - 26	26 - 27	27 - 28	
Pre-Dusk	17.33/ .96	3.67/ .16	.83/ .05	4.0 / .12	.33/ <.01	5.23/ .26
Dusk	18.5 / 1.23	4.0 / .13	1.5 / .03	3.5 / .21	2.0 / .03	5.9 / .33
Post-Dusk	27.25/ 1.07	25.0 / .76	20.25/ .13	7.5 / .13	54.0 / 1.30	26.8 / .68
Pre-Dawn	42.83/ .56	28.33/ .85	123.0 / .94	10.17/ .16		51.08/ .63
Dawn	12.0 / .69	5.0 / .48	57.0 / .75	1.0 / .01		18.75/ .48
Post-Dawn	5.75/ .31	.75/ .45	10.5 / .13	.5 / <.01		4.38/ .23